Drought Management in a Changing Climate: Using Cost-Benefit Analyses to Assist Drinking Water Utilities

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Drought Management in a Changing Climate: Using Cost-Benefit Analyses to Assist Drinking Water Utilities

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FOREWORD

The Water Research Foundation (the Foundation) is a nonprofit corporation dedicated to the development and implementation of scientifically sound research designed to help drinking water utilities respond to regulatory requirements and address high-priority concerns. This publication is a result of a research project funded by the National Oceanic and Atmospheric Administration's Sectoral Applications Research Program (NOAA/CPO/SARP). In general, projects in which the Foundation participates or which it funds directly are managed closely from their inception to the final report by the staff and a large cadre of volunteers who willingly contribute their time and expertise. The Foundation provides planning, management, and technical oversight of research projects in which it participates.

A broad spectrum of water supply issues is addressed by the Foundation's research agenda, including resources, treatment and operations, distribution and storage, water quality and analysis, toxicology, economics, and management. The ultimate purpose of the coordinated effort is to assist water suppliers to provide a reliable supply of safe and affordable drinking water to consumers. The true benefits of the Foundation's research are realized when the results are implemented at the utility level. The Foundation's staff and Board of Trustees are pleased to offer this publication as a contribution toward that end.

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EXECUTIVE SUMMARY

Droughts are expected to occur more frequently and at a greater intensity due to climate change. What climatologists refer to as “hydrological drought,” or low water supply, can also be characterized by deterioration of water quality, increased water demand due to rising outdoor water use when precipitation is low, and damage to drinking water infrastructure. Changes in streamflow and precipitation due to climate change can adversely affect the ability of drinking water utilities to store and distribute safe drinking water to customers. While some utilities have formal plans and defined activities to manage drought, many others do not. Drought planning may be of increasing importance as drought begins affecting utilities in areas that are not traditionally drought-prone. Drought management practices can help utilities respond to and mitigate the impacts of drought, thereby achieving significant savings. Such activities include drought- and conservation-related customer outreach; implementation of water audits, leak detection, or rebate programs for customer installation of more water-efficient technology; infrastructure repair or replacement; water treatment modifications; and replacement or addition of water sources. Because the impacts of drought vary widely, utilities will likely need to adapt industry-leading practices and tools to their specific needs and conditions.

A cost-benefit analysis can help utilities evaluate and compare alternative drought management practices and select those that have the greatest net benefit for their systems. Although drinking water utilities may be aware of how drought can affect their ability to provide reliable and safe drinking water (e.g., effects on water quality and quantity, infrastructure, and customer demand), estimating the costs of these effects and weighing the relative benefits of available drought management practices can be challenging. Research is needed to provide drinking water utilities with the means to estimate such costs and benefits and to use that information to select appropriate drought management practices.

The objectives of this research report are to (1) summarize available information on the costs and benefits of drought management practices at drinking water utilities, and (2) provide guidance for utilities to conduct a cost-benefit analysis to evaluate and select appropriate drought management options. The research team has characterized the common vulnerabilities of drinking water utilities and the relevant impacts and costs associated with drought, both for the utilities and for communities. Consideration was given to a range of water sources and local circumstances that affect water supply and use. The leading drought management practices being implemented by utilities nationwide and the associated costs and benefits were identified. To provide a more comprehensive range of potential costs associated with drought management, the analysis was expanded to include planning, outreach, operations, maintenance, and capital improvement costs incurred by utilities. Such activities (e.g., cost of replacing water mains or building a new water treatment facility) are not specifically designed to address drought itself but may improve a utility’s resilience, should drought occur.

The research approach for this study included the following steps:

1) Collected information on drought management practices used by drinking water utilities in the United States and elsewhere
2) Reviewed available literature for the costs and benefits of those practices
3) Conducted a workshop with partner drinking water utilities to share information on approaches to drought management
4) Conducted interviews with utilities for developing case studies on their experiences with drought

5) Provided background on the data needs and methodology for cost-benefit analyses
6) Demonstrated the use of a cost-benefit analysis for drought planning by a hypothetical utility

The research team conducted a workshop in Denver, Colorado in December 2014 with partner drinking water utilities to evaluate the feasibility of how utilities might design cost-benefit analyses for planning drought mitigation activities. Workshop participants shared information on past, present, and planned efforts to ensure continued water service during drought conditions. The research team conducted interviews with the utilities to gather estimates of costs for drought management, as well as costs for water resource management activities that also advance drought management goals. The interviews also covered the challenges associated with drought management practices. While no cost-benefit analyses were conducted with the partner utilities, case studies documenting the costs, benefits, challenges, and successes of drought management practices were developed.

Recognizing that vulnerabilities to drought vary from utility to utility, this report documents a broad range of drought impacts and a variety of mitigation and response practices. Each utility has a unique customer base, and there is variability in the tolerance of each community for individual drought response measures. It is evident from the case studies that the drought management options available to drinking water utilities vary widely. Costs may differ significantly among utilities, depending upon the complexity of their drought management practices. Further, utilities may achieve different outcomes even when conducting the same activities. This study provides background information for utilities interested in developing utility-specific cost-benefit analyses to evaluate drought management practices, including identification of the most relevant impacts, costs, and mitigation options. Future research efforts are needed to evaluate further the use of cost-benefit analyses to plan for drought under future climate change scenarios.

Chapter 1 provides general background on the occurrence of drought in the United States as the climate changes. It also reviews the impacts of drought on a utility when planning efforts have not begun. Chapter 2 documents the range of impacts and costs a utility could incur when faced with short- or long-term drought conditions, such as costs of water infrastructure impacts, water quality impacts, water reliability, land subsidence, and revenue losses. This chapter also presents the costs and benefits of drought management practices that utilities have implemented, including the challenges involved in producing estimates of those costs and benefits. The leading drought management practices discussed are demand management (public outreach, end user conservation, water loss control programs and water audits, conservation and drought pricing) and supply management (supply augmentation). Some of the challenges of using a cost-benefit approach are as follows:

1) Cost comparison amongst utilities is problematic because costs are site dependent
2) It is difficult to document costs at a sufficient level of detail for cost-benefit analysis
3) It is hard to separate drought management costs in the short term from longer term water resource management plans
4) It may be hard to estimate total cost of a drought management initiative for a single utility if it is part of a regional water management response

One promising approach is to use avoided costs as a proxy for estimating benefits. Chapter 3 presents case studies of five drinking water utilities (El Dorado Irrigation District, CA; City of San

Diego Public Utilities Department, CA; Aurora Water, CO; Denver Water, CO; and Cobb County Water System, GA). These utilities have incurred costs because of drought, and provided information about the drought impacts they encountered, actions they took to address those impacts, and the related costs. Chapter 4 examines the value of cost-benefit analyses for utilities to evaluate alternative drought management practices. Analyses can be tailored to the circumstances of a specific water utility, taking into account utility size, water sources, local climate conditions, projected climate change, etc. This chapter explores concepts of triple bottom line, multiple perspectives (societal, customer, and utility), ways to catalog cost-benefit costs (accounting cost and benefits, escalating future costs and benefits, and qualitative measures of non-quantitative costs and benefits), discounting, evaluation measures (net present value, benefit cost ration, cost effectiveness ratio, internal rates of return, and payback period), and analyzing uncertainty. Chapter 5 summarizes the results of this study and areas for future research. Cost-benefit analysis allows utilities to compare drought management approaches, evaluate trade-offs among preparedness, mitigation, response and recovery activities, and choose the most cost-effective approach to drought management. Appendix A provides a snapshot of about 40 examples of drought management practices used by drinking water utilities across the United States and their associated costs, primarily collected from online sources. Appendix B provides an example of a utility that has used cost-benefit analysis for water resource management. Appendix C demonstrates an example of how a hypothetical utility may use a cost-benefit analysis for evaluating a suite of drought management practices. WRF is publishing the details of Appendix C as a separate MS Excel file, called 4546 Example Cost-Benefit Analysis. It may be downloaded from the 4546 project page under Project Resources/Project Papers. Appendix D provides financial data collected from participating utilities on their water resource management practices (which include drought management practices).

Note that in this report, most financial data are reported as real values in 2014 dollars (2014$). These real values are provided in parentheses following the original costs and year of costs reported from the literature to account for inflation and allow consistent comparisons of the real value of costs and benefits over time. The exceptions to this are the financial data presented in Chapter 3. These data are included as originally reported by the water utilities, without adjustments for inflation. Values in 2014$ were calculated using the Bureau of Labor Statistics' Consumer Price Index (CPI) inflation calculator.[1] When the original year of the financial data was not clearly identified, data were assumed to be from the following:

- The year prior to the literature's publication date (e.g., data presented in a source published in 2013 were assumed to be in 2012 dollars),
- The midpoint year of odd numbered range of years (e.g., 2003 for the period 2000–2005), or
- The older of the two years representing the midpoint for an even numbered range of years (e.g., 2004 for the period 2000–2010).

In addition, water volumes are reported in gallons or million gallons to allow for easy comparisons of water quantities.

[1] The CPI calculator (http://www.bls.gov/data/inflation_calculator.htm) uses the average CPI for a given calendar year. The CPI represents the change in the price of all goods and services purchased by urban households in a given year. For the current year (2015), the CPI is from March 2015.

CHAPTER 1
THE IMPACTS OF DROUGHT ON DRINKING WATER UTILITIES

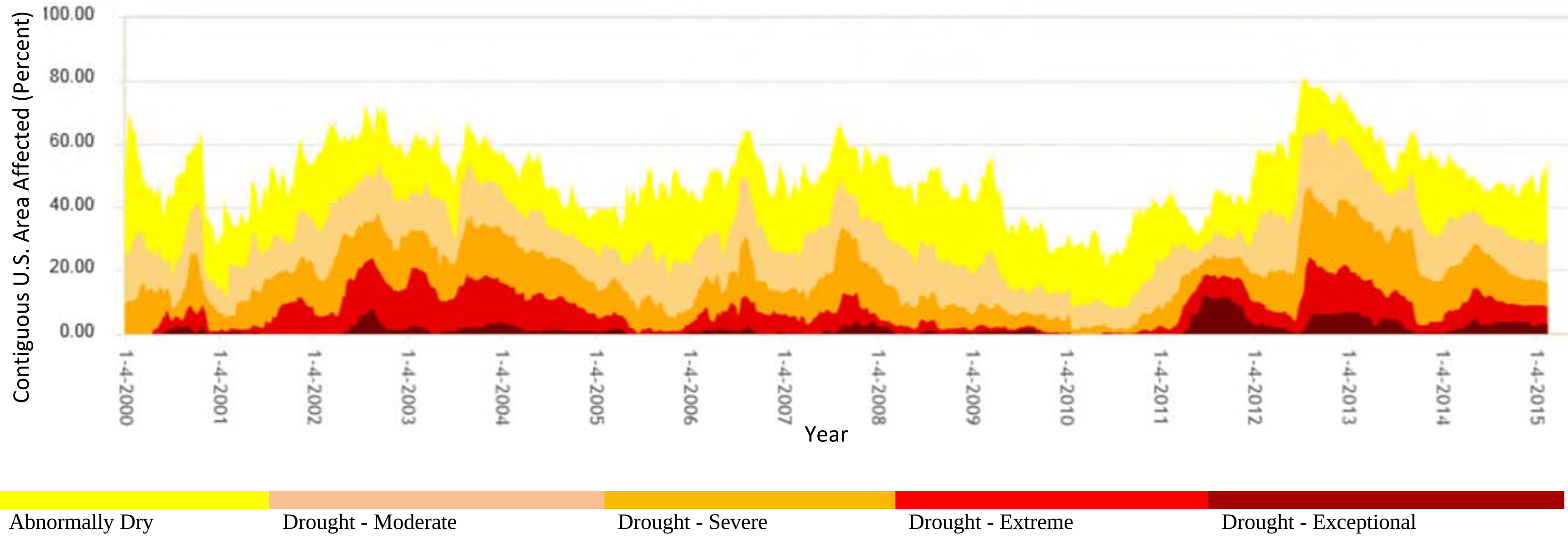
1.1 OCCURRENCE OF DROUGHT IN THE UNITED STATES

Drought conditions originate from insufficient precipitation over a prolonged period, usually one or more seasons, resulting in a water shortage (NDMC-UNL 2015a). Some natural hazards, such as hurricanes and earthquakes are defined in a quantitative manner, but a universally accepted quantitative system does not apply for droughts. This is due to the challenge of defining the start and end of a drought period, and in part to the wide-ranging effects that drought can have over time (NOAA National Climatic Data Center 2003). The climatological community defines four types of drought: (1) meteorological drought as a consequence of dry weather patterns; (2) hydrological drought due to low water supply; (3) agricultural drought, which is when crops are affected, and 4) socioeconomic drought, which is the impact of drought on the supply and demand of various commodities (NOAA National Climatic Data Center 2015). Some regions can experience snowmelt drought, in which there is insufficient peak snowmelt discharge in areas that rely on snowmelt for water supply (Van Loon et al. 2014).

Drought may affect larger geographical areas and last significantly longer than other natural hazards (National Drought Policy Commission 2000). The length, frequency, severity, and impacts of drought vary by region and climate regime, and conditions that constitute drought in one region may not constitute drought in others. For example, conditions that would be considered drought in historically wetter areas such as the northeastern United States may constitute relatively wet conditions in more arid areas such as the southwest United States (NOAA National Climatic Data Center 2003). Moreover, criteria or thresholds that determine when a region has been affected by drought will vary by who is using the water and defining the drought (NDMC-UNL 2015a, Wilhite et al. 2007). The lack of a clear definition can make it challenging to understand, monitor, respond to, and mitigate drought at some scales.

Rising temperatures, most likely resulting primarily from human activities, are expected to continue to rise. Temperature records that date back as far as 1895 indicate that the most recent decade has been the nation's warmest. Warmer temperatures from this human-induced climate change have led to increased rates of evapotranspiration and more rapid drying of soils. Soil moisture levels can be a key indicator of drought conditions, as they influence the exchange of water between the land surface and the atmosphere, the production of runoff, and groundwater recharge. Dorigo, de Jeu, Chung et al. (2012) mapped the annual change in soil moisture per year between 1988 and 2010 based on satellite data and showed that most of the country is experiencing increased drying, except for the Northeast, Florida, the upper Midwest, and the Northwest.

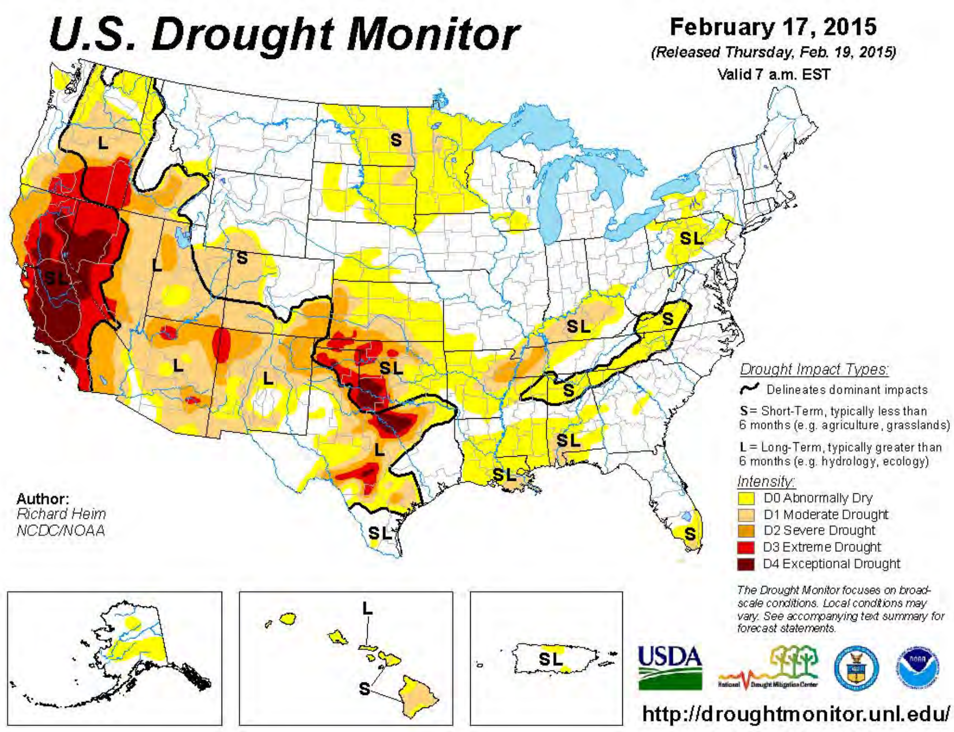
Historic weather patterns confirm that drought is a recurring event across North America, with some regions experiencing longer and more frequent droughts than others (NOAA National Climatic Data Center 2003). At any given time between 2000 and 2014, roughly 10 to 60 percent of the United States was in drought, with another 10 percent affected by abnormally dry conditions, as shown in Figure 1-1 (NDMC-UNL 2015b). In 2012, more than half of the United States was affected by drought because of exceptionally hot summer temperatures and low snowfall (Freedman 2012). Figure 1-2 provides a snapshot of drought conditions in the United States as of February 2015 and illustrates the recent severe drought to exceptional drought conditions centered in the western United States and southern Great Plains.



Source: National Drought Mitigation Center, University of Nebraska-Lincoln (NDMC-UNL) 2015c.

Figure 1-1 Percent area of the United States affected by drought 2000–2015 shown in a time series graphic from the U.S. Drought Monitor[2]

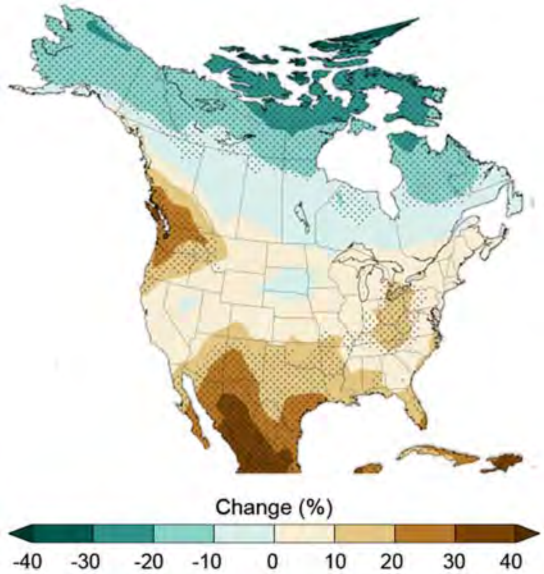
[2] The U.S. Drought Monitor is jointly produced by the National Drought Mitigation Center at the University of Nebraska-Lincoln, the United States Department of Agriculture, and the National Oceanic and Atmospheric Administration.



Source: NDMC-UNL 2015c.

Figure 1-2 U.S. Drought Monitor map depicting drought across the United States as of February 17, 2015

Predicting drought conditions depends on the ability to forecast two key climate parameters: precipitation and temperature (NDMC-UNL 2015a). As climate change occurs, most regions can expect one or more of the following: a greater frequency of extreme weather events, longer and more intense heat spells, heavy downpours, rising sea levels, and floods (USGCRP 2014). Droughts throughout the world, including in regions such as the Mediterranean and West Africa, have become more frequent and prolonged (Horton et al. 2015). Available data suggest that although there has been an overall increase in the number of heavy precipitation events, short-term droughts are expected to intensify in most U.S. regions (USGCRP 2014). Areas that are especially vulnerable to drought, such as the southwest, the southern Great Plains, and the southeast, are expected to experience more intense long-term droughts (USGCRP 2014). Forecasts from modeling of future scenarios that assume higher greenhouse gas emissions suggest that more frequent and widespread droughts in the central and southern United States are possible (USGCRP 2014). Figure 1-3 shows that the number of consecutive dry days (i.e., those receiving 1 mm or less of precipitation) is expected to increase, relative to historic levels, across the country. Higher temperatures and drier conditions will increase evapotranspiration and reduce water supplies, leading to drought or exacerbating existing drought conditions (USGCRP 2014).



Source: J.M. Melillo, T.C. Richmond, and G.W. Yohe, Eds., 2014: Climate Change Impacts in the United States: The Third National Climate Assessment. U.S. Global Change Research Program, 841 pp. doi:10.7930/J0Z31WJ2.

This map depicts the change in the annual maximum number of consecutive dry days, i.e., days receiving less than 0.04 inches or 1 mm or precipitation, between a historic period (1971-2000) and a future period (2070-2099). Future climate changes are projected with CMIP5 models and assume a scenario of continued emissions increases (RCP [Representative Concentration Pathway] 8.5).

Figure 1-3 Projected change in the number of consecutive dry days

1.2 BROAD IMPACTS OF DROUGHT

Droughts can have widespread and devastating environmental, social, and economic consequences that extend beyond the area that is physically experiencing the drought (Brislawn et al. 2014). Environmental threats include damage to wetlands, wildlife habitat, forests, groundwater, and soils (Hillyer and Hofbauer 1998). These effects, which vary by region and ecosystem, can have major repercussions for the condition of both aquatic and terrestrial ecosystems and the services they provide (Brislawn et al. 2014).

Additionally, industries such as tourism that rely on water-based recreational activities may experience economic stress (Hillyer and Hofbauer 1998, Wilhite et al. 2000). Collectively, these impacts can bring about severe economic losses across multiple sectors, can adversely affect quality of life, and can require significant expenditures by federal, state, and local agencies providing disaster relief.

Federal expenditure on drought response during major U.S. droughts

1953-1956 drought: $3.3 billion ($4.8 billion in 2014$)
1976-1977 drought: $6.5 billion ($9.4 billion in 2014$)
1988-1989 drought: $6 billion ($8.7 billion in 2014$)

Source: Data from National Drought Policy Commission 2000; costs were originally reported in 1998$.

1.3 IMPACTS OF DROUGHT ON DRINKING WATER UTILITIES AND CUSTOMERS

For drinking water utilities to manage and plan for drought effectively, it is important to consider not only the impacts of drought on their customers, but also the related impacts on the environment and society. The information below focuses on the impacts of drought absent the implementation of drought management practices (e.g., measures for mitigating the impacts of drought and long-term adaptation solutions). Chapter 2 provides cost estimates for these unmitigated impacts based on information provided in case studies and reports.

Changes in streamflow and precipitation due to climate change can adversely affect the ability of drinking water utilities to store and distribute safe drinking water to customers. Drought can lead to higher concentrations of pollutants in water and to sedimentation of reservoirs. In combination with higher temperatures, drought can lead to lower dissolved oxygen levels and increased color and odor from microbial growth (Arizona Governor's Drought Task Force 2004). Drier conditions during droughts also increase the risk of wildfires (USGCRP 2014), which can severely affect source water quality, potentially necessitating new or more advanced filtration and treatment procedures at drinking water utilities (Sham et al. 2013). Investment in dredging of reservoirs due to post-wildfire reservoir sedimentation may also be needed. These activities are significant expenditures for utilities. Decreased supplies and increased demands for water during a drought present concurrent challenges for drinking water utilities (USGCRP 2014).

The impacts of drought on drinking water utilities are organized into four categories and are discussed in detail below:

- Impacts driven by decreased water supply.
- Impacts driven by increased demand for water.
- Impacts on drinking water infrastructure related to changes in water supply or demand.
- Water quality degradation.

1.3.1 Decreased Supply

Drought reduces water availability through the combined effects of reduced precipitation and runoff (i.e., decreased supply), and increased consumption and withdrawal (i.e., increased demand) (USGCRP 2014). Many regions rely on the storage capacity of lakes and reservoirs to provide a consistent supply of water during seasons with low precipitation and during periods of drought (Dziegielewski and Kiefer 2007). During a prolonged drought, the level of water in reservoirs can drop significantly, thus decreasing a water utility's reserve supply. For example, a multi-year drought in Texas resulted in 23 drinking water utilities having fewer than 180 days of water in October of 2011 and a similar situation for 45 drinking water utilities in October of 2013 (Patton 2013). In California, the current (2014) drought has resulted in a significant reduction in the water level in the Folsom Lake Reservoir compared to the water level in 2011. In July 2011, Folsom Lake Reservoir was at 97 percent of total capacity and 130 percent of its historical average for that date. By January 2014, however, the reservoir level had fallen to 17 percent of total capacity and 35 percent of its historical average (NASA 2014).

Long-term drought also reduces groundwater availability. Decreased precipitation reduces the amount of surface water that can contribute to aquifer recharge (USGCRP 2014), with results that are potentially more devastating than reductions in surface water quantity alone. This is because surface water sources are highly visible and hold cultural significance for aesthetic and recreational reasons, and reduced surface water levels due to drought can be clearly seen. However, groundwater sources hold approximately 75 percent of the freshwater storage in the lower 48 states (Dziegielewski and Kiefer 2007) and are virtually the sole source of water in some parts of the country (USGCRP 2014). Groundwater is an important resource for many regions that do not have reliable rainfall, and it is essential for water supply stability, food security, and ecosystems (USGCRP 2014).

1.3.2 Increased Demand

Drought has affected more people in North America than any other type of disaster event (NOAA National Climatic Data Center 2003), and it is typically characterized by hot, dry conditions over a prolonged period, leading to a rise in the demand for water (USGCRP 2014). Dziegielewski and Kiefer (2007) predicted that, over a 30-year period beginning in 2007, the effects of severe drought on water demand and resource competition will likely be greater than the effects from other factors such as population growth, energy production, and ecosystem services. In agriculture, water demand for crop irrigation and landscaping will increase in the face of drought due to changes in soil moisture, overall temperature, and potential evapotranspiration (USGCRP 2014). Power plants will also have a net increase in water usage because of limits on the amount of water they can recycle back to rivers and streams due to elevated freshwater temperatures (USGCRP 2014).

Brown et al. (2013) projected that water withdrawals in the contiguous United States from 2005 to 2060 (taking into account population and socioeconomic changes) would increase 3% without climate change or 34 percent with climate change.

Drinking water utilities often use groundwater to maintain a consistent supply when drought conditions reduce the availability of surface water (USGCRP 2014). In a typical year, California's Department of Water Resources estimates that groundwater supplies meet approximately 40 percent of the state's demand for water. However, it is estimated that the state's reliance on groundwater in 2014 will be close to 65 percent of all water use because of the ongoing long-term drought (Borchers and Carpenter 2014).

Under the increased demand and decreased recharge associated with drought conditions, groundwater supplies can become susceptible to overdraft. The impacts of overdraft are numerous and include water quality degradation; increased energy costs for groundwater pumping; costs for well deepening or replacement; loss of conveyance capacity in nearby rivers and streams; and land subsidence (Borchers and Carpenter 2014). Prolonged overdraft can lead to irreversible damage to aquifers. In coastal aquifers, for example, saltwater intrusion due to overdraft can be costly to treat (Johnson 2007). Two communities that have addressed salt water intrusion issues (the City of Hallandale Beach and Lake Worth, FL) are discussed in section 2.1.2. In addition, significant overdraft leading to land subsidence (depression of the land surface) can permanently reduce the storage capacity of aquifers (USGS 2000). A well-known photograph of Joseph Poland of the U.S. Geological Survey documenting land subsidence in California's San Joaquin Valley from 1925 to 1977 shows the effects of overdraft (Figure 1-4).

Over the last 30 years, drinking water utilities have implemented short- and long-term water conservation policies to reduce water demand or to reallocate water resources (USGCRP 2014, Hughes and Leurig 2013). With many inefficiencies already addressed, particularly in areas that have already experienced drought, it becomes harder for utilities to reduce water use further in times of drought.

Source: USGS 2000.

Figure 1-4 Subsidence resulting from groundwater withdrawals in California

1.3.3 Impact on Water Infrastructure

Infrastructure critical to the collection, storage, treatment, and delivery of water, ranging from major dams and reservoirs to small distribution mains, is vulnerable to the effects of drought. Low water supply levels, extreme temperatures, and dry soil contribute to conditions that threaten this infrastructure.

Low water levels along the faces of dams decrease pore water pressure, threatening the structural integrity of earthen dams, which are critical for water storage in many parts of the county (Brislawn et al. 2014). Drought also increases sediment influx into reservoirs as shorelines are exposed by low water levels and are more susceptible to erosion when precipitation eventually occurs. If drinking water utilities must withdraw from a lower level in the reservoir, additional sediment could be transported via the intake into the water treatment plant potentially causing damage to equipment, increased sludge volumes, and clogging of the filters. These potential impacts can require drinking water utilities to increase maintenance and oversight during times of drought. If sediment build-up in the reservoir is severe, dredging may be necessary (Brislawn et al. 2014).

Reductions in surface water storage (i.e., reservoir levels) may also require drinking water utilities to modify their infrastructure or build new infrastructure to continue to provide water to their customers. In 2005, the Southern Nevada Water Authority (SNWA) approved the construction of a third intake at Lake Mead that will allow the system to withdraw an adequate supply of water even when the lake level is very low. The new intake will also protect customers from water quality degradation (e.g., increased concentrations of point source and non-point source pollutants) associated with low lake levels (SNWA 2015). Similarly, due to a 33-foot drop in water levels at the White River Reservoir in Texas, the White River Municipal Water District was forced to lower its water intake to continue to withdraw water (USGS 2013, Patton 2013). Figure 1-5 shows the original intake piping, which is now higher than the water level, and new flexible blue tubing added by the utility to extend the intake pipes. The water utility installed floatable pumps to access the water at the lower level and connected the pumps to the intake via the blue tubing (Patton 2013).

Source: Patton 2013.

Figure 1-5 Example of a modified intake structure to access water at lower levels in Texas

High temperatures and drought, when experienced over long periods, can contribute to dry conditions that lead to increased incidence of wildfire (USGCRP 2014). Wildfire damage may necessitate a variety of infrastructure modifications at the drinking water utility to ensure safe drinking water. For example, a water utility may need to relocate intakes or repair intakes that were damaged by debris from the wildfire (Sham et al. 2013).

Changes in soil structure due to drought can lead to water main breaks, especially in areas with clay-rich soils, which can swell when wet and shrink under dry conditions. Buckling of the soil upon shrinkage can damage infrastructure, including water mains. This is a concern, for example, in Texas, where large portions of the state have clay-rich soils (Combs 2012). Several cities have experienced significant damage to water mains because of prolonged drought. During the 2011 drought, Austin, TX had, on average, 10 to 15 more water main breaks per week because of shifting soils (Auber 2011). A record number of water main breaks in Kansas City during the summer of 2012 was attributed to drought conditions, and the City struggled to keep pace with the needed repairs (Vaughn 2012). In addition to soil type, a 2007 study of water main breaks (Grigg 2007) showed that the risk of main breaks is also influenced by pipe diameter, the year of installation, the number of days below freezing in a year, annual rainfall, joint type, and pipe depth. Aging mains are at a greater risk of failure than new mains (AWWA 2012a).

Water main breaks pose a threat to public health and safety, disrupt business and residential communities, and waste valuable and potentially scarce water resources. They can also be very costly to address (AWWA 2012a). According to the Water Research Foundation (undated), breaks in large-diameter mains (approximately 12-inch diameter or larger) can lead to significant damage due to flooding and service disruptions, and necessitate boil water orders. Such mains are likely to be more expensive to repair than smaller-diameter mains in large part due to property damage resulting from the break. Main breaks in smaller-diameter pipe, while likely less costly to repair, occur more frequently (Grigg 2007). Smaller mains serve areas with fewer customers (e.g., residential or semi-residential areas), and only those customers would be affected if water outages were to occur.

1.3.4 Water Quality Degradation

Drought can lead to degradation of water quality, and thus make it more difficult for drinking water utilities to treat water to meet required standards (Brislawn et al. 2014). In surface water bodies (i.e., rivers, lakes, and streams), the low water levels and reduced streamflow during prolonged drought periods are often associated with higher nutrient concentrations and longer residence times in streams. These conditions promote algal blooms and low oxygen conditions (USGCRP 2014). In addition, with less frequent precipitation, pollutants can accumulate on the land surface for longer periods. When rain events do eventually occur, the runoff will contain elevated concentrations of pollutants that will be transported to water supplies. In tidal regions, reduced streamflow can cause saltwater intrusion, which can reduce water quality at water supply intakes (Brislawn et al. 2014); as the flow of water out to the ocean declines, the flow of water inland from the ocean pushes the freshwater/saltwater dividing line further inland.

Over time, degraded surface water quality can also affect groundwater quality as the water percolates down to surficial aquifers (Arizona Governor’s Drought Task Force 2004). In addition, increased demand on groundwater during drought conditions can cause a drop in water level in an aquifer, necessitating the withdrawal of water from deeper in the aquifer, where the water has a higher dissolved solids content. Higher pumping rates and pumping from lower depths can also cause movement of poor quality water and existing plumes of contaminated groundwater toward drinking water supply wells (Arizona Governor’s Drought Task Force 2004).

In addition to damaging infrastructure, wildfires, which may increase during droughts, can cause dramatic chemical and physical damage in rivers and streams, degrading source water quality for drinking water utilities drawing from these affected water bodies. Heavy rainfall following a wildfire carries debris into source water, creating water quality problems such as increased turbidity, high levels of organic carbon, and increased concentrations of nutrients and other constituents. The period of time that the degradation persists depends upon a number of factors including fire severity, climate, and geology (Sham et al. 2013). Wildfires can also change the landscape of the watershed and cause increased flooding, peak flows, erosion, and debris flows. These effects result not only in substantial environmental damage and costs to communities (e.g., related to road closures), but also damage to source water, which can be costly to address. In some cases, damage to the water source may be so extensive that the source must be abandoned altogether. In these cases, utilities must identify new water sources (Sham et al. 2013).

1.4 DROUGHT MANAGEMENT

Recent droughts in the United States highlight the need for drinking water utilities to proactively prepare for drought and mitigate its impacts. Drought planning may become especially important as droughts become more intense and patterns shift due to climate change (USGCRP 2014).

Drought management practices can play a key role in mitigating both short-term and long-term effects of drought. In general, drought management practices can be classified as those that increase water supply, those that reduce demand for water, or those that reduce the impacts of drought (Rossi et al. 2007). Long-term measures include increasing the capacity of storage facilities, integrated water resources management, and improving water use efficiency (Rossi et al. 2007). Short-term measures include contingency or emergency plans, or conservation measures implemented in severe drought conditions (Rossi et al. 2007).

Drought occurs over longer time frames (a few months to several years) compared to other natural hazards. Costs of drought, therefore, are often underestimated relative to events for which damages are more apparent and losses are incurred in a shorter period of time (Walker et al. 1991). Data gathered by NOAA's National Climatic Data Center show that between 1980 and 2011, drought represented 16 of 133 climate disaster events[4] in the United States that exceeded $1 billion in direct damages[5] with the 16 events accounting for 24 percent, or $210.1 billion in 2011$ ($221.12 billion in 2014$), of the total damages from all 133 events (Smith and Katz 2013).

Effective management of natural hazards such as droughts can be costly, but can also result in significant cost savings at the federal, state, local, and utility levels. For example, the Multihazard Mitigation Council (2005) calculated that every dollar spent by the Federal Emergency Management Agency on hazard mitigation grants provides the nation approximately four dollars in future benefits.[6] Drought-related monitoring, communication, and planning efforts can help alleviate drought impacts on communities, thereby potentially reducing the costs of drought (Svoboda et al. 2011). Each drought can present different climatic, social, economic, and political conditions, requiring a utility to assess and respond to the current event rather than solely relying on practices that were effective in a previous drought. Drought management plans guide decision-making before, during, and after a drought, and include critical information for managing

[4] Climate disaster events assessed in this study include tropical cyclones, floods, droughts / heat waves, severe local storms (*e.g.*, tornado, hail, straight-line wind damage), wildfires, crop freeze events, and winter storms.
[5] Direct damages include physical damages to residential, commercial and government/municipal buildings, material assets within a building, time element losses (i.e., time-cost for businesses and hotel-costs for loss of living quarters), vehicles, public and private infrastructure, and agricultural assets (e.g., machinery, buildings, livestock).
[6] Although this estimate was based on only some natural hazards (earthquakes, wind, and flood), researchers anticipate it is likely that similar estimates may be realized for drought (Svoboda et al. 2011).

drought events, such as descriptions of drought stages, triggers, monitored indicators, and responses (Fontaine et al. 2014).

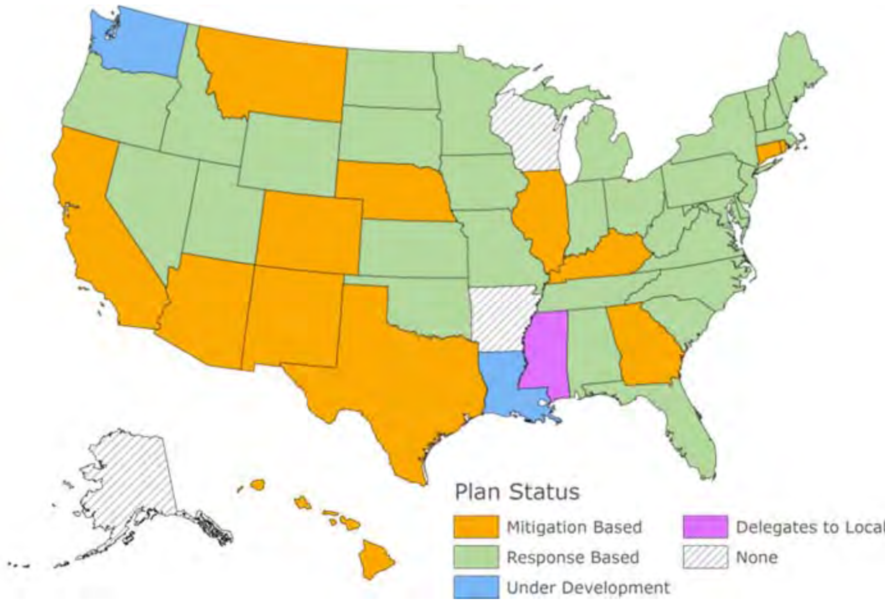
Drought planning and decision-making can occur at all levels: individual, community, utility, tribal, state, basin or watershed, national, and international. Missions, mandates, and authorities related to drought management vary across federal, state, and local agencies (Dennis 2013). As Figure 1-6 shows, nearly all U.S. states (with the exception of Alaska, Wisconsin, and Arkansas) have drought management plans either in place or currently under development (NDMC-UNL 2014). Several states, such as Texas and Arizona, now mandate that drinking water utilities develop drought mitigation or contingency plans to respond to and alleviate drought impacts (Texas Commission on Environmental Quality 2015, Arizona Governor's Drought Task Force 2004, and AWWA 2011).

AWWA's 7-Step Water Shortage Contingency Planning and Implementation Process

- Step 1: Form a water shortage response team
- Step 2: Forecast supply in relation to demand
- Step 3: Balance supply and demand and assess mitigation options
- Step 4: Establish trigger levels
- Step 5: Develop a staged demand reduction program
- Step 6: Adopt the plan
- Step 7: Implement the plan

Source: Data from AWWA 2011.

To maximize the effectiveness of drought management, drinking water utilities are encouraged to develop individualized plans. The earliest such utility-level drought management plans were developed in the 1980s, with a significant number of drinking water utilities developing them in the early 2000s (AWWA 2014). In a survey of 485 drinking water utilities conducted by the American Water Works Association (AWWA), 58 percent of the utilities reported that they had a formal, written water shortage contingency plan that was specific to their utility (AWWA 2014). Development and implementation of such plans is key to helping utilities meet their responsibility of providing safe water supply to communities even during water shortages (Chesnutt et al. 2012, Dziegielewski 2000).



Source: NDMC-UNL 2014.

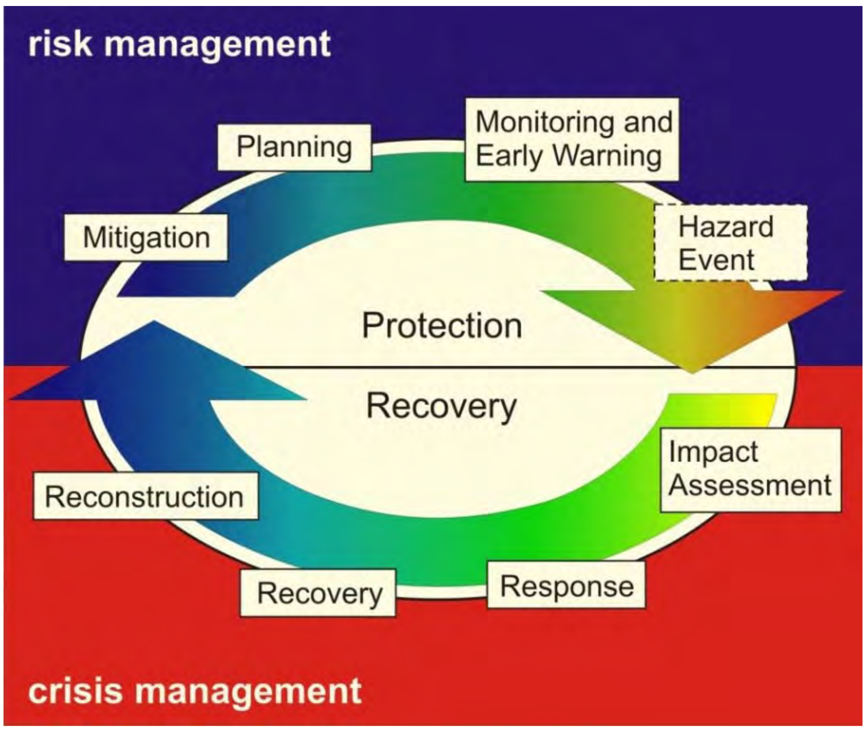
Figure 1-6 Drought management plans by state (as of 2013)

Drinking water utilities can engage in drought management practices before, during, and after drought. Managing drought entails four stages, some of which may occur concurrently (Knutson 2013, Davies 2000):

- Mitigation: Employing infrastructure-based measures (e.g., engineering projects) or non-structural measures (e.g., policies) to reduce impacts of future droughts.
- Preparedness: Preparing and enhancing community and institutional coping capabilities, developing forecasting and warning systems, and making contingency or emergency plans prior to the onset of drought conditions.
- Response: Providing assistance during or immediately after a drought disaster to protect life and ensure community subsistence. If planned in advance, these strategies can be a part of mitigation.
- Recovery: Restoring communities to pre-drought or "normal" living conditions.

Risk is managed most effectively when drought management practices are implemented prior to the onset of drought. Responses to drought can be characterized as crisis management. Risk management and crisis management activities are often undertaken concurrently or may even be indistinguishable (Davies 2000). For example, identifying different levels of drought that trigger specific restrictions on water use may be considered both preparedness and mitigation. Proactive management of drought entails prioritizing risk management approaches over crisis management approaches (Figure 1-7, Dennis 2013). Severe drought conditions can generate the institutional and public will needed to respond to and recover from drought, which can be leveraged to develop long-term proactive risk management strategies (Dennis 2013). Longer-term planning and mitigation approaches can lessen the impacts of future droughts and may eventually eliminate the need for short-term implementation of emergency plans (Dziegielewski 2000). Implementing proactive drought management practices may also buffer utilities against the anticipated changes in the duration and intensity of drought due to climate change. A utility may find a cost-benefit analysis helpful in identifying the measures with the greatest net benefit to the utility, the environment, and society.

Many of the practices used to manage drought also have broader advantages. Conversely, many utilities are already implementing practices that, while not intended specifically to manage future impacts of drought, will help make the utility more resilient in times of drought. Conservation initiatives such as universal metering, leak detection programs, and water audits can help utilities to reduce consumption and water loss (and therefore lost revenue), and may in turn help ensure greater water availability and acceptance of more significant water restrictions in drought conditions. Additionally, routine infrastructure maintenance (e.g., pipe repair and replacement) can reduce the vulnerability of the water utility to the impacts of drought. Although it may be challenging to identify which best practices implemented outside of drought conditions should be incorporated into a cost-benefit analysis of drought management options, their impact should not be overlooked.



Source: Smith and Knutson 2015.

Figure 1-7 Risk management vs. crisis management in drought planning

1.5 USE OF COST-BENEFIT ANALYSES IN DROUGHT PLANNING

The costs that drinking water utilities incur because of either proactive or reactive drought management practices can be significant. Yet as droughts intensify and widespread drought becomes more common due to climate change, lack of proper planning may lead to significant costs as well. To ensure that customers continue to receive reliable and safe drinking water, utilities may need to invest heavily and over a prolonged period in conservation programs; identify, procure, and deliver alternative water supplies; or modify existing or build new infrastructure, among other activities. Therefore, in selecting an appropriate portfolio of drought management strategies, utilities need to examine the short-term and long-term financial implications of their decisions. A cost-benefit analysis can be a highly effective tool for accomplishing this often complex and daunting task.

A cost-benefit analysis can help drinking water utilities catalog information on drought management practices and evaluate various alternatives. A cost-benefit analysis involves identifying the costs of each potential drought management practice (or practices) that, while not implemented specifically for drought management purposes, will help improve the utility's resilience to drought), and comparing them to the benefits. Costs and benefits of drought management practices are typically realized over many years. As such, a cost-benefit analysis would allow a utility to compare the anticipated future value of water, which may be higher relative to other costs due to more frequent and intense droughts predicted by climate change models. Ideally, a cost-benefit analysis would account for the impact of the drought mitigation practice on the triple bottom line, which considers the financial stability of the utility, the effect on the environment, and social concerns. (The triple bottom line concept is discussed in more detail in Chapter 4.) The practice with the largest net benefit is considered the best alternative.

The research approach for this study included the following steps:

1. Collect information on drought management practices used by drinking water utilities in the United States and elsewhere
2. Review available literature for the costs and benefits of those practices
3. Conduct a workshop with partner drinking water utilities to share information on approaches to drought management
4. Conduct interviews with utilities for developing case studies
5. Provide background on the data needs and methodology for cost-benefit analyses
6. Demonstrate the use of a cost-benefit analysis for drought planning by a hypothetical utility.

CHAPTER 2
THE COSTS AND BENEFITS OF DROUGHT MANAGEMENT

2.1 COSTS OF DROUGHT IMPACTS

A drinking water utility conducting a cost-benefit analysis needs a complete collection of accurate, monetized drought-related costs that the utility would incur without any drought management practices. However, costs attributable to the impacts of drought can be difficult to estimate. Drinking water utilities may be most concerned with the financial costs they will directly incur because of the drought and they may choose to include social costs that will affect their customers or the community as a whole. Including these social components in a cost-benefit analysis will result in a more comprehensive understanding of the true costs of drought. The following section is organized to distinguish the costs to utilities from the costs to society, to the extent possible.

2.1.1 Costs of Water Infrastructure Impacts

Water main breaks are a common occurrence for drinking water utilities. Sturm et al. (2014) identified a benchmark pipe failure frequency in North America of approximately 25 failures per 100 miles per year, based on six published studies. Changes in soil structure associated with worsening drought conditions (discussed in section 1.3.3), however, may increase the number of breaks. In a cost-benefit analysis, utilities may use the costs of their normal pipe repair activities to estimate costs associated with drought-induced breaks. The exact cost to repair or replace a broken main depends on several factors including pipe diameter, depth of cover, type of pipe, and local material and labor prices (Hillyer and Hofbauer 1998). The costs are thus utility-specific and event-specific. Studies that estimate the number of main breaks that can be attributed to drought are not readily available. Therefore, this section presents the costs for general pipe repair and replacement, although the studies citing such costs did not necessarily analyze these costs in the context of drought management. Such studies should be considered as a starting point, but utilities will need to consider the factors noted above to determine anticipated costs of their own main breaks.

Gaewski and Blaha (2007) estimated the cost of main breaks to water utilities and to society by examining costs associated with 30 large-diameter[7] water main failures across North America. Direct costs of water main breaks, which consist of expenses paid by the water utility or by the utility's insurance carrier (construction, landscaping, legal fees, materials, etc.) were estimated to range from $6,000 to $8.5 million in 2006$ ($7,045 to $10 million in 2014$), with an average cost per break of $833,333 in 2006$ ($978,571 in 2014$).[8] Approximately 52 percent of these costs were associated with claims paid by the utility for property damage.

In addition to repair costs incurred by a water utility, water main breaks waste water, may threaten public safety, and are generally disruptive to society (AWWA 2012a). The costs to society of a water main break will depend on the extent of damage caused by the break itself, such as damage to property or other underground infrastructure (Water Research Foundation undated).

[7] Gaewski and Blaha (2007) define large-diameter mains as pipes that are 20 inches or greater in diameter.
[8] Gaewski and Blaha (2007) did not provide costs per main break, but rather an aggregate cost for all 30 breaks. The average cost to the water utility per main break was calculated by dividing the direct costs for all breaks by 30.

Societal costs, which are those that are not paid by the utility or by the utility's insurance carrier, include lost wages, traffic disruptions, public health impacts, and property damage (Gaewski and Blaha 2007). In their study of 30 large-diameter water main failures, Gaewski and Blaha (2007) estimated that societal costs ranged from approximately $0 to $8.3 million in 2006$ ($0 to $9.8 million in 2014$) per main break, with a mean of $900,000 in 2006$ ($1.1 million in 2014$).[9]

A study by Grigg (2007) documented the costs of water main breaks reported by five drinking water utilities (four from the United States and one from Canada) over one year. Table 2-1 provides a breakdown of several aspects of repairs, with average costs calculated by dividing the total reported costs for the five utilities by the total number of water main breaks. Pipe materials consisted of cast iron (four utilities) and steel (one utility) (Grigg 2007). Note that the Grigg study examined breaks in pipes of smaller diameter than those examined by Gaewski and Blaha. As noted in section 1.3.3 and shown in the table below, main breaks in smaller-diameter pipes are less costly to repair (compared to the average cost per break for large-diameter pipes cited by Gaewski and Blaha), but they occur more frequently (Grigg 2007). The cited costs for repair of large diameter pipes often include costs related to the significant property damage resulting from the breaks.

Table 2-1
Cost data per main break as reported by five utilities (in 2014$)

Break cost item	Average $/break
Ordinary repairs (schedulable)	$6,332
Emergency repairs (unplanned)	$10,217
Pavement restoration	$747
Claims/property damage	$341

Source: Grigg 2007; nominal costs reported in 2000$.

2.1.2 Costs of Water Quality Impacts

Because source water quality can be affected by drought conditions (i.e., sedimentation can increase and runoff is likely to have elevated concentrations of pollutants, as discussed in section 1.3.4), drinking water utilities will likely face increased costs related to water treatment during drought. To examine the impact of source water contamination on treatment costs, Dearmont et al. (1998) modeled treatment costs using a variety of parameters including gallons treated, turbidity, pH, and rainfall (to account for runoff and increases in sediment levels). Using data from systems in Texas, the authors determined that the cost of water treatment would increase by $94.75 ($171.62 in 2014$) per million gallons[10] when elevated concentrations of chemical contaminants are present in source water, which may occur during drought (as discussed in section 1.3.4). Furthermore, the study determined that a 1 percent reduction in turbidity would reduce the cost of treating water by 0.27 percent (Dearmont et al. 1998).

Water quality degradation due to saltwater intrusion is a concern for utilities that rely on coastal groundwater sources, and it may be exacerbated by overdrafts during drought (as discussed

[9] Gaewski and Blaha (2007) did not provide societal costs except as an aggregate cost for all 30 breaks. The mean of the cost to society per main break presented here was calculated by dividing the aggregate cost by the number of pipe failures. The low and high estimates for societal costs were approximated using bar charts in the report.
[10] Costs reported were for a range of years from 1988-1991.

in section 1.3.2). The costs associated with this impact can be very high and affected utilities should consider such costs in their cost-benefit analyses. For example, the City of Hallandale Beach in south Florida has incurred significant costs due to saltwater intrusion associated with increased demand and the resulting overdraft. The City was forced to decommission six of its eight wells, and spent more than $9 million ($9.1 million in 2014$) for drilling a new well and developing a stormwater injection system to deflect intruding saltwater away from the wellfield (City of Hallandale 2014). Another Florida city's (Lake Worth) wells were at risk of saltwater intrusion following a 2001 drought. The City made the decision to supplement its existing wells with three new wells drawing brackish water from the Floridan Aquifer, and spent $24 million ($26.1 million in 2014$) to build a reverse osmosis plant to treat the brackish water (Reid 2011).

Saltwater intrusion in surface water resources in coastal areas due to reduced streamflow during drought (as discussed in section 1.3.4) may also have significant financial implications for water utilities. The drought of 2011–2013, which affected the South, resulted in saltwater intrusion so extreme that it threatened industrial and municipal water intakes more than 60 miles inland from the Gulf of Mexico (Brislawn et al. 2014). In this case, the U.S. Army Corps of Engineers spent $5.8 million ($6 million in 2014$) to build a sill on the bottom of the Mississippi River to prevent the saltwater from migrating further inland (Elliot 2013). Despite this effort, saltwater reached the drinking water intakes for the water utility serving Plaquemines Parish, a community south of New Orleans. To continue supplying water to Plaquemines Parish customers, the city of New Orleans delivered approximately 1 million gallons of drinking water per day through an interconnection between the two systems (Alexander-Bloch 2012). This event is described in detail in section 2.2.2.1 below.

In wildfire-affected areas, effects on surface water (e.g., increased loadings of sediment and organic and inorganic constituents associated with increased post-fire runoff; as discussed in section 1.3.4) can necessitate costly mitigation measures or changes in treatment. In particular, the costs associated with increased turbidity can be substantial. The Santa Fe Municipal Watershed Plan estimated that the cost associated with the impacts of a 7,000-acre fire in its watershed would be $22 million ($24.2 million in 2014$) (City of Santa Fe 2009). To address the effects of the historical Buffalo Creek Fire (1996) and the Hayman Fire (2002), Denver Water spent $26 million in 2002 ($34.2 million in 2014$) to restore water quality and remove the large volume of sediment from one of its reservoirs (Denver Water 2015a).

2.1.3 Costs of Water Reliability

Decreased precipitation, as well as increased consumption and withdrawals during drought (due to the needs of the agricultural sector and power plants, discussed below) reduce water supplies available to consumers (as discussed in section 1.3.1). This reduction in water availability during drought may lead to changes in water use patterns among water customers (Hillyer and Hofbauer 1998). Some studies have examined customers' willingness to pay for a reliable water supply in an effort to estimate the value of water from the perspective of the customer. Values for willingness to pay represent the maximum amount an individual is willing to pay to avoid an undesirable outcome (e.g., reduction in water availability). Although willingness to pay is not equivalent to the cost of a reduction in the availability of water, it can serve as a proxy for the cost to customers to adapt to new behavior relating to their water use.

Koss and Khawaja (2001) used a contingent valuation method (CVM) to estimate California water users' willingness to pay to avoid water shortages of a given severity and frequency. Mean monthly willingness to pay estimates vary according to the severity (percent reduction in full service) and frequency (occurrence per number of years) of the drought. California water users' willingness to pay varies with the quantity and timeframes of the water shortages they might face. When faced with the idea of a 10 percent reduction in water availability every 10 years, California water users are willing to pay $11.67 per month in 1993$ ($19.12 in 2014$) to avoid the water shortage. However, to avoid a 50 percent reduction in water availability every 20 years, they are willing to pay $16.92 per month in 1993$ ($27.72 per month in 2014$). The results indicate that water customers are willing to pay more to avoid the impacts of severe, infrequent droughts compared to the impacts of mild, frequent droughts (Koss and Khawaja 2001).

2.1.4 Costs of Land Subsidence

Land subsidence can occur in areas with significant overdraft of aquifers (as discussed in section 1.3.2) and can result in substantial costs to the water utility and the community. Water infrastructure such as treatment plants, tanks, and pump stations can shift, which would affect operations. The effects and costs of land subsidence on water- and non-water-related infrastructure can be significant, as illustrated by data for six locations that have experienced subsidence (Table 2-2).

Table 2-2
Impacts and costs associated with land subsidence (in 2014$)

Location	Land Subsidence	Impacts	Estimated Costs	Reference
Santa Clara Valley, CA	14 feet in San Jose (1910-1995)	Diking to prevent flooding; water well and sanitary and storm sewer system repairs; modifications or repairs to major infrastructure.	$768 million[1]	Borchers and Carpenter 2014
San Joaquin Valley, CA	28 feet in some areas (by 1970)	Major impacts on infrastructure and physical features, including the San Joaquin River, Delta Mendota Canal, Friant-Kern Canal, and San Luis Canal; damage to privately owned canals and related infrastructure.	$1.32 billion[2]	Borchers and Carpenter 2014
Sacramento Valley, CA	--	Wide-scale failure of steel groundwater well casings, sometimes making wells unusable.	--	Borchers and Carpenter 2014
Antelope Valley, CA	--	Impacts to Edwards Air Force Base; increased flooding and erosion; failed well casings; damage to roads, homes, and other structures.	--	Borchers and Carpenter 2014
Pinal County, AZ	7.5 feet (1947-1967)	Major impacts on infrastructure, including damages to highways and road beds; well damage; impacts to agricultural fields and grazing lands, necessitating crack and ditch repair.	$911,082 annually[3]	McCauley and Gum 1975

(continued)

Table 2-2 (Continued)

Location	Land Subsidence	Impacts	Estimated Costs	Reference
Houston, Pasadena, Baytown, and La Porte, TX	8 feet (1943-1974)	Infrastructure and property damage and increased flooding	$$526 million property loss and damage; $19.2 million in public costs[4]	Warren et al. 1974

Source: Data from sources noted in References column.

[1] *Borchers and Carpenter (2014) reported costs in 2013$ for the range of years 1910-1995.*
[2] *Borchers and Carpenter (2014) reported costs in 2013$ for the range of years 1955-1972.*
[3] *McCauley and Gum (1975) reported costs in 1975$.*
[4] *Warren et al. (1974) reported costs in 1974$ for the range of years 1943-1973.*

Land subsidence can also affect property owners by causing damage to home foundations. Furthermore, water use restrictions during times of drought limit the ability of homeowners to soak dry ground as a preventive measure. The cost to repair a foundation typically ranges from $15,000 to $20,000 ($16,285 to $21,713 in 2014$) but can be as much as $50,000 ($54,283 in 2014$) in cases with severe sagging and damage to plumbing (Wear 2011).

2.1.5 Revenue Losses

Utility revenue can increase in the early stages of drought with the onset of increased water demand and before utilities implement short-term and long-term conservation measures (Hughes and Leurig 2013). At a 2011 workshop, attendees (representing more than 20 of the nation's largest water utilities and privately owned water service providers) cited revenue uncertainty (driven by variability in water use, among other key factors) as one of their biggest concerns (Haskins et al. 2011).

Drinking water utilities may experience significant net revenue losses due to conservation. However, it may be possible for utilities to minimize or even avoid losses through conservation pricing (discussed in Section 2.2.1.4), among other drought management approaches. In particular, utilities that rely heavily on revenues from outdoor irrigation can experience a drop in revenue as customers reduce outdoor water usage. Revenue shortfalls resulting from a decrease in demand can limit a utility's ability to maintain infrastructure and pay for operating costs such as energy and labor. Revenue instability can also increase the cost to the utility of borrowing. Revenue unpredictability and variability must be considered in a cost-benefit analysis; the effect of drought mitigation activities on revenue stability is discussed later in this chapter.

The costs of drought impacts described in this section are summarized Table 2-3.

Table 2-3
Examples of costs associated with the impacts of drought (in 2014$)

Type of Impact	Location	Impact Costs	Reference
Water main breaks	15 utilities across the United States	$7,045 to $10 million per break in direct costs to the utility for general water main repairs; approximately $0 to $9.8 million per break in direct costs to society for general water main repairs	Gaewski and Blaha 2007
Water main breaks	Five utilities from California, Kentucky, and Canada	$6,332 per break for planned routine repairs	Grigg 2007
Wildfire	Denver Water, CO	$34.2 million to restore water quality and remove excess sediment and debris after wildfires	Denver Water 2015a
Wildfire	Santa Fe Municipal Watershed, NM	$24.2 million (estimated) to address impacts of a wildfire in watershed	City of Santa Fe 2009
Decreased water supply	10 water districts in California[1]	$19.12 to $27.72 per month willingness to pay to avoid decrease in supply	Koss and Khawaja 2001
		$10,217 per break for emergency repairs	
Land subsidence	Santa Clara Valley and San Joaquin Valley, CA	$768 million to $1.32 billion for land subsidence from 1955-1972	Borchers and Carpenter 2014
Land subsidence	Unspecified	$16,285 to $21,713 for repairing general foundation damage and sagging and broken plumbing	Wear 2011

Source: Data from sources noted in References column.

[1]*Almeda County Water District, Contra Costa Water District, Los Angeles Department of Water and Power, Municipal Water District of Orange County, Orange County Water District, Metropolitan Water District of Southern California, San Diego County Water Authority, City of San Diego, San Francisco Water Department, and Santa Clara Valley Water District.*

2.2 LEADING PRACTICES IN DROUGHT MANAGEMENT AND THEIR COSTS

The diversity in drinking water utilities across the United States is significant in terms of number of customers served; the type of customer served; scope of services (e.g., wholesale or retail, provision of both water and wastewater services); ownership profile (public, private, or non-profit); regulatory and economic oversight; and water rights (Chesnutt et al. 2012). The defining characteristics of a utility can affect the type and scope of drought management options available and the relative ease or complexity (and, in turn, the relative cost) of implementing them. When evaluating drought management practices, drinking water utilities must also consider financial and personnel resources; existing water resources and related infrastructure; geography; legal, social, and environmental effects; political climate; and the appropriate scale (national, regional, or local) at which those measures will be most effective (Knutson 2013). To the extent that these factors can be monetized, a cost-benefit analysis can help utilities identify the most cost-effective drought management practices.

Table 2-4
EPA Water Conservation Plan Guidelines – water conservation measures

Basic	Intermediate	Advanced
• Universal metering • Water accounting and loss control • Costing and pricing • Information and education	• Water-use audits • Retrofits • Pressure management • Landscape efficiency	• Replacements and promotions • Reuse and recycling • Water-use regulation • Integrated resource management

Source: Data from EPA 1998.

Leading practices in drought management include managing water demand (end user conservation, conservation and drought pricing and water loss control programs), identifying and implementing measures to augment the existing water supply (either short or long term), and communicating related information to the public. A recent survey of drinking water utilities conducted by AWWA (2014) identifies the strategies that are most commonly and least commonly used by water utilities to prepare for water shortages (Table 2-5).

Table 2-5
Summary of AWWA survey results on water shortage preparedness strategies

Category	Most common strategy (% of utilities using it)	Least common strategy (% of utilities using it)
Demand management	Voluntary and mandatory conservation (88%)	Restricting new meters or new connections (17%), offering hotel guests the option not to launder linens daily (18%)
Supply management	Establishing mutual aid agreements, transfers, or interconnections with other agencies (54%)	Building emergency dams (2%) and reactivating abandoned dams (0.3%)
Public outreach	Reaching out to local decision-makers (84%)	Outreach targeting wholesale customers (37%)

Source: Data from AWWA 2014.

The leading practices in drought management presented in Table 2-4 capture the majority of the conservation measures outlined in the EPA Guidelines. Appendix A includes a compilation of about 40 examples of drought management practices implemented by water utilities and their associated costs, primarily from online sources. This list illustrates the diversity of drought practices and the variation in cost of similar practices across U.S. utilities. Factors that can affect the cost of drought management include customer base; available resources; location; the extent of any existing impacts from water supply shortages or drought; and, the complexity of the selected drought management practices.

A triple bottom line analysis considers the potential environmental, social, and financial (for the utility) effects of a selected practice (see Chapter 4 and Chapter 5). A thorough understanding of utility-specific costs and benefits is necessary to conduct a cost-benefit analysis and evaluate the alternative drought management practices discussed in this chapter. The following section discusses leading drought management practices of utilities across the country, presents the costs and benefits of these practices when possible, discusses the challenges with calculating these costs and benefits, and provides examples of these practices in action.

2.2.1 Demand Management

Drinking water utilities can mitigate the effects of drought through conservation measures and incentives aimed at reducing demand for water from customers (residential, agricultural, commercial, and industrial) and promote the utility's efficient delivery of treated water to the customer. This section begins with some general considerations for demand management programs and then discusses specific aspects such as public outreach and education (section 2.2.1.1), end user conservation (2.2.1.2), conservation and drought pricing (2.2.1.4), and utility water loss control programs (2.2.1.3).

Conservation measures can include the use of new devices or technology (e.g., low flow toilets, leak detection equipment, drip irrigation) to improve water efficiency, and the promotion of behavioral and water management practices (e.g., turning off faucets when not in use, limiting lawn watering, water-efficient landscape practices), as discussed in section 2.2.1.2 (Vickers 2001). Conservation incentives can include public outreach and education (discussed in section 2.2.1.1), financial incentives (discussed in section 2.2.1.2), and regulatory approaches, which can originate at the local, state or federal levels (Vickers 2001). Some conservation measures and incentives are designed to affect long-term water use and others are targeted to curtail short-term water use in an effort to immediately alleviate the effects of drought.

The approach that a water utility may take to implement a specific conservation initiative or broader program can vary, depending on the immediacy of the need for reduced water usage, the breadth and complexity of the initiatives or programs, available resources, whether the utility is using a contractor to design and implement the initiatives or programs, and the size and makeup of the customer base (A & N Technical Services, Inc. 2004). Water utilities with no current supply constraints that serve communities that are not expected to experience significant growth in the future may take a more limited approach to conservation. In contrast, utilities at the other extreme may see the need for more significant conservation initiatives (Beecher et al. 1994). Once there is a recognized need or

Denver Water's Investment in Outreach Campaigns

In 2006, Denver Water initiated its "Use Only What You Need" campaign, which is internationally recognized and a notable example of the use of media to promote water conservation. Using billboards, bus stops, print media, television, and other marketing vehicles, Denver Water promotes the reduction of water demand by 22 percent by 2016. The cost associated with Denver's outreach campaign varies from year to year, but in the 2013 the cost of the campaign was approximately $700,000 (Colorado WaterWise and Aquacraft 2010).

impetus for conservation, the general process for implementing a conservation program will involve (A & N Technical Services, Inc. 2004, Chesnutt et al. 2012, Vickers 2001):

- Establishing conservation goals;
- A data collection and design phase (which may include evaluating the effects of previous conservation initiatives, building a water use profile, identifying and evaluating potential options and incentives using data collected);
- A pilot phase, which may be followed by adjustments or more significant changes to the initial design;
- Full-scale implementation; and
- Ongoing program assessment and evaluation, adjusting the program (and conservation plans and supply and demand forecasts) as needed.

Water conservation (and efficiency) measures help reduce the utility's costs of operations, particularly for energy and chemicals. The same measures will allow utilities to avoid costs resulting from investments in unnecessary capacity (primarily source development and treatment) to meet inflated demand for water services (Beecher et al. 1994). By reducing the utility's long-term costs, revenue requirements are also reduced. The challenge for the utility is to educate customers about the long-term benefits of water conservation (A & N Technical Services, Inc. 2004).

In evaluating the costs and benefits of potential conservation measures or incentives, water utilities might encounter problems at each phase of implementation, e.g., availability of data to evaluate the type and extent of conservation measures or incentives needed, training for utility staff, staffing, and regulatory and revenue implications. There are existing models for calculating the costs and benefits of conservation program practices, such as the Conservation Benefit Cost Model (Chesnutt et al. 2012) and the Conservation Tracking Tool (AWE 2011). Chesnutt et al. (2012) created a *Compendium of Water Use Efficiency Cost and Savings*, which lists about 20 water efficiency measures and example costs and savings from the literature. The compendium includes a wide variety of measures such as universal metering, high efficiency washing machines, pre-spray rinse spray valves used in food service, and water budgets for large landscapes.

Because the goal of end user conservation measures and incentives is to encourage customer participation, the type of implementation challenges the utility will face will depend on the type of customer the conservation initiative targets (Chesnutt and Pekelney 2004).

A 2009 study examining the research on price- and non-price-based water conservation measures found that price-based demand management approaches are more cost effective than non-price measures, such as mandatory water use restrictions or voluntary adoption of water-efficient technology (Olmstead and Stavins 2009). Utilities may find that combining conservation pricing with non-price-based demand management initiatives, such as educational programs that offer ideas and tools to help customers reduce their water use, leads to maximum results (GA EPD 2007; Beecher et al., 1994). This approach may be less cost effective than implementing pricing methods on their own (Olmstead and Stavins 2009). These findings are not universally accepted, however, because of uncertainty about the effect of the price of water on demand.

2.2.1.1 Demand Management - Public Outreach

Customer education and outreach can be critical to the effectiveness of a utility's conservation efforts, and it is often the first step that water utilities take in implementing a broader conservation program (Vickers 2001). Drinking water utilities may use public outreach to raise awareness about drought and associated water shortages, disseminate information about and garner support for conservation initiatives and pricing changes, and engender behavior change among customers. Public outreach may include media communications, school education, and public seminars to provide customers with information about their water consumption and the drought mitigation efforts undertaken by the utility (Colorado WaterWise and Aquacraft 2010). Drinking water utilities may also use follow-up surveys to determine the reach and effectiveness of their campaigns. A study of customer behavior in Australia found that, in addition to other key factors (most notably a general pro-environment attitude and desire to seek out information on water-related issues), customers were motivated to conserve water if they had previously experienced, been limited by, or changed their behavior in response to water use restrictions. The authors conclude that outreach campaigns should emphasize the negative and personal consequences of water shortages and how those consequences can be avoided (Dolnicar et al. 2012). A second study of water use and customer behavior in Australia indicated that outreach efforts might be most effective if targeted at particular end uses, such as clothes washing, showering, tap use, and irrigation (Willis et al. 2011). Silva et al. (2010) discuss design and implementation of an effective public outreach program including that rebate messaging and water use audits should be targeted to high water use customers.

The costs of outreach and education campaigns can vary greatly. In a small sample of utilities, typical conservation communications ranged from 3% to 50% of the conservation program budget and increased during drought (Silva et al. 2010). For some utilities, the drought management outreach and education campaign may be fairly resource intensive. For example, water agencies in California responded to recent droughts with a range of outreach campaigns:

- The Metropolitan Water District of Southern California authorized $5.5 million in early 2014 for an outreach campaign to promote conservation using radio, TV, and print media (Zimmerman 2014).
- The Santa Clara Valley Water District (California) spent $1 million ($1.1 million in 2014$) in the summer of 2009 on a public outreach campaign that urged its customers to reduce their water use (Rogers 2010).
- The City of Sacramento (California) conducted a campaign from January to May 2014 to educate water users on new restrictions on yard watering (Gies 2014).
- The Monterey Peninsula Water Management District (California) instituted the "Save Water, Go Blue" initiative, which involved sending notices to customers reminding them to reduce use and providing additional steps customers can take to keep water rates low (Urton 2014). The initiative, which was anticipated to cost the District $75,000 ($76,216 in 2014$), includes advertising campaigns and conservation workshops.

Drinking water utilities may also provide their customers with free in-home water use audits or consultations. During these consultations, conservation experts may check for leaks and provide information about water efficient practices, products, and strategies. Many water utilities provide tips and strategies about landscape irrigation and design. The City of Watsonville in California uses water consultations to create water budgets for its customers as well as explain its current conservation programs (Dennis 2013, City of Watsonville 2015). These incentives can lead to cost savings for customers, which can in turn help to engender broader support for conservation initiatives (Beecher et al. 1994).

Some drinking water utilities are also using norm-based messaging, a method that promotes behavioral change, to inform customers about water conservation and motivate them to use less water. The East Bay Municipal Utility District (MUD) in northern California provides data in each customer's water bill on how their water use compares to similarly sized homes in their neighborhood (Cuff 2014). In a test program of 10,000 East Bay MUD households, customers could see how their water use ranked among their neighbors, which led to a 5 percent decrease in water use over a year.

In a study conducted by Ferraro and Price (2013) in conjunction with the Cobb County Water System in Georgia, approximately 12,000 residential households were assigned to one of three groups (36,000 total households): a group that received technical advice on water conservation (i.e., general water conservation tips); a group that received both technical advice and a letter explaining why they should conserve water (e.g., the County is in a drought); and a group that received the advice, the letter, and information regarding the individual household's prior summer usage as compared to the County's median usage. After receiving the information, water usage for these households was tracked over the next 5 months (including summer months). Those who received the socially-based options (groups 2 and 3) achieved the greatest reduction in water usage (2.7 and 4.8 percent, respectively) (Bernedo et al. 2014, Ferraro and Price 2013). Voluntary conservation measures such as these can help to accelerate the adoption of water-efficient devices and practices, which can, in turn, contribute to long-term reductions in water demand (Colorado WaterWise and Aquacraft 2010).

Outreach measures may include activities related to both voluntary and mandatory conservation programs; these were identified as being the most commonly used approaches to address water shortages in a recent survey of water utilities (Table 2-5, AWWA 2014).

2.2.1.2 Demand Management - End-User Conservation

Voluntary measures, such as rebate programs or self-imposed water use reductions, encourage customers to reduce water use both over the short and long term, without enforcement on behalf of the utility. While utilities may be concerned that voluntary conservation measures may make it more difficult to implement more stringent, mandatory water use restrictions in times of drought, implementing such voluntary conservation measures should help to limit the need for such additional, mandatory restrictions (Beecher et al. 1994).

Voluntary conservation measures can be targeted to both residential and non-residential customers, and to both indoor and outdoor water usage, and will vary accordingly. Common measures include, but are not limited to: rebates and retrofits; landscape efficiency programs; universal metering; and water loss audits. Examples of application of these initiatives are provided below. For a more detailed discussion, see references like Chesnutt et al. (2012), AWWA G480-13 Water Conservation Program Operation and Management (AWWA 2013), or AWE (2011).

Many utilities have offered rebates for the replacement of household and commercial appliances with more efficient water-saving devices. The City of Hays in Kansas has implemented a program that offers $100, $50–$150, and $300 rebates for water-efficient washing machines, toilets, and urinals, respectively (City of Hayes 2014). Similarly, the Sonoma County Water

Agency (SCWA) in California offers rebates for the use of water-efficient household appliances, including washing machines ($125 rebate) and toilets ($300 rebate), as well as water-efficient commercial appliances such as medical equipment steam sterilizers ($700 rebate) and cooling tower conductivity controllers ($5,000 rebate) (SCWA 2015).

Utilities may also offer rebates or other financial incentives through landscape efficiency programs. For example, the Los Angeles Department of Water and Power (LADWP) implemented an incentive program that pays residential customers $3.75 per square foot for the first 1,500 square feet and $2.00 per square foot thereafter for replacing turf with native plants, mulch, or permeable pathways (LADWP 2014). LADWP also offers commercial customers up to $3.00 per square foot for xeriscaping (LADWP 2014). The Dallas Water Utilities target industrial, commercial, and institutional entities by providing free water efficiency assessments and up to $100,000 in site-specific rebates for water-efficient equipment and processes (Dallas Water Utilities 2015). Such rebate programs have been found to reduce water use by 1.1 to 4.0 percent (Michelsen et al. 2007). The success of these programs has also led some drinking water utilities to increase funding to extend their programs and promote long-term conservation. For example, the Desert Water Agency in California increased funding for its lawn replacement program from $250,000 to $1 million ($254,056 to $1 million in 2014$) (James 2014).

When employing rebate programs, drinking water utilities will incur the costs offered by the rebate as well as the costs of implementing the program. Implementation costs include the costs of additional labor for processing the rebate applications and inspecting the devices or new xeriscaping installed under the program. Implementation will also entail overhead costs from public outreach campaigns to promote the program. Some examples of rebate programs and their associated costs are provided in Table 2-6.

Table 2-6
Summary of rebate program costs by drinking water utility (in 2014$)

Water Utility	Location	Program (and years of implementation)	Rebate per unit	Implementation Costs; Total Cost
City of Austin	Austin, TX	Toilet and shower retrofit (2001 pilot study)	$60 per toilet; $2.39 per showerhead	$42,449 in implementation costs; $329,468 total program cost
Albuquerque Bernalillo County Water Utility Authority	Albuquerque, NM	Residential and commercial toilet rebate (1995-2002)	Residential rebate of $125 for 1st toilet; $75 for 2nd toilet; $50 for 3rd toilet; Non-residential $90 per toilet	$366,250 in implementation costs; $3.34 million total program cost
Irvine Ranch Water District	Irvine, Lake Forest, Tustin, Newport Beach, CA	Turf replacement (2006)	$1 per sq. ft. of lawn replaced with synthetic turf	$32,304 in implementation costs in 2006; $41,511 total program cost

(continued)

Table 2-6 (Continued)

Water Utility	Location	Program (and years of implementation)	Rebate per unit	Implementation Costs; Total Cost
Aurora Water	Aurora, CO	High-efficiency appliance and low-flow toilet rebate (2002-2006)	$100 per toilet using 1.6 gallons per flush (GPF); $150 per toilet using 1.28 GPF; $125 per washing machine	$87,149 in implementation costs; $1.1 million total program cost

Source: Data from Western Resource Advocates 2008. Costs were reported for different years in this study, as indicated by the years of implementation, and were converted to 2014$ in this table.

Financial incentives for conservation can also take the form of direct payments to agricultural customers for reducing water use (i.e., suspending withdrawal rights). This is intended to reduce water demand in the short term and to mitigate damage to the utility's water sources caused by drought and excessive use. The Edwards Aquifer Authority in Texas offers irrigators an annual rebate for participating in a voluntary program to cease withdrawals from the aquifer when the level declines to at or below 635 feet above mean sea level. For a 5-year commitment, irrigators receive $50 per acre-foot ($153 per million gallons) per year for participation and an additional $150 per acre-foot ($460 per million gallons) if they must cease withdrawals for a specific year. For a 10-year commitment, the amount increases to between $57.50 and $70.20 per acre-foot in 2014$ ($176 to $215 per million gallons) to participate and an additional $172.50 to $210.60 per acre-foot in 2014$ ($529 to $646 per million gallons) to cease withdrawals (Huddleston 2014, Edwards Aquifer Authority 2015). The annual cost of the program is difficult to estimate because it depends on the amount of water involved, but the program is estimated to save 13 billion gallons of water annually, allowing for improved spring flow at Comal Springs during the most severe drought (Edwards Aquifer Authority 2015). The Authority anticipates spending $8 million in 2014$ on this program in 2015 (Horne 2014).

2.2.1.3 Water Loss Control: Water Audits and Water Loss Reduction

Most demand management programs encourage the customer to reduce water demand, but the focus of water loss control programs are a means for a utility to systematically account for utility water distribution efficiency, reduce water losses, and increase revenue recovery. AWWA (2009) recommends water loss control programs and water audits and have explained the process and benefits in their *Manual 36: Water Audits and Loss Control Programs*, 3rd edition. Water loss control program include activities like metering water use, performing utility water audits (which may vary in sophistication and data required), and implementing interventions like meter testing and repair, leak detection and repair, or optimizing pressure management. By reducing water losses, utilities may reduce the amount of water withdrawn from sources, reduce energy and treatment costs for pumping and treating excess water, and reduce costs associated with equipment repair and replacement. The cost of investing in an effort such as universal metering may be offset by the revenue realized by more accurately tracking and accounting for water usage (EPA 2010). This proactive leak management strategy may start to address the poor condition of the drinking water infrastructure which is a major concern and threat to public health and safety, an obstacle to the efficient and controlled use of threatened water supply, and, as noted previously, an even greater threat in times of drought (due to stress exerted on the pipe wall by the compaction of clay soils). Aging distribution systems are a major contributor to water losses, but utilities can also lose revenue through administrative, data management, or billing problems, as well as due to inaccurate meters (EPA 2010).

There are many examples of the benefits of employing the water loss control program concepts such as Halifax Regional Water Commission which reduced distribution system leakage by 9 million gallons per day in 6 years, which allowed a corresponding reduction in plant output to realize an annual savings of $550,000 Canadian (Kunkel et al. 2006). (For a detailed discussion of water loss control programs, including the costs and benefits, refer to resources like Fanner et al. (2007a), Fanner et al. (2007b), AWWA (2009), and Sturm et al. (2014).) States have, in increasing numbers, been providing detailed guidance on or even requiring utilities to conduct water audits. For example, the State of Georgia's 2010 Water Stewardship Act requires utilities of a certain size to conduct annual water loss audits and implement a water loss control program (GA DNR 2015). These approaches could be more widely used, Sturm and Thomas (2010) estimated that water losses were 1.6-6.6 times higher than optimum at 17 California utilities and that 40% of the losses could be economically recovered.

Metering can help manage demand by improving overall water use knowledge, as well as help identify water losses and allow for volumetric pricing (discussed in section 2.2.1.4), which is a price signal to customers. In combination with effective pricing, metering may reduce water usage by up to 20 percent (Pacific Institute, 2014). While most customers (especially single-family residential customers) are metered in the U.S., some are not metered, such as those in Sacramento, California and the City of Fresno. In response to California State Assembly Bill 2572, the City of Sacramento has been installing meters on more than 80 percent of its service connections which will allow them to transition from a flat fee structure to volumetric-based pricing (City of Sacramento 2015a, City of Sacramento 2015b). Given the ongoing drought conditions, the City has accelerated its schedule and now plans to complete the project in 2020, 5 years earlier than originally planned. As of January 2015, 53 percent of customers had been metered (Lillis 2015). The project is estimated to cost approximately $445 million ($452 million in 2014$) and plans to accelerate the work may ultimately lead to some cost savings (Sacramento Bee 2014, Lillis 2015). Another example of the benefits of metering is with the City of Fresno. Between 2008 and 2012, in response to California Assembly Bill 514, the City of Fresno installed water meters at all unmetered single-family residences, at a cost of approximately $75 million ($77 million in 2014$) (City of Fresno 2008, Haagenson 2012). In 2014, it was estimated that Fresno's installation of meters had contributed to a 25 percent reduction in water usage (ACWA 2014). Additional benefits are possible with the installation of automated meter reading and advanced meter infrastructure technology further facilitates the collection real-time data that can be used to identify potential problems more quickly or identify opportunities for conservation across all customers.

Another key foundation of tracking water use besides metering is the utility water audit. The water audit is the first step in developing an effective and comprehensive water loss control program (AWWA 2009 and EPA 2010) since it is a systematic accounting of water by the utility. There are three types of water audits, the first is a top-down water audit and can be readily accomplished with existing utility data, and will be discussed in this section, (The other types of water audits use more detailed data, either on leaks or detailed field measurements and are detailed in AWWA 2009.) At a very high level, a water audit determines how much water enters the distribution system, how much consumption is authorized, and how much water is lost. Losses are then categorized as apparent losses (e.g., due to unauthorized use, metering, or administrative errors) or real losses (leakage) (AWWA 2009 and EPA 2010). Findings from each audit can be used to benchmark performance in the intervening period or can be used for comparison against larger datasets. For example, Chastain-Howley et al. (2013) found average real losses was 57.42 gallons per day per connection based on 2011 and 2012 water audits from 32 utilities. The value of the losses are determined using either the retail cost (apparent losses) or the variable production cost to treat and deliver the water (real losses) and may be used for determining the appropriate level of investment into solutions to mitigate losses (AWWA 2009).

Utilities also employ numerous leak detection approaches to identify the source of water losses. Leak detection efforts can be important conservation investments because leaks—particularly in supply lines—are often the primary reason for water loss (Lahlou 2001, GA EPD 2007). Leak detection can involve the active or passive use of sonic equipment and other methods, and may prove most economical and effective if conducted every 1 to 3 years (Lahlou 2001), however each utility should calculate the frequency their leak detection campaigns based on their water losses and the cost of their water. For example, leak detection campaign frequency will vary if the cost of your water is inexpensive or if it is high. Cost-benefit considerations for leak detection activities must also weigh the expense of the various possible responses to any identified problems (e.g., pipe clamps or collars vs. complete pipe replacement, depending on severity) (Lahlou 2001). For example, in 2006, the Kirtland Air Force Base, located in a high altitude desert region of New Mexico, initiated a leak detection and repair program, motivated by the limited and declining water resources at the base. The approach included an active leak detection survey using acoustic listening devices, estimation of the size and volume of leaks, and determination of a priority order for repairs. Survey staff determined that approximately 16 percent of the base's water use could be attributed to water loss through leaks, caused either by misaligned joints or by corroded pipe. The survey cost $75,000 ($82,761 in 2014$) and repairs (made in order of severity of the leaks) took 3 months and cost $514,000 ($567,186 in 2014$). The total savings from eliminating the more than 179 million gallons of lost water were estimated at $330,000 ($364,146 in 2014$) annually (USDOE 2009).

Reducing water pressure or optimizing pressure management in the distribution system may also help to decrease water loss through leaks and slow the deterioration and wear of water system infrastructure and end-use fixtures. Nevertheless, utilities must be mindful of not reducing pressure below local or state standards and regulations, or of compromising water quality or service (EPA 1998). Halifax Regional Water Commission found that trials of fixed outlet pressure control and flow modulated pressure control in a district-metered area reduced real losses by 45 and 53 gallons/connection/day respectively (Fanner et al. 2007a). LeChevallier et al. (2014) cite the benefits of optimizing a utility pressure management program, for example, a utility reduced its background leakage by 83% by reducing the distribution system pressure by 28 psi (or 24%) and another utility with a history of high break frequencies significantly reduced new break frequencies by making a relatively small reduction in pressures.

2.2.1.4 Conservation and Drought Pricing

Demand management has traditionally focused on non-price strategies, such as the voluntary or mandatory conservation and the promotion of water-efficient technologies or fixtures discussed above. While they remain the most commonly used tactics to promote conservation, the results of non-price approaches sometimes do not achieve the desired level of water savings (Olmstead and Stavins 2009). The installation of water-efficient technologies may be accompanied by unintended behavior changes (e.g., longer showers under low-flow showerheads and multiple flushing of low-flow toilets). Mandatory restrictions may have a similar effect, such as watering lawns longer under day-of-the-week or time-of-day restrictions (Olmstead et al. 2007). Even short-term conservation programs have been shown to sustain effects on customer behavior (Hughes and Leurig 2013). The use of pricing signals to achieve conservation may still be somewhat limited. According to AWWA's recent water shortage preparedness survey, only approximately 30 percent of utility respondents relied on drought pricing or increased unit rates as demand management strategies (AWWA 2014).

Conservation pricing, or the use of water rates to manage customer demand and water use efficiency, is a critical tool for drinking water utilities. As noted previously, pricing measures can be cost effective (Olmstead and Stavins 2009), but the ability of a utility to modify pricing or pricing structures can be constrained or facilitated by the utility's institutional structure (Chesnutt et al. 2012), legal requirements, and political and public opinion (Olmstead and Stavins 2009). If drinking water utilities need to adjust their current rate structures or adopt new ones to address drought, they may incur implementation costs, such as establishing billing and customer service systems and handling new data. They also may face resistance to the higher charges from their customers, who may need to pay the same amount or more for lower volumes of water. As noted previously, by facilitating water conservation and helping fund other drought mitigation measures, changes in pricing may help utilities to avoid more significant costs related to supply or treatment in the future and may reduce operation and maintenance costs (Ayala and Satija 2014).

City of Wichita's Economic Modeling to Determine Conservation Priorities

To determine the economic impact of drought management practices, the City of Wichita developed an economic model that accounted for cost savings from delaying the need for a new supply, lost revenue from reduced demand (below current levels), and the cost of implementing conservation measures (City of Wichita 2014). This analysis led to the development of the 2014 Water Conservation Program, which is estimated to cost \$1.2–\$3 million (\$1.22–\$3.05 million in 2014\$) after full implementation (including the cost of the rebates) and would provide savings of 0.39–0.95 MGD or 0.68–1.67 percent reduced water usage. The 2013 rebate program cost the city \$1 million (\$1.02 million in 2014\$) and reduced water usage by 0.44 percent (City of Wichita 2014).

Nationwide, there has been a downward trend in household water demand (Coomes et al. 2010 and Hughes and Leurig 2013). The reasons for this are numerous and include the economic recession, but widespread introduction of more water efficient appliances and implementation of short- or long-term conservation programs by water utilities are two critical drivers of lower demand. Water utilities must adjust their overall financial planning to accommodate these changes. While the challenge of managing revenue variability is not a new one (Eskaf et al. 2014), the more recent, prolonged droughts in the western United States have underscored the need for continued innovation and forward thinking regarding how utilities can balance the need for revenue stability and sufficiency with the need to reduce (in some cases, permanently) customer water use.

Changes in water rates can affect both the volume of water demanded and the revenue of the utility. The price elasticity of demand measures the percentage change in revenue for percentage change in price. Water utilities will need estimates of the price elasticity of demand to determine the impact of rate changes on demand and their revenue. Numerous empirical studies have shown that residential water demand is relatively inelastic (Olmstead et al. 2007; Beecher et al. 1994). In other words, the change in demand is less than proportionate to the change in price. Hughes et al. (2014) finds that the literature suggest that price elasticity for residential water “generally ranged between 0 and -0.75” and that “residential customers, on average, respond to rate increases by lowering their consumption to some degree.” The exact price elasticity of demand for water will depend on a number of factors including geographic location, the type of customer, the timeframe, and water uses (Beecher et al. 1994; Olmstead and Stavins 2009; Hughes et al. 2014). Empirical analyses suggest that the average response to a 10 percent increase in the marginal price of water will reduce demand by approximately 3 to 4 percent in the short run and by nearly 6 percent in the long run in an urban residential setting (Olmstead and Stavins 2009).

Conservation prices must balance competing requirements for affordability, full-cost recovery and the no-profit constraints on many utilities, and sending a price signal that encourages conservation. There are several critical challenges related to conservation pricing. First, utilities determine how to best influence customer demand and usage through price signals, without inflating prices to an extent that would be unacceptable to decision makers, regulators, or customers. If new pricing structures are designed with care, customers may see little or even no impact on their water bills unless they exceed a certain level of consumption. The utility may also see reduced costs in the long term if the cumulative effects of water efficiency and conservation eliminate or delay the need for supply and infrastructure augmentation. Second, utilities must consider their vulnerability to revenue variability due to drought and changes in pricing. In addition to modifying or creating a new rate structure, utilities may consider other revenue stabilization approaches (as practicable and allowable, given any institutional constraints), including maintaining reserves, modifying the length of the financial planning period, and investment in weather derivatives (Eskaf et al. 2014). More details can be found in Hughes et al. (2014) which discusses the broader concept of utility revenue resiliency, including creative new rate models (peak set base, customer select, and water wise dividends) that don’t rely solely on volumetric charges.

Traditionally, the rate development process includes revenue projections under the existing pricing structure; determining future revenue requirements (based on anticipated operations and maintenance costs, capital costs, etc.); determining service rate revenue requirements; and allocating rates across customer classes. More importantly, utilities involved in the rate development process in the past generally did not consider the need for implementation of conservation measures or incentives, or the resulting revenue impacts of these initiatives. Utilities are increasingly aware that revenue neutrality or stability requires that they incorporate the effects of conservation pricing into the rate-making process. Cost/benefit considerations related to conservation pricing must consider the expense of implementing or adjusting revenue forecasting practices, modifications to the utility’s budgeting process, and modifications to the rate structure (as well as subsequent communication and outreach to customers regarding the new pricing approach). The optimal result is water rates that meet the utility’s revenue needs while sending a clear signal to customers on the environmental and social costs of excess usage (Chesnutt et al. 2012).

While there are significant variations in utility rate structures across the country, most consist of base and volumetric charges and take the form of a uniform rate, declining or increasing block rates, or seasonal rates (or a hybrid approach that uses a combination of rate structures). Base charges offer predictability and revenue stability for the utility, but generally, the volumetric charges send a price signal to motivate customers to conserve water (Eskaf et al. 2014). Because the characteristics and revenue needs of drinking water utilities vary greatly, there is no single rate structure that utilities can and have applied to guarantee achievement of conservation goals and revenue sufficiency. Both known conditions (e.g., seasonal variations in usage, historical rates of indoor vs. outdoor water usage) and unknown conditions (e.g., future weather conditions) can affect the relative appropriateness of a rate structure for each utility.

Some utilities have also begun applying specific rates at the customer or customer class level (i.e., water budget-based rates), such as specific rates for irrigation-only customers or single-family residential customers, or rates based on the number of persons in a household or lot size (AWE and California Urban Water Conservation Council 2014, Mayer et al. 2008). For example, the Western Municipal Water District in Southern California adopted a budget-based rate structure that used five customer tiers defined by the relative efficiency or inefficiency of water use. Customers receive individual water budgets, and usage is billed at lower rates as long as customers remain within the bottom two tiers, after which any excess water usage is billed at a higher rate (AWE and California Urban Water Conservation Council 2014). The implementation costs of such a rate structure can vary significantly, depending on the utility's particular circumstances. In some cases, the effort and research leading up to a structural change and the necessity of introducing a new billing system to accommodate such change can result in significant costs. For example, the City of Boulder, CO invested $1 million [$1.1 million in 2014$] in a new billing system during the process of implementing water budget-based rates (Mayer et al. 2008).

Finally, revenue and demand forecasting can help utilities to better prepare for short- or long-term declines in water supply and decreases in demand. Improved forecasts and forecasting or modeling tools can also help utilities to optimize and strategically time capital investments (Roberson et al. 2013). While it remains challenging or even impossible to accurately predict and account for the impact of future variations in weather or climate, measures to reduce the uncertainty of forecasting include collection and evaluation of additional weather data, evaluation of potential changes in demand and service area demographics, and understanding and addressing uncertainty, among others (Roberson et al. 2013). The benefits of improved forecasting approaches are highlighted in the El Dorado Irrigation District (CA) and Denver and Aurora (CO) case studies included in Chapter 3.

Price-based conservation measures can also take the form of drought surcharges and pricing or fines to enforce short-term mandatory conservation measures. Temporary price changes during times of drought or emergency shortage send an even stronger signal to customers on the need to reduce usage, provide any funding needed to purchase water from alternative sources, lessen the effect of any sharp revenue declines, and may help to prepare customers for future increases in standard (non-emergency) water rates, to reflect an ongoing, sustained need for conservation (AWWA 2012b, AWE and California Urban Water Conservation Council 2014). In 2014, for example, the Lower Colorado River Authority (LCRA) established a one-year drought rate for consumers of firm water (water that is reliably available during severe drought), raising the price from $151 to $175 per acre-foot ($471 to $546 per million gallons) starting in 2015 for consumers in Austin and several other cities in Central Texas (Price 2014). Drought pricing models exist; two examples are the Drought Response Model (Chesnutt et al. 2012) and the Sales Forecasting and Rate Model (AWE 2014).

Surcharges can take the form of fixed, volumetric, or percentage-based (i.e., based on the customer's total bill) charges, and may be presented separately from standard rates, along with labeling that identifies the reasons for the surcharge (AWWA 2012b). Surcharges can also be levied across all customer classes, or can be applied based on volumetric use, type of customer, individual water use, or other factors (AWWA 2012b). Surcharges can be relatively simple to implement and administer, unless they are tied to a more complex, stage-based drought management procedure (AWWA 2012b), but their effectiveness may be somewhat limited by how evident the need for such surcharges is, and how well that is communicated to customers (AWE and California Urban Water Conservation Council 2014).

In addition to encouraging conservation through water pricing, utilities may also levy fines for failure to comply with mandated (at the state, regional, local, or utility level) conservation targets related to the amount, timing, and purpose of water use. For example, on May 1, 2014, Santa Cruz Municipal Utility in California declared a 'Stage 3' water shortage emergency due to the ongoing drought and notified its customers that they were subject to mandated monthly water allotments that varied based on the account type (single-family residential, multi-family residential, business/industrial, or agricultural). Excessive water use penalties can be incurred for single-family, multi-family, and large landscape irrigation accounts where a billing unit is charged an additional $25 per cubic foot ($3.34 per gallon) for the first 10 percent over its monthly allotment or $50 per cubic foot ($6.68 per gallon) if it is more than 10 percent over its monthly allotment. In addition, the Santa Cruz Municipal Utility has four levels of penalties for violating outdoor water restrictions. The first offense is met with a written warning; the second offense incurs a fine of $100; the third offense incurs a fine of $250; and the fourth offense incurs a fine of $500 and the installation of a flow restrictor at the customer's expense (City of Santa Cruz 2014). These types of restrictions may be enforced by utility staff, the local police, or city code enforcement officers to promote drought awareness and foster compliance with the water utility's practices (Forstner 2015, Dennis 2013, and City of Southlake 2015). For the Cobb County Water System in Georgia during the 2007–2008 drought, the average hourly salary for personnel enforcing the water restrictions was $15.94 in 2007$ ($18.20 in 2014$); with overtime pay at 1.5 times the normal rate, the water utility paid approximately $24 ($27.40 in 2014$) per hour for overtime pay (Nguyen 2014).

Finally, utilities may also employ mandatory conservation measures on a regular basis. For example, the Las Vegas Valley Water District has year-round conservation measures (including mandatory restrictions) in an attempt to reach a conservation goal of 199 gallons per capita per day by 2035 (Las Vegas Valley Water District 2015a).

2.2.2 Supply Management

2.2.2.1 Short-Term Supply Augmentation

Drought directly affects water supplies and can make it difficult for drinking water utilities to continue to meet customer demand. Utilities may seek to supplement their existing sources in times of drought through any of several short- or long-term options, usually undertaken in combination with demand management strategies. A water utility may regularly purchase water from neighboring utilities to augment its water supply. It may construct or use an existing interconnection between the drinking water utilities; approximately 55 percent of the utility respondents in AWWA's 2014 water shortage survey identified that they established transfers or interconnections with other agencies to augment their supplies and 35 percent noted that they negotiated purchases or options with other agencies (AWWA 2014).

In response to an emergency (e.g., a utility cannot provide water due to loss of supply or adverse water quality) where an interconnection is not in place or not viable, a utility may need to transport water by truck or barge from a neighboring utility. More than 25 percent of the utility respondents in AWWA's water shortage survey indicated that they rely on importing water by truck to augment supplies (AWWA 2014). In 2012, the Plaquemines Parish (Louisiana) water supply was threatened by saltwater intrusion in the Mississippi River due to drought-related issues (see section 2.1.2). The New Orleans Sewage and Water Board agreed to open a 750-foot connector pipeline to Plaquemines in an agreement that will send about 1 million gallons of potable drinking water a day to the parish at a cost of $2.89 ($3.04 in 2014$) per 1,000 gallons, or approximately $29,000 ($30,521 in 2014$) per day (Alexander-Bloch 2012). Although purchasing water can provide immediate relief from the effects of drought, it is only feasible if the water utility has access to other utilities with excess water to sell. In extreme cases, such as when drought conditions prevent a utility from providing water through its distribution system, the utility may decide to provide bottled water to its customers.

Drinking water utilities that operate multiple systems have the option of shifting their water supply from one system to another as needed. For example, the El Dorado Irrigation District (EID) in California operates three water systems, each of which has its own independent supply. When the water level in the river supplying the Outingdale system fell below the supply intake and total coliform counts increased due to low flows, EID trucked in water drawn from its other system's supply at a cost of $0.04 per gallon in 2014$, costing the utility $30,160 total from September 9, 2014 to October 4, 2014 (D. Strahan, pers. comm.).

2.2.2.2 Long-Term Supply Augmentation

Reductions in water supply and rising agricultural water demands during drought (see Chapter 1) limit the ability of drinking water utilities to provide a reliable source of water to their customers. In some cases, drinking water utilities may need to augment or even replace their existing supplies to continue to meet customer demand.

Purchasing water from a neighboring utility, as discussed in the previous section on short-term supply augmentation methods, can also be a long-term approach to mitigate the impacts of drought, but this will require the construction of an interconnection between two drinking water utilities if one does not already exist. Some drinking water utilities have established long-term contracts for purchased water (see the text box on the Lone Chimney and Stillwater, OK utilities). In another example, since 1981, the City of Round Rock in Texas has used an existing interconnection to purchase and pump water from two lakes owned by the Brazos River Authority over a cumulative distance of 37 miles (City of Round Rock 2015a, City of Round Rock 2015b). In 2014, the City purchased 24,854 acre-feet (8,099 million gallons) of water from this interconnection, at a rate of $69.50 per acre-foot ($213 per million gallons) (Pena 2014). In its 2015 fiscal year, the City plans to spend $1.7 million on purchasing water from the Brazos River Authority and $1.8 million to reserve 6.8 billion gallons of water from Lake Travis via another interconnection operated by the LCRA (Pena 2014).

> ***Interconnections between Lone Chimney and Stillwater systems, OK***
>
> Lone Chimney Water Association, a private water utility serving 16,000 customers in three counties in Oklahoma, relies on Lone Chimney Lake for its water supply. Due to drought in 2013, lake levels dropped to their lowest since 1985, when the lake was originally created by damming a creek (Jackson 2013). In response, the Lone Chimney Water Association entered into a 30-year contract with the nearby Stillwater utility to purchase at least 2 million gallons per month, at a cost of $85,000 ($87,644 in 2014$) annually. Lone Chimney Water Association also paid for the construction of a $3.35 million ($3.45 million in 2014$) interconnection between the two utilities (Dennis 2013), using a Drinking Water State Revolving Fund loan.

The City of West Goshen in California serves 400 residents, and in 2014 was considered by the state of California to have acute drinking water shortages due to drought (Martineau 2014).

With $3 million ($3.05 million in 2014$) in federal funding, the City was able to make improvements to reduce water loss and was also able to construct an interconnection between the West Goshen water utility and the California Water Service Company in Visalia. The interconnection project was credited with resolving the utility's drought-related problems (Martineau 2014). Appalachian State University and the Town of Boone in North Carolina have also built an interconnection between their two water systems that can be used during times of drought and other emergencies (Appalachian State University News 2010, Town of Boone 2015, Appalachian State University 2015). The two systems serve approximately 16,000 and 14,000 residents, respectively, and they shared the $310,393 cost ($342,511 in 2014$) of the interconnection (Appalachian State University News 2010). Finally, in October 2014, the City of San Antonio approved a $3.4 billion ($3.5 billion in 2014$) project to provide groundwater from Burleson County, more than 140 miles away. The controversial project will provide an estimated 16 billion gallons of water to the City per year (Satija 2014b).

Where interconnection is not feasible or cost effective, utilities have accessed new or alternative ground or surface water supplies. In Texas, the LCRA supplemented its water supply with five new wells for $15 million ($15.2 million in 2014$) and is constructing a new reservoir for $250 million ($254 million in 2014$) that will potentially add as much as 29 billion gallons of water to the Authority's annual supply (LCRA 2014, KVUE staff 2014). Due to a decline in existing reservoir and groundwater supplies, the Catalina Island Company in California is planning to construct a $2 million ($2.03 million in 2014$) well that will access water supplies in a deeper aquifer (Sahagun 2014). The City of San Angelo in Texas has funded a $120 million project to construct new wells (along with associated treatment, pumping, and piping) to draw water from the Hickory Aquifer (City of San Angelo 2015).

Financial or geographical constraints may, however, prevent utilities from seeking new water sources, in which case utilities may need to improve existing or develop new infrastructure to draw on existing water supplies more effectively. For example, when water levels in Lone Chimney Lake in Oklahoma dropped below the level of a drinking water intake, the Lone Chimney Water Association installed a submersible pump that could rise and fall with the water level at a cost of $119,000 ($122,702 in 2014$) (Dennis 2013). If modifications cannot be made to an existing intake, a new intake may be necessary, as is the case for the Southern Nevada Water Authority (SNWA). The SNWA is constructing a new intake because unprecedented drought conditions have lowered water levels in Lake Mead to a critical level that could render one of the Authority's two existing intakes inoperable. The $817 million ($830 million in 2014$) intake will be able to draw water from Lake Mead even when lake levels are low (Cooper 2014, SNWA 2015).

Drinking water utilities can also enhance existing reservoirs to bolster water supply, as has been done by San Diego County Water Authority (SDCWA) in Southern California. SDCWA has raised its San Vicente Dam by 117 feet at a cost of $838 million in 2014$. This project has more than doubled the storage capacity of the San Vicente reservoir, which will now be able to supply water if imported supplies are reduced due to a severe drought, earthquake, or other emergency (SDCWA 2015a).

Utilities have also sought regional, cooperative solutions to ongoing or anticipated water supply concerns. Regionalization can mean many things, but in broad terms, involves "integration or cooperation on a regional basis" (Grigg 1989). This integration or cooperation can involve a formal integration of one or more aspects of utility operation or management, including use of water supplies, or voluntary efforts to address water supply or other issues on a regional basis (Grigg 1989). Depending on the form it takes, regionalization can face significant political, institutional, financial, and technical hurdles (Triangle J Council of Governments 2014, Grigg 1989), and a real or perceived loss of control over water supplies can be difficult for utilities. At the same time, regionalization approaches may allow utilities to realize economies of scale, and therefore capital and operational savings (Grigg 1989), though Zeff et al. note that water transfers between utilities are limited by available supply and infrastructure and may create interdependencies between utilities that lead to unintended consequences (and financial instabilities) (Zeff et al. 2014).

In 2009 in North Carolina, the Jordan Lake Regional Water Supply Partnership was formed by 13 local governments and utilities in response to drought and water shortages coupled with significant population growth. (Jordan Lake is managed jointly by the State of North Carolina and the U.S. Army Corps of Engineers [Triangle J Council of Governments 2014]). The Partnership seeks to ensure the sustainability of the region's water supplies, in part through conservation and efficiency, interconnection, and other efforts related to the Jordan Lake supply (Jordan Lake Partnership 2015). Specifically, the Partnership is seeking to improve water use efficiency (through ongoing conservation efforts, tiered rate structures, and other initiatives), make use of stone quarries for storage, expand existing reservoirs and run-of-river withdrawals, develop new or expand existing water sources, and allocate the remaining water supply in Jordan Lake (Triangle J Council of Governments 2014, Davis 2010). At the time the Partnership was formed, nine of the partners held Jordan Lake allocations (six of whom were using or had used water from the supply) totaling 63 MGD, and an additional 33 MGD had yet to be allocated by the state (Davis 2010). The Partnership is committed to serving as a model for regional cooperation and local leadership (Davis 2010). The Partnership also developed a regional water supply plan for meeting demand through 2060.

In 2009, during one of the area's most severe droughts of the past century, the Metropolitan Washington Council of Governments (MWCOG) in the Washington, DC region developed a Water Supply and Drought Awareness Plan. In addition to year-round promotion of efficient water use and conservation, the Plan also called for a coordinated, regional-level awareness of and responsiveness to drought. Nearly three-quarters of the area's water supply comes from the Potomac River but, in times of drought, the Potomac may not be able to meet water demand. In these cases, the Section for Cooperative Water Supply Operations on the Potomac, or CO-OP, coordinates management across the entire water supply system, guiding decisions on allocations of water from existing reservoirs to increase flow in the Potomac (MWCOG 2014).

In response to the severity of the water supply problem in certain regions of the country, some utilities have significantly expanded their water supply portfolios by using a combination of the approaches described above. For example, in response to recent droughts and the dwindling water supply in the Edwards Aquifer, the San Antonio Water System is implementing multiple supply augmentation approaches, including desalination, aquifer storage and recovery, purchasing treated water from another supplier, and using recycled water for certain non-residential customer uses (SAWS 2015a). In addition, San Antonio is a member of the Canyon Regional Water Authority (CRWA), a water supply partnership created by the State of Texas in 1989. The partnership is made up of cities, districts, and water supply corporations, which purchases untreated surface water from the Guadalupe-Blanco River Authority, then treats and distributes it to its members, including up to 4,000 acre-feet (approximately 1,300 million gallons) per year to San Antonio (which in turn leases 500 acre-feet [163 million gallons] per year to another community) (CRWA 2015 and SAWS 2015b). San Antonio has additional purchase agreements with the Canyon Regional Water Authority to obtain water from other sources (SAWS 2015b).

Water supplies can also be reallocated among customer types or classes, where such reallocations are permitted, usually between agricultural sellers and urban buyers. These transfers can be facilitated by an agency or entity referred to as a water bank. Although both the buyer and the seller gain from the transfer (i.e., the seller is paid for the water sold and the buyer increases its water supply), other parties that use the water may be affected either positively or negatively by the transfer (e.g., through better or worse water quality or quantity). Water transfers can have adverse effects on the rural agricultural sector by causing losses of income and employment due to reduced agricultural production. However, such effects are not a given; Howe et al. (1990) found that when considered at the state level, water transfers in the Arkansas Valley in southeastern Colorado did not result in significant losses to the state's agriculture or general economy (Howe et al. 1990). They reported that the loss of state net income of $53 per acre-foot in 1982$ ($399 per million gallons in 2014$) due to water transfers was offset by the cost savings realized for the cities buying the water, because it was no longer necessary to develop new sources, which cost $2,000 per acre-foot in 1982$ ($15,057 per million gallons in 2014$). Overall, it is likely that a large proportion of the loss of revenue or productivity affecting the agricultural sector can be offset by the benefits accrued in urban areas. Water transfers, which occur in many of the western states, vary in price depending on location and the amount of water available. For example, in parts of Idaho, water was sold at $3.00 per acre-foot ($11.85 per million gallons in 2014$), while in Colorado, water transfers resulted in costs up to $1,000 per acre-foot ($3,948 per million gallons in 2014$) (Clifford et al. 2004).

Some utilities are also taking proactive approaches to mitigate indirect impacts of drought, such as wildfires caused by dry conditions. For example, recently (2010–2015), Denver Water spent $16.5 million ($16.8 million in 2014$), and a matching amount was contributed by the U.S. Forest Service, for forest and watershed protection upstream of Denver's reservoirs and water delivery infrastructure to avoid water quality problems (Denver Water 2015a).

2.2.2.3 Other Supply Augmentation Strategies

A variety of approaches may be used to supplement or augment water supplies, including reuse, desalination, and aquifer storage and recovery (or the more broad term, managed underground storage). Although these approaches may be highly resource intensive and their feasibility may depend heavily on the utility's location, some utilities have chosen to invest in these technologies in the face of long-term threats to their water supplies due to drought and other factors. Utilities may also choose to pursue some form of regionalization, instead of or in addition to investing in supply augmentation technologies and infrastructure (and some approaches to regionalization may involve infrastructure investments).

Close to 15 percent of the respondents in AWWA's 2014 survey of water utilities identified increased use of recycled water as a strategy for supply augmentation (AWWA 2014). In 2013, the Colorado River Municipal Water District in Texas constructed a reclamation facility for $14 million ($14.4 million in 2014$) that recycles treated effluent from the City of Big Spring Wastewater Treatment Plant for direct potable reuse. This facility can produce 2 MGD of additional supply at a cost of approximately $3.48 ($3.59 in 2014$) per 1,000 gallons (Bufe 2013). In July 2014, the City of Wichita Falls' (Texas) Direct Potable Reuse Project went online. The project, which cost the City $13 million in 2014$, provides 5 million gallons of water per day, accounting for one third of the City's daily demand (City of Wichita Falls 2015). Aurora Water in Colorado spent $650 million ($661 million in 2014$) to implement the Prairie Waters Project, which provides 50 million gallons of potable water per day to the City of Aurora (Whitney 2014).

Recycled or reclaimed water can also be used for purposes that do not require higher quality, potable water, thus decreasing the burden on drinking water supplies. In addition, Aurora Water spent approximately $11 million ($11.2 million in 2014$) to upgrade the existing Sand Creek Water Reclamation Facility, which provides water for irrigation and, thus, reduces demand on Aurora's drinking water supply (WERF 2015). Denver Water invested $81.5 million ($84 million in 2014$) in a recycling plant that can provide billions of gallons of water per year for industrial and irrigation uses (Denver Water 2013). This will reduce the demand on Denver Water's potable water supply, which currently serves 43,000 households (Denver Water 2015b).

Desalination plants remove salt and other minerals from highly saline sources (e.g., seawater or brackish water) to achieve drinking water standards, generally using either distillation or membrane technologies (i.e., reverse osmosis) (NRDC 2014). Due to high capital and operational costs (e.g., energy use), desalination is often more expensive than other supply augmentation practices. Less than 5 percent of utility respondents in AWWA's 2014 water shortage preparedness survey indicated that they were using desalination to increase supplies (AWWA 2014). Six such plants were constructed in Australia, and four are now largely unused, though customers continue to shoulder some of the financial burden of construction (Gillis 2015). The City of Santa Barbara, in California also constructed a reverse osmosis desalination plant in response to severe drought conditions in the late 1980s, at a cost of $35 million in 1990$ ($63 million in 2014$) (Covarrubias 2015). However, the plant was never fully operational; when freshwater supplies were replenished during the plant's trial phase, the plant was placed in "long-term standby mode" (City of Santa Barbara 2015). Reactivation of the plant may take up to 2 years, but the City is now in the process of reactivating the facility at a potential cost of $40 million (City of Santa Barbara 2015; Gillis 2015). The plant could meet up to 30 percent of the City's demand (Covarrubias 2015).

Rogers (2014b) states that the typical cost of desalinated water is $2,000 per acre-foot ($6,138 per million gallons), and that it is nearly double the cost of obtaining water from recycling wastewater or constructing a new reservoir, and nearly quadruple the cost of the water obtained (or saved) from conservation initiatives such as drip irrigation or landscaping or other rebates. However, there is no standard definition of what costs should be included in desalination plant cost estimates. For example, should treatment costs, pumping costs, and energy for treatment costs be included? Desalination plant treatment costs should detail the types of costs that have been included. A 50-MGD desalination plant that will treat seawater is currently under construction in Carlsbad, California. It will be the largest such plant in the Western Hemisphere, costing nearly $1 billion ($1.02 billion in 2014$) to build (Rizzetta 2013). It is estimated that once the plant is operational, customer water bills in San Diego County will increase by $5.04 per month and that the plant will provide treated water equal in volume to approximately 7 to 8 percent of the County's water consumption (Gillis 2015). Examples of other desalination plants that are being planned or have been built include the following, plus Tampa Bay, FL and El Paso, TX:

- The Bay Area Regional Desalination Plant, Contra Costa County, CA – capital cost $200 million in 2014$ for a 20-MGD plant to treat brackish water, completion date still to be determined (Bay Area Regional Desalination Project 2015).
- City of Beckville Desalination Plant, Beckville, TX – capital cost $400,000 ($501,294 in 2014$) for a 0.216-MGD plant to treat brackish water, completed in 2004 (Shirazi and Arroyo 2010, Nicot et al. 2005).

- City of Brady Desalination Plant, Brady, TX – capital cost $9 million ($11 million in 2014$) for a 3-MGD plant to treat brackish water, completed in 2005 (Shirazi and Arroyo 2010, Nicot et al. 2005).

Aquifer storage and recovery (ASR) provides a reserve water supply that can be used during an emergency or extended drought. ASR involves drawing water, usually from a surface water source such as a lake or river, and pumping it into an aquifer from which it can be retrieved at a later time. ASR can also help protect against subsidence due to overdraft and pump damage associated with water table decline. The Las Vegas Valley Water District in Nevada began its groundwater recharge project in 1987 and has since stored roughly 104 billion gallons of water, which can be re-tapped by the 70 recovery wells in place (Las Vegas Valley Water District 2015b). This project costs approximately $218 per acre-foot ($987 per million gallons in 2014$) of water stored through artificial recharge (Katzer et al. 1998). While ASR wells have been successfully recovering water when needed, disadvantages can include potentially low recharge and recovery rates, water quality issues associated with mixing surface water and groundwater, clogging with fine particulates or microbial activity, and high energy costs due to pumping (National Research Council 2002).

Utilities have also turned to cloud seeding to help recharge reservoirs during periods of inadequate rainfall by increasing the amount of precipitation through the dispersal of chemicals (e.g., silver iodide, potassium iodide, or dry ice particles) into the clouds. Regional cloud seeding initiatives in the Colorado River Basin have been underway since the early 2000s. Water utilities in this region may apply for cloud seeding grants, which are jointly funded by the Colorado Water Conservation Board, the Southern Nevada Water Authority, the Central Arizona Water Conservation District, and the California Six Agency Committee (Colorado Water Conservation Board undated). The City of Wichita Falls in Texas spent $300,000 in the spring of 2014 on a cloud seeding project to bolster its water supply. State seeding experts indicated that the project may increase potential rainfall production from a thunderstorm by 10–15 percent (City of Wichita Falls 2014). The main drawback to cloud seeding, however, is that it is difficult to predict or quantify the amount of water generated in a cloud seeding event. It is, therefore, difficult to determine if the process is cost effective (Sommer 2015).

2.3 BENEFITS OF DROUGHT MANAGEMENT PRACTICES

Drinking water utilities often assess the costs of planning, conducting, enforcing, and monitoring drought practices as a part of their budgeting and expenditure tracking efforts, but the benefits of these practices are not often quantified in monetary terms (AMEC 2010). It is, however, possible for utilities to measure or estimate the amount of water saved through monitoring efforts. In most cases, the value of these benefits is the avoided costs of inaction. In addition, drought management practices can lead to less tangible benefits such as new ways of thinking (e.g., greater acceptance of conservation programs), behavior change, new projects, and new collaborations.

Avoided costs in water management are the savings associated with not having to produce an additional unit of water to meet demand (Beecher 1996). The cost of producing another unit of water is known as the "marginal" cost of water (A & N Technical Services and Gary Fiske and Associates 2006). In the short term, marginal costs typically consist of variable operating costs within the existing capacity of the water utility, such as the costs of labor, power and chemicals. In the long term, marginal costs include changes in the capacity of the utility, such as acquiring new water sources or expanding storage capacity (A & N Technical Services and Gary Fiske and Associates 2006). These avoided costs can be used as a proxy for benefits in a cost-benefit analysis.

In an avoided cost analysis approach, drinking water utilities planning for drought would compare the savings they can achieve by not producing an additional unit of water or water service during drought with the incremental cost of the drought management practice (Beecher 1996). For example, when the unit cost of public outreach to conserve water is lower than the cost of producing an actual unit of water (i.e., the avoided cost), then public outreach is considered beneficial. An avoided cost analysis may also help utilities assess which drought management options (i.e., demand management vs. augmentation) may be most appropriate for their utility to pursue (see Chapter 4).

Avoided costs can be used to measure the benefit of drought management strategies for the triple bottom line, discussed in Chapter 4. Avoided costs are of three types (Beecher 1996):

- Direct Costs: Capital, operations, and maintenance costs avoided by not having to build new resource alternatives. Direct costs are borne by the utility and include capital investments, energy costs, and labor costs.
- Indirect Costs: Avoided costs of externalities and corollary functions associated with water. These costs accrue to the utility customers, related industries, the environment, and society. They include the costs of wastewater treatment, impacts on power generation and energy savings for customers. (For example, water-saving appliances may reduce the cost to the customer of heating water.)
- Opportunity Costs: Avoided costs are savings achieved. By not investing in resources to produce and deliver additional water, drought management strategies may free up funds that could be used elsewhere by the utility, its customers, and society as a whole.

2.3.1 Implementing Avoided Cost Assessments

The first step in conducting an avoided cost assessment is to develop baseline assumptions about future water supply and infrastructure investments that would occur absent any drought management (A&N Technical Services and Gary Fiske and Associates 2006). Some key issues that can significantly shape the results of the analysis include: the time horizon over which costs and benefits are evaluated, the geographic area in which options are possible, the range of tools and technologies available to the water utility, and the priorities of the customer base that may determine which cost avoidance options are possible (Beecher 1996).

Examples of avoided cost analyses for water management exist, but they are limited. Some utilities have successfully used avoided cost analyses to estimate the benefits of conservation programs to manage drought as compared to the cost of meeting demand during a drought without those measures:

- The San Antonio Water System (SAWS) examined long-range capital costs for new water supplies as well as the operational and maintenance costs of water delivery and wastewater treatment over a 50-year period (BBC Research and Consulting 2003). These were compared to conservation efforts over the 50-year period, which were estimated to cost a present value of $210 million in 2003$ ($270 million in 2014$). The avoided costs were $870 million to 1.46 billion in 2003$ ($1.12 billion to $1.88 billion in 2014$) for new water supplies, new water treatment plant expenses, and operating and capital costs at SAWS's water and wastewater facilities that would otherwise be needed over the 50-year period.

- The Pagosa Area Water and Sanitation District (PAWSD) in Colorado estimated that, without conservation activities, it would need to spend up to $150 million in 2006$ ($176 million in 2014$) over 20 to 30 years to upgrade existing treatment facilities and construct new facilities to divert, store, and treat water (PAWSD 2008). The cost of these investments was $20,000 per acre-foot in 2008$ ($67,488 in 2014$ per million gallons) of raw and treated water. Through conservation, PAWSD would be able to save an estimated 130 to 163 million gallons of water per year and reduce its water loss from 20 to 12 percent by 2018, resulting in an avoided cost of $8 to $10 million in 2008$ ($9.68 to $11 million in 2014$).
- Over a 30-year period (1984–2004), the City of Austin conducted several water efficiency and conservation programs that resulted in a cumulative water savings of approximately 5.8 million gallons per day.[11] The City estimated the avoided cost of infrastructure to be $3.97 ($4.66 in 2014$) per gallon per day, which equates to a total avoided cost of just over $22.8 million ($26.8 million in 2014$) (Gregg et al. 2007).
- The City of Albuquerque, NM avoided a cost of more than $1 billion ($1.09 billion in 2014$) to expand its wastewater treatment plant by reducing per capita demand for water by 20 percent since the mid-1990s (4CORE 2011).
- The Massachusetts Water Resources Authority cancelled its plan to construct a dam on the Connecticut River as a result of a 25 percent reduction in water deliveries, amounting to an estimated savings of $500 million ($543 million in 2014$) in capital expenditure (4CORE 2011).

2.3.2 Assessing the Triple Bottom Line

Consistent with the triple bottom line approach, drought management practices provide benefits not only to drinking water utilities, but also to their customers, the environment, the economy, and to society as a whole. Customers value water for consumption, basic health and sanitation, and the reliability of the service. The value customers place on water can be measured by their willingness to pay for the water, as reflected in water rates (Rosen and Gayer 2008). Because the rate customers pay for the marginal unit of water may not equal its marginal cost (as would be the case in a private, competitive market), the marginal benefit to customers of drought management may be different from the marginal benefit to utilities. Customers may also benefit in other ways from drought management practices through reduced energy use and other corollary impacts, as discussed above.

The environmental benefits of drought management practices can be assessed through a variety of metrics such as reduced withdrawals of surface water or groundwater, or avoiding developing new supplies. Because a significant amount of energy is consumed in treating and distributing water, particularly in arid regions like the southwestern United States, reducing water usage and the associated energy consumption will also reduce greenhouse gas emissions (NRDC 2009). The value of these benefits may be difficult to quantify, however. In some cases, the costs

[11] This value was calculated by summing the water savings, listed in Table 1 of Gregg et al. (2007), through 2005.

of avoided remediation can be used to estimate benefits. In another approach, contingent valuation studies attempt to measure directly customers' willingness to pay for environmental protection. Furthermore, as markets for carbon develop, the price of carbon can be used to measure the benefit of greenhouse gas reductions. Qualitative measures may also be needed to evaluate the benefits of environmental protection (i.e., whether the drought management program has a small or large impact on the environment).

The total societal gains from effective drought management will integrate all the benefits conferred upon utilities and their customers, the environmental impacts, and the effects on individuals and businesses. One method for deriving the total benefit to society is to add all of the avoided costs: capital investments, operations and maintenance costs, costs to customers, and environmental costs.

2.4 SUMMARY AND CONCLUSIONS

The costs of drought management practices vary widely across drinking water utilities, depending on utility size or population served, geography, complexity of the drought mitigation practice, and presence or absence of regional collaborations. Thus, cost comparison among utilities is problematic. Furthermore, there are many challenges associated with documenting costs at a sufficient level of detail for a cost-benefit analysis. The diversity of drought management practices and their costs is documented in the list presented in Appendix A, which was compiled primarily from online sources. This list provides a compilation of examples of utility-level drought management efforts that are already underway and may serve as a useful resource for utilities that are just beginning the drought planning process or are looking to add additional drought management approaches to their existing portfolio of activities.

Available cost data can help a given utility assess drought management options, but there are several confounding factors. Drinking water utilities may conduct drought management practices as part of longer-term water resource management plans and, therefore, find it challenging to separate the costs for drought programs from other costs. Furthermore, drinking water utilities that are working collaboratively with other utilities or regional water management boards may find it difficult to apportion the total cost of a regional drought management initiative to their utility, making a cost-benefit analysis at the local scale challenging. Associating a dollar value with the benefits of drought mitigation practices is often difficult because many benefits are qualitative. In the face of these challenges, one promising approach is to use avoided costs as a proxy for estimating benefits.

CHAPTER 3
CASE STUDIES ON WATER UTILITY EXPERIENCES WITH DROUGHT

The impacts and costs of drought vary widely among drinking water utilities depending on several factors, including their geographic location, types of customers (e.g., residential, commercial), and their water sources, as noted previously in this report. The following four case studies provide examples of drought impacts experienced, measures each utility took in response to those impacts, and costs associated with those measures but are not examples of cost-benefit analyses. These case studies were developed using information and financial data presented by the utilities at a workshop conducted in Denver, Colorado in December 2014, as well as information gathered through communications with utility staff and through literature reviews. Financial data are listed in this chapter as reported by the utilities (i.e., they are not consistently reported in 2014$). A complete listing of costs provided by these utilities is presented in Appendix D of this report.

Drawing from experiences in Colorado, California, and Georgia, these case studies illustrate that, regardless of location or size, drinking water utilities may experience many of the same impacts. The costs associated with these impacts can differ depending on the specific circumstances and responses taken by each water utility. Although the drinking water utilities employed many of the same measures, their overall strategies differed to accommodate their specific circumstances (e.g., focusing on community outreach in one case and water use restrictions in another case). These case studies highlight the need for a utility-specific cost-benefit analysis to evaluate and select appropriate drought management practices.

3.1 CASE STUDY 1: A MULTI-PRONGED APPROACH TO DROUGHT MANAGEMENT IN EL DORADO, CA

3.1.1 Background

El Dorado Irrigation District (EID),[12] a large water system located in El Dorado County in northern California, was established in 1925. EID serves about 118,500 customers through nearly 40,000 service connections. The average daily demand served by the utility in 2014 was 26.6 MGD[13]. EID provides a range of services to its customers including drinking water through three public water systems; wastewater management; recycled water

El Dorado Irrigation District's Drought Management Snapshot

- EID developed a formal Drought Preparedness Plan (2008) based on estimated impacts of future climate scenarios.
- EID developed an internal Drought Action Plan outlining specific response actions.
- Due to comprehensive planning and ongoing forecasting efforts, EID can anticipate and adjust to the financial variability caused by the costs of response and decreased revenue during drought.

[12] Information in this case study was obtained through personal communication with EID staff unless otherwise indicated.
[13] The average daily demand in 2014 was a 24% reduction from that in 2013 (i.e., 35.5 MGD), largely due to EID's conservation efforts.

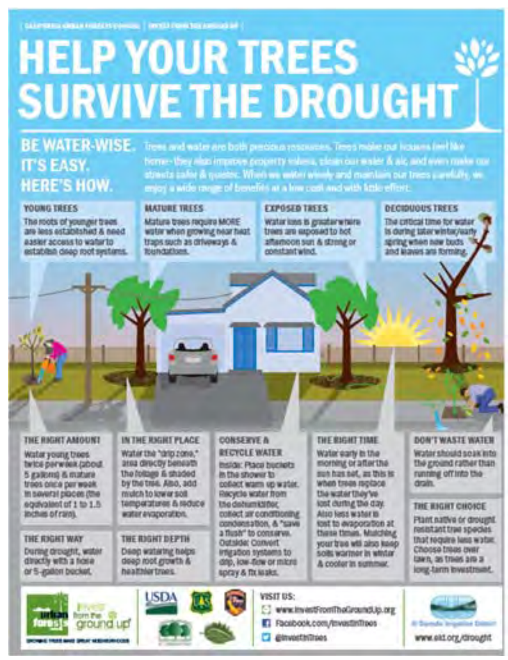
for irrigating private and public landscapes; recreation; and operation of a hydropower system (EID 2015a).

EID's three public water systems draw from numerous sources in the foothills of the Sierra Nevada Mountains. EID holds water rights to approximately 75,000 acre-feet of water per year, or about 24,439 million gallons, across these sources and manages water distribution to each of the three drinking water systems through an integrated, intra-basin system (EID 2013). Due to the size of its service area (over 225 square miles) and variations in elevation (ranging from 500 to 4,000 feet above sea level), EID's distribution system relies on a complex matrix of 181 pressure-regulating zones; multiple treatment plants, storage reservoirs, and pumping stations; and over 1,200 miles of pipe and 27 miles of ditches (EID 2015b).

3.1.2 Impact of Drought

EID instituted drought planning and mitigation efforts in advance of the 2014 drought in California, in large part due to their experience over the previous decades with severe drought and its impact on drinking water supplies. California's driest calendar year ever recorded was 1977 (California Department of Water Resources 2015, State of California Natural Resources Agency, and California Department of Water Resources 2014). This severe drought reduced Jenkinson Lake, one of the primary water sources for EID's largest water system, to, in the words of Dana Strahan, Drinking Water Operations Manager at EID, "little more than a puddle." In response, EID implemented extreme conservation measures that required more than a 50 percent reduction in water use. The region saw significant agricultural losses because of the 1977 drought (Strahan 2014).

More recently, California experienced water year 2014 (October 1, 2013 to September 30, 2014), which, in addition to being one of the driest on record, was also one of the warmest. By mid-summer 2014, more than half of the state was classified as being in "exceptional" drought, the most extreme of the drought categories used by the U.S. Drought Monitor (California Department of Water Resources 2015).



Source: Courtesy of EID.

Figure 3-1. An example of public outreach and education material

3.1.3 Response to Drought

In 2007, EID obtained funding from the U.S. Environmental Protection Agency (EPA) and the National Oceanic and Atmospheric Administration (NOAA) to develop a formal Drought Preparedness Plan. The Plan is based on estimates of the impact of climate change-induced droughts on water resources in El Dorado County, as estimated by the Water Evaluation and Planning System (WEAP) model.[14]

[14] Developed by the Stockholm Environment Institute, the WEAP model is a comparative analysis water resource simulation tool that calculates water demand, supply, and other variables (e.g., runoff, infiltration, flows, storage)

EID's Board of Directors retained a consultant to help develop the Drought Preparedness Plan and formally adopted the plan in January 2008. Subsequently, District staff developed a detailed Drought Action Plan outlining the specific steps to be taken in preparation for and during drought conditions. The original Drought Action Plan was finalized in March 2009 and has been updated several times since then, most recently in the spring of 2015.

The Drought Action Plan outlines four stages of drought and response measures associated with each stage. Response actions include conservation measures and associated demand reduction targets, customer outreach/awareness, and enforcement, among others. Figure 3-1 and Figure 3-2 exemplify some of the information and messages promoted through EID's outreach program. In addition to detailing the activities to be conducted under each of the drought stages, the Action Plan also identifies ongoing drought management practices by staff function (e.g., legal, public outreach, engineering and operations, etc.). The ongoing activities occur even under non-drought conditions, ensuring that EID is prepared for and can, to the extent possible, effectively mitigate the impacts of possible drought.

3.1.4 The Costs of Drought Mitigation and Response

In addition to the costs of these drought-related activities, Table 3-1 provides costs of the EID's water management practices. Note that although the programs listed in Table 3-1 may improve the utility's ability to mitigate or respond to drought impacts, many of these programs would be in place as part of the EID's overall resource management strategy to address issues unrelated to drought, such as conservation and repair and replacement of water mains. The discussion below focuses only on the costs of those activities that have a major impact on the utility's resilience to drought.

EID's extensive planning efforts and its adoption of a comprehensive framework for drought management mitigated the need for many expensive emergency response activities. Nevertheless, costs of responding to extreme drought conditions can still be considerable. For EID, the ongoing 2014 drought has resulted in additional costs incurred related to:

- Customer outreach, including media coverage, flyers, and updates to EID's website.
- Tracking, reporting, and enforcement to ensure that customers meet mandatory water use restrictions. This information is also used to vary water use schedules based on the community's ability to meet overall water use reduction requirements.

Source: Courtesy of EID

Figure 3-2. An EID poster developed to encourage conservation

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under a variety of future climate scenarios and hydrological regimes (Stockholm Environment Institute 2015). It is designed to allow users to project fluctuations in supply, demand, and other parameters, so they can develop management strategies accordingly.

- Emergency response and projects, including trucking in water when a water source runs dry. Decreased water demand on certain days (due to water use restrictions) increased pressure in the water transmission and distribution systems, which caused infrastructure damage, necessitating emergency repairs.
- Forecasting and monitoring, done on an ongoing basis even under non-drought conditions. During drought, EID more closely monitors water use across all sources.
- Operations, with a focus on maximizing direct diversions to critical water sources. EID set a target of storing 25,000 acre-feet of water, or approximately 8,146 million gallons, in the Jenkinson Lake reservoir, which it achieved by optimizing water right diversions for each of its water systems based on real-time monitoring data. Additional staff resources were also needed to adjust pressure throughout the system to avoid continued stress on the water mains.
- Water quality and water age management, in particular. Reduction in water use led to increased water age and more time in the distribution system for the formation of disinfection byproducts. As a result, EID was forced to flush a higher volume of water, even during drought conditions, to manage water age and remain compliant with state and federal drinking water quality standards.

To improve understanding of the costs associated with drought management and response, EID established a drought tracking number with its finance department, to which all relevant operating and capital costs are now tied.

As of December 2014, EID estimated that drought response and mitigation activities (outside of normal operating practices) involved 3,417 personnel hours for a total cost of $153,880 (2014$). The costs of materials and supplies, including costs to truck water to residents when needed, totaled slightly under $195,000 (2014$) for a combined total of close to $350,000 (2014$).

At the same time, conservation measures led to an anticipated but significant $2.3 million reduction in water sales, a $250,000 reduction in recycled water sales, and $2 to $3 million (2014$) in lost revenue from unrealized power sales. In total, EID estimated that required conservation would lead to a 14 percent decline in overall revenue. However, because of the comprehensive planning measures, the long-term supply, demand, revenue forecasting, and the resulting ability to anticipate and react to worsening drought conditions, EID has been able to manage the financial variability associated with periods of drought.

> In July 2014, water levels in the Middle Fork of the Cosumnes River, the source for one of EID's water systems, were so low that pumping and treating the water was impossible. For one month, EID trucked water from another of its sources to nearly 500 people at a trucking cost of 4 cents per gallon (2014$). The water was pumped, and stored on site. EID also spent $10,000 (2014$) to install a transfer pump.

Table 3-1 (below) provides examples of costs EID has incurred for key water resource management and drought mitigation and response activities. Although this is not an exhaustive list of drought-related activities, it represents some of the district's more significant efforts.

Table 3-1
Costs of water resource and drought management practices for El Dorado Irrigation District (in 2014$)

Activity	Cost
Trucking-in water	$0.04/gallon; $30,160 total from September 9, 2014 to October 4, 2014
Long-term ongoing outreach	$50,000
Rebates and other incentives for conservation	$25,000 budgeted for 2015
Outreach and enforcement for temporary conservation measures	$295,000
Repair of water mains	$873,290 annually ($1,537/event, average 568 events/year)
Replacement of water mains	$250,000 for 2014 (1,200 feet replaced)
Improvements in interconnection infrastructure	$10,000
Recycled water (storage, distribution, and operations and maintenance)	$23,000,000 (including current book value and budgeted amount for 2015)

Source: D. Strahan (El Dorado Irrigation District), pers. comm.

Costs shown above reflect costs of water resource management practices, which include costs of programs designed to mitigate or respond to drought. The precise amounts dedicated to drought mitigation and response are not always discernable from costs associated with other water resource management activities.

3.1.5 Looking Forward

Recognizing that extreme weather conditions may increase in frequency and intensity, EID has integrated drought planning and mitigation activities and related costs into normal operations. These activities are formalized in EID's Drought Preparedness Plan and related Action Plan. EID is currently considering development of a revised integrated financial plan and moving beyond the use of rate surcharges tied to each of the four established stages of drought. One key issue currently under discussion is how to measure or determine the base year of water usage.

EID continues to monitor precipitation patterns, reservoir levels, and customer usage carefully. Through these efforts and the transfer of water across its integrated intra-basin system, EID has been able to maintain significantly higher levels of stored water in the most recent drought period than in 1977, when there were no drought planning measures in place. EID has cited the integration of its three water systems (such as trucking water from one system to another) as being one of the most critical factors for maximizing reliability of supply.

3.2 CASE STUDY 2: REVENUE DILEMMA IN MANAGING DROUGHT IN COBB COUNTY, GA

3.2.1 Background

The Cobb County Water System (CCWS),[15] a large public water system, serves 650,000 customers (92 percent of whom are residential) through 173,000 connections including the cities of Acworth and Kennesaw, Georgia. The average daily demand for CCWS in 2014 was 48 MGD. The system purchases all of its water from the Cobb County-Marietta Water Authority (CCMWA), accounting for close to 70 percent of the Authority's total sales. The CCMWA draws water from two surface water sources, the Chattahoochee River (in the Chattahoochee Basin) and Allatoona Lake (in the Coosa Basin) and operates two water treatment plants. The Authority's distribution system is designed so that all customers can be served by only one source if needed.

3.2.2 Impact of Drought

In 2005, precipitation levels in North Georgia began to decline, and by spring 2006, the area was experiencing drought. At that time, the state declared a Level 1 drought, followed by a Level 2 declaration in spring 2007. By July 2007, the region had surpassed all indicators for Level 4 drought, the most severe category; although the state did not officially declare a Level 4 drought until late September 2007 (one week after CCMWA did so).

From October to December 2007, Allatoona Lake's water level was only 1 foot above the bottom of the CCMWA intake. Prior to the 2007 drought, CCMWA had never used the bottom-most intake gate. In addition to posing a supply concern for the approximately 800,000 people served by the Authority, the drought conditions also resulted in significant and expensive water quality problems, including severe algal blooms and higher manganese concentrations in pumped water (Nguyen 2012).

The area did not emerge from drought conditions until nearly two years later, in May 2009, when the state lifted all water use restrictions. The repercussions on water use and local economies continued to be felt as the drought conditions and restrictions led to lost revenues and closures among local businesses as well as persistently lower revenues and water use at CCWS.

Cobb County Water System's Drought Management Snapshot

- To achieve state-mandated drought restrictions, CCWS developed a drought response plan (2007), which included education and outreach, leak detection, and water budget allocations.
- CCWS' water use decreased by 25 percent within one month of implementing the drought response plan in October 2007.
- Despite the termination of drought restrictions in 2009, post-drought water demand and associated revenue did not rebound to pre-drought levels.
- The State of Georgia is currently revising its 2003 Drought Management Plan and developing a Drought Management Rule that will incorporate the most critical lessons learned from the 2006–2009 drought.

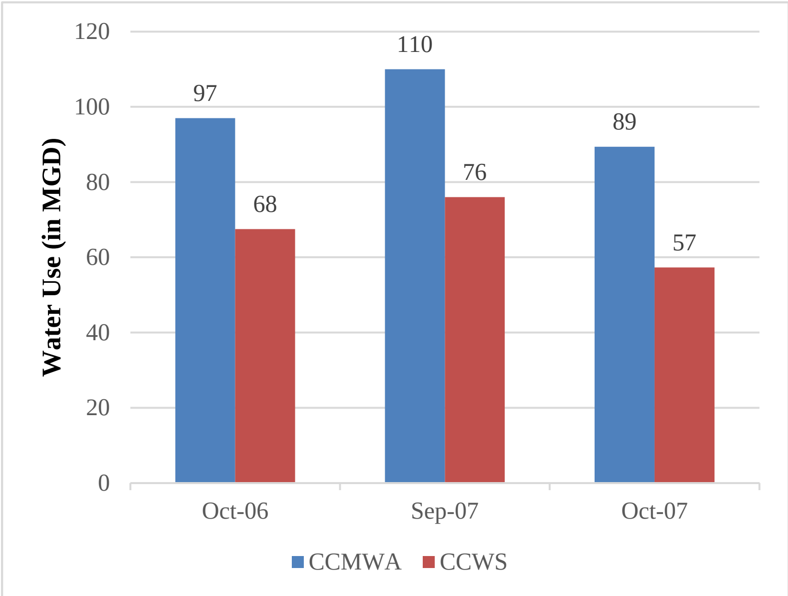
[15] Information in this case study was obtained through personal communication with CCWS staff unless otherwise indicated.

3.2.3 Response to Drought

The actions taken in response to the 2006–2009 drought did not entail significant planning efforts prior to the onset of the drought. State and local officials and utilities made decisions and acted in response to those decisions when drought conditions were at their most extreme. However, CCWS had a water efficiency program in place since 2005 as well as state-mandated year-round watering rules that are active even in non-drought years.

Georgia, unlike other states in the southeastern region of the country, has permitting authority over entities that withdraw over 100,000 gallons of water per day, such as CCMWA (Manuel 2008). In October 2007, following a statewide ban on all outdoor watering, the state unofficially entered a Level 5 drought. Governor Sonny Purdue issued an executive order requiring the state Environmental Protection Division (EPD) to modify those permits to require a 10 percent reduction in water withdrawals from the previous winter (December, January, February, and March) average. CCMWA holds the withdrawal permit and was required to meet the new withdrawal limit. CCWS was responsible for implementing the state's water use restrictions with end users and helping CCMWA achieve the reduction targets.

To achieve the state-mandated reductions, CCWS developed a drought response plan, which built on the drought planning practices mandated by the state. CCWS adopted several best management practices including the Pick 10 Challenge, an educational and outreach program encouraging customers to save 10 gallons of water per day, a leak detection program, a ban on recreational pool draining, a water waste ordinance, and a water budget for commercial customers. The immediate impact of the drought and Executive Order on CCMWA's and CCWS' water use is shown in Figure 3-3.



Source: Data from Nguyen 2014.

Figure 3-3. Comparison of water use in Cobb County before and after implementation of drought practices

Although the EPD noted in March 2008 that the region was entering the dry season in a worse position than it had in the previous year, the EPD eased some water use restrictions beginning in early 2008, when it allowed hand watering and added a new landscape exemption. In May 2008, Governor Purdue signed House Bill 1281 into law, which prohibited local governments from implementing more stringent short-term outdoor water restrictions or exemptions from state-imposed restrictions, without following an extensive waiver process overseen by EPD.

A year later, in March 2009, the state issued a drip and soaker hose exemption from the water use restrictions. By June 2009, the region was officially out of drought and all restrictions were lifted.

3.2.4 The Costs of Drought Mitigation and Response

In addition to the costs of these drought-related activities, Table 3-2 provides costs of CCMWA's and CCWS' water management practices. Note that although the programs listed in Table 3-2 may improve the ability of these entities to mitigate or respond to drought impacts, many of these programs would be part of their overall resource management strategy to address issues unrelated to drought, such as leak detection and water main repairs. The discussion below focuses only on the costs of those activities that have a major impact on the utility's resilience to drought.

CCWS estimated its total revenue loss from 2007 to 2008 to be $18.4 million. The system was able to defer some capital expenditures and delay planned maintenance activities to limit the impact of the unanticipated decline in revenue. CCMWA experienced approximately $9.5 million in revenue loss over the same period and, like CCWS, delayed some capital projects as a result. The Authority had to move forward with several significant projects to ensure compliance with new federal disinfection byproduct regulations. As a result, the Authority increased rates by 37 percent in 2008, instead of the anticipated 11.5 percent. CCWS, in turn, raised its water rates by 26 percent.

A broader informal survey of the impact of the drought on Atlanta-area utilities found that water use reductions led to utility revenue losses ranging from 4 to 25 percent. Most communities postponed capital projects as a result, and they saw water use reduce from 10 percent (the minimum requirement under the governor's 2007 executive order) to 25 percent of pre-mandate water use levels.

The financial impact of the drought on CCWS and CCMWA included both lost revenue and additional costs of enforcing water use restrictions and managing issues related to the reduced water supplies. CCWS had two field staff members working overtime shifts for enforcement purposes from 4 to 7 a.m. on weekdays and weekends and 7 to 10 p.m. on weekdays. The average salary for these employees was close to $16 per hour, or nearly $24 per hour for overtime (i.e., approximately $48 per hour total for two field staff conducting enforcement activities).

CCWS also incurred (but did not track) costs related to vehicle use. In addition, as total water use declined, concentrations of wastewater solids increased, increasing the cost of wastewater treatment (also untracked).

Dramatically low water levels in Allatoona Lake during the drought created significant water quality problems. Treating algal blooms cost CCMWA approximately $500,000 in total. Costs to address manganese problems were not tracked, but were reported to be lower than those for treating the algal blooms.

Overall, CCWS found that, although resources can be significantly strained in times of drought, it is difficult to determine exactly what expenditures or resource implications can be tied directly to drought, beyond lost revenue due to reductions in water use. Table 3-2 (below) provides examples of the costs CCWS has incurred for key water resource management and drought mitigation and response activities. Although this is not an exhaustive list of drought-related activities, it presents some of the system's more significant efforts.

Table 3-2
Costs of water resource and drought management practices in Cobb County

Activity	Cost
Wholesale water	$2.68 per 1,000 gallons (2014$)
Trucking reused water during irrigation season[1]	$2,500 (2008$) total from weekly trucking
Long-term ongoing outreach	$38,000 annually in 2007/2008 (2009$)
Rebates and other incentives for conservation	$381,000 annually (2008$)
Outreach for temporary conservation measures	$10,000 (2009$)
Enforcement of temporary conservation measures (i.e., outdoor watering ban)	$144,000 (2008$)
Enforcement of retrofitting program	$27,000 (2008$) during the 2007–2009 drought
Enforcement of xeriscaping program	$17,000 (2007$)
Leak detection program	$200,000[2]
Water main repairs	$1,035 (2009$) per repair, ~180 repairs per year (frequency varies widely), $186,300 total
Infrastructure development (dams, reservoirs, and other major storage)	$100,000,000 (2012$)[3]

Source: K. Nguyen (Cobb County Water System), pers. comm.

Costs shown above reflect costs of water resource management practices, which include costs of programs designed to mitigate or respond to drought. The precise amounts dedicated to drought mitigation and response are not always discernable from costs associated with other water resource management activities.
[1] Reused water was used to assist a county program by saving trees planted by the nonprofit entity, Keep Cobb Beautiful.
[2] Year of financial data not available.
[3] Expenses incurred by the wholesaler, CCMWA. Further, this reservoir was underway for years before the drought, and is not specifically associated with responding to this drought.

3.2.5 Looking Forward

Although the experiences from the 2007 to 2009 drought helped the Authority and CCWS better manage water resources and improved their response to the more recent drought of 2010 to 2012, demand has still not rebounded from the previous drought, and revenue levels remain below expectations. Rate-setting approaches have not yet been reevaluated and modified to reflect the ongoing situation and the potential for more frequent and significant droughts in the future. The utilities and State continue to work on updating the state drought rules. Furthermore, the issue of revenue stability and the state's role and authority to ensure adequate revenue to utilities during a drought is being evaluated and considered.

Comprehensive and proactive drought planning and mitigation activities are still in progress. The state is currently working to revise its 2003 Drought Management Plan and current rules on outdoor water use. These revisions will be included in an overarching Drought Management Rule (GA EPD 2014a). The state intends for the Rule to address the most critical lessons learned from the 2006 to 2009 drought, including the need for flexibility in the drought declaration process and implementation of water use restrictions, the importance of uniform recording and reporting approaches, and support for drinking water utilities implementing drought response measures in their service areas. The state is also considering including pre-drought mitigation strategies, indicators and triggers, response strategies, and methods for developing baselines (GA EPD 2014b).

3.3 CASE STUDY 3: FOCUSING ON OUTREACH CAMPAIGNS IN SAN DIEGO, CA

3.3.1 Background

The City of San Diego's Public Utilities Department (City)[16] is a large public water system providing drinking water to more than 1.3 million people over an area of more than 200 square miles. The average daily water demand in the city, as of 2013, was 172 MGD (Meda 2013). Approximately 80 to 90 percent of the city's water is imported from the Colorado River or Northern California. The city also sells water to several nearby communities and the California American Water Company (City of San Diego Public Utilities Department 2015a).

The city is one of 24 member agencies of the San Diego County Water Authority (SDCWA). The SDCWA is a wholesale water supplier; it obtains its water from the Metropolitan Water District of Southern California (MWD), of which it is in turn a member agency. MWD's water supplies include the Colorado River (via the Colorado River Aqueduct) and the Sacramento-San Joaquin River Delta. SDCWA also draws Colorado River water through agreements with Coachella Valley and Imperial County agencies. The City relies solely on user rates and service charges for its revenue.

City of San Diego's Drought Management Snapshot

- The City of San Diego developed a city-scale public outreach campaign in 2009. It resulted in a sharp decline in water use.
- During the 2014 drought, the City worked collaboratively with its wholesale supplier, neighboring utilities, and the state to launch a regional-level conservation outreach campaign.
- When the City's wholesale water supplier raised its rates to offset investment in new water supplies, the City absorbed these costs rather than passing them on to its customers, while continuing to promote efficiency and conservation.
- The City has many long-term ongoing drought management efforts, including conducting data-driven conservation modeling to assess factors affecting consumption, examining the use of per-customer water allocations and associated surcharges, and large capital improvements, such as desalination and potable reuse.

[16] Information in this case study was obtained through personal communication with the City staff unless otherwise indicated.

3.3.2 Impact of Drought

The City of San Diego has experienced two recent severe, multi-year droughts that affected its water supply: in 2009–2011 and again in 2013–2014 (drought ongoing as of January 2015). During drought, the City experiences frequent wildfires. In addition, 2014 was one of the hottest years on record for the city (Bower 2014). Because the City imports the vast majority of its water, its ability to meet water demand depends considerably on climatic conditions in the regions that supply water to the Colorado River and the Sacramento-San Joaquin Delta. In addition, the 2009–2011 and 2013–2014 droughts resulted in severe cutbacks in water allocations from the Sacramento-San Joaquin Delta.

3.3.3 Response to Drought

The City of San Diego is required by the State of California to develop and submit an urban water management plan, including a water shortage contingency plan, every 5 years. The 2008 contingency plan was developed in collaboration with other regional stakeholders to ensure there were consistent restrictions and levels of drought response across the area.

Customer outreach during 2009-2011 droughts was mostly from the City (and to a lesser degree from MWD). In 2009, the City began its first-ever advertising campaign to communicate the urgency of the drought and to help customers accept and understand the need to conserve. The City also reached out to its largest users (commercial and industrial customers, multi-family dwellings, the golf industry, and others) directly via email blasts and bill inserts. Water use declined sharply to a low of 127 gallons per capita daily (GPCD) in fiscal year (FY) 2011, before increasing slightly to an average of 134 GPCD in FY 2013. In contrast, in 2000, per capita daily use was over 175 GPCD.

After the drought ended in 2011, the City stopped drought-related outreach and messaging to the community. It did, however, modify a city ordinance to make some water conservation efforts permanent, including prohibiting irrigation runoff and excess irrigation, prohibiting hosing down of driveways or paved areas, and requiring restaurants to serve water to customers only upon request. The City also continued to promote water conservation, but they transitioned from drought-related messaging to a longer-term "San Diegans Waste No Water" campaign promoted on buses and billboards, among other media.

As the state reentered drought conditions early in 2014, the SDWCA imposed Level 1 drought watch conditions, and the City did the same on July 1, 2014. Level 1 includes voluntary restrictions on landscape watering, vehicle washing, ornamental fountains, and watering during rain events, as well as a target water leak repair time of no more than 72 hours. In 2014, the City, along with SDCWA, MWD, and the state, launched conservation outreach campaigns. This is contrast to the 2009–2011 drought, when most outreach messaging came solely from the City. Although this increase in messaging underscored the seriousness of the drought, the lack of consistent themes across the campaigns may have been confusing to customers.

Also in 2014, the State Water Resources Control Board (SWRCB) began demanding conservation measures from water agencies, including water shortage contingency plans and mandatory restrictions. By that time, however, San Diego had already taken the required steps. The SWCRB set 2013 as the baseline year against which to assess conservation efforts. Water use was relatively light in 2013 because of demand hardening. Achieving additional conservation in 2014 took considerable effort against this lower 2013 baseline and because the summer of 2014 had more extreme high temperatures than 2013.

Prior to the more recent drought events, the City and SDWCA were already looking for longer-term solutions to supplement or replace imported water. The Carlsbad desalination plant is under construction and expected to come on line in 2016, nearly two decades after the planning and permitting stages (The Carlsbad Desalination Project 2015). SDCWA will purchase treated water from Poseidon Water, the project developer, and has signed a 30-year contract stipulating a minimum annual purchase of 48,000 acre-feet, or 15,640 million gallons, of water (Rogers 2014b). The City may also benefit from other SDCWA efforts to enhance the water supply, including expanding the capacity of the San Vicente reservoir by raising its dam, investigating groundwater sources in the San Diego region, and optimizing recycled water use (SDCWA 2015b).

In 2009, the City initiated a 1-MGD water reuse demonstration project and, in November 2014, it received unanimous approval from the city council to undertake the Pure Water San Diego initiative. Pure Water is a 20-year effort to treat recycled wastewater to meet up to one-third of San Diego's drinking water needs. The City hopes to have a 15-MGD treatment facility in operation by 2023 and to be producing as much as 83 MGD of recycled water by 2035 (City of San Diego Public Utilities Department 2015b). The treatment facility will use filtration, reverse osmosis, advanced oxidation, and ultraviolet disinfection. The treated wastewater will be pumped to a reservoir and combined with local runoff and imported water before being treated again prior to being used as drinking water (City of San Diego Public Utilities Department 2013).

3.3.4 The Costs of Drought Mitigation and Response

This section identifies and describes costs incurred by the City because of drought. In addition to the costs of these drought-related activities, Table 3-3 provides costs of the City's water management practices. Note that although the programs listed in Table 3-3 may improve the utility's ability to mitigate or respond to drought impacts, many of these programs would be in place as part of the City's overall resource management strategy to address issues unrelated to drought, such long-term ongoing outreach to encourage conservation. The discussion below focuses only on the costs of those activities that have a major impact on the utility's resilience to drought.

Drought-related outreach campaigns from 2009 to 2010 and in 2014 cost the City approximately $950,000 ($750,000 for media buys and $200,000 for consulting services) and $450,000 (consulting services and media buys), respectively. SDCWA estimates that purchasing desalinated water will cost the SDCWA $1,848 per acre-foot, or $5,671 per million gallons, when capital, operations, and maintenance costs are considered. The Authority anticipates that the higher relative cost of desalinated water will result in rate increases, which will affect the City (Rogers 2014b). The City is estimating that its Pure Water project may cost up to $3.5 billion ($3.56 billion in 2014$), but hopes that diverting wastewater to the new treatment and reuse facility will avoid the need to invest almost $2 billion ($2.03 billion in 2014$) in retrofits for an existing wastewater treatment plant (Brennan 2014).

The City recognized the effect that drought and related conservation efforts would have on its revenue and responded by finding ways to reduce its budget accordingly in future fiscal years. However, due to increased investment in new water supplies and infrastructure, SDCWA raised its rates by 7.5 percent for 2012 and 9.6 percent for 2013, increasing the City's cost of purchasing water. The City made a decision to absorb the costs of these rate increases for 2012 and 2013, rather than passing them on to customers, and continued to promote its efficiency and conservation programs.

Table 3-3 (below) provides examples of costs the City has incurred for key water resource management and drought mitigation and response activities. While this is not an exhaustive list of drought-related activities, it represents some of the utility's more significant efforts.

Table 3-3
Costs of water resource and drought management practices for the City of San Diego

Activity	Cost
Purchasing water	$829 per acre-foot ($2,544 per million gallons) for untreated; $1,103 per acre-foot ($3,385 per million gallons) for treated
Long-term ongoing outreach	$450,000 ($250,000 for media buys and $200,000 for consultant services) for 2014
Water survey	$200 per acre-foot ($614 per million gallons)
Repair of water mains	$800,000 per mile
Replacement of water mains	$1,600,000 to $2,295,253 per mile (depending on pipe type and thickness)
Desalination	$1,848 per acre-foot ($5,671 per million gallons)[1]
Recycled water (tertiary treatment only and delivery)	$1,721,841 to $2,333,319 (for 4.33 to 7.68 million gallons of beneficially reused water in fiscal year 2014)

Source: L. Generoso (City of San Diego Public Utilities Department), pers. comm.

Costs shown above reflect costs of water resource management practices, which include costs of programs designed to mitigate or respond to drought. The precise amounts dedicated to drought mitigation and response are not always discernable from costs associated with other water resource management activities.
[1] *Expenses incurred by the wholesaler, SDCWA.*

3.3.5 Looking Forward

The City is using a data-driven water conservation model to examine the various factors affecting water consumption, and it is conducting cost of service studies every 2 years. When reviewing the factors affecting consumption, the City estimated that the recent recession could be responsible for 6 to 7 percent of the nearly 20 percent drop in consumption in 2009. The City also plans to reexamine the baseline years against which conservation is being measured as well as reasonable targets for further reductions in water use.

Finally, the City and region's water reuse and desalination facilities may have a major impact on water availability and production trends in the longer-term. The City anticipates gaining nearly 93,000 additional acre-feet, or 30,304 million gallons, per year from its Pure Water Program by 2035. Other activities to enhance the City's water sources include groundwater development and rainwater harvesting; these additional sources may add nearly 4,500 acre-feet, or 1,466 million gallons, per year to the City's resources. The City projects that these additional sources, combined with conservation efforts, will reduce the City's reliance on imported water from approximately 80 to 50 percent of its demand.

3.4 CASE STUDY 4: ADAPTING DROUGHT MANAGEMENT TECHNIQUES OVER TIME IN COLORADO

3.4.1 Background

Denver Water is Colorado's oldest and largest water utility (Weber 2014). Denver Water serves about a quarter of the state's population but uses less than two percent of all water, treated and untreated, in Colorado. Denver Water serves 1.3 million people through approximately 312,000 connections, and is funded by water rates and new tap fees. The average daily demand for this utility, established for the 2008-2013 period, is 180 MGD. Denver Water relies on rivers and streams fed by snowmelt (and therefore snowpack). Water sources include the South Platte River, Blue River, Williams Fork River, and Fraser River, as well South Boulder Creek, Ralston Creek, and Bear Creek (Denver Water 2015c).

Denver Water's Drought Management Snapshot

- Denver Water's drought management practices include extensive public outreach, updating their drought response plan, using utility-specific drought assessment tool, and water reuse.
- Due to the utility's conservation efforts, water use has declined by 21 percent since 2002, despite a 10 percent increase in the city's population.
- The utility has long-term investments in water quality improvements, sediment and debris removal, reclamation techniques, and watershed protection projects.

Aurora Water's Drought Management Snapshot

- Based on lessons learned from the 2002 drought, Aurora Water increased its focus on conservation, implemented water restrictions, and developed a utility-specific model to predict the utility's ability to supply water under various drought stages and future population increases.
- Water management practices have led to a 20 percent decline in water use since 2002.
- During periods of drought, the utility increases the number of staff members dedicated to conservation and monitoring and increases resources for public outreach.

Similar to Denver Water, Aurora Water depends almost entirely on snowmelt for its water supplies, drawing from the Colorado, South Platte, and Arkansas River basins. The city supplements these surface water supplies with a relatively small amount of groundwater and relies on 12 reservoirs and lakes for water storage (Aurora Water 2015). Aurora Water can lease water to other users in years of abundant supply and will lease water itself if needed in times of drought. This large water utility serves approximately 314,000 people through more than 75,000 service connections, the majority of which are single-family residences (Aurora Water 2011, Reidy 2008). The average daily consumption in Aurora, as of 2011, was 25.3 MGD (Aurora Water 2011, Reidy 2008).

3.4.2 Impact of Drought

In the past 15 years, Colorado has experienced two major droughts: one occurred in 2002–2004 and one occurred from 2012–2013. During both droughts, the entire state was in drought conditions. Calendar year 2002 was one of the single driest years on record for the state, with conditions that were the most severe since the 1930s Dust Bowl (City of Denver 2015). The spring of 2012 (March to May) was the second warmest in more than 100 years, and early summer temperatures continued to be higher than normal. Snowpack in both years was below average, although it was somewhat higher in 2012. Water levels in 2012 were below average in 13 of the state's 14 major reservoirs (NIDIS 2012).

During the 2002–2004 drought, Aurora Water's reservoir levels reached a low of 27 percent of capacity, fell below what was considered emergency status, and Aurora Water had an estimated nine-month water supply. In 2013, reservoir levels declined again, but to 47 percent of capacity. (Stanley 2013, Reidy 2008)

Similar to the effect at Aurora Water, the 2002–2004 drought had a significant impact on Denver Water's reservoir levels. By the spring of 2003, the reservoir levels reached a low of 40 percent capacity. Until a large snowstorm in March 2003, Denver was anticipating dire circumstances due to the drought. Stronger restrictions and drought surcharges were put in place that year until the runoff was complete and conditions improved (Greg Fisher [Denver Water], pers. comm.). The effects of severe drought on Denver Water's water supplies were compounded by major forest fires in the summer of 2002, fueled by high winds and extremely dry conditions. The Hayman Fire was the largest in the state's history and covered more than 137,000 acres at its peak (Colorado State Forest Service 2015).The fire and runoff containing fire debris deposited ash and other residue in critical water sources. A combination of debris from the Hayman Fire and a wildfire that occurred in 1996 resulted in an estimated accumulation of 1 million cubic yards of sediment in one of Denver Water's reservoirs (Denver Water 2015a).

3.4.3 Response to Drought

Denver Water and Aurora Water[17] weathered both droughts with a proactive and adaptive approach to drought management. Each utility developed and implemented drought management initiatives during or in response to the 2002–2004 drought and examined these efforts and improved upon them for the 2012–2013 drought.

The "rapid and aggressive adoption" (Kenney 2007) of a comprehensive array of demand management and drought mitigation initiatives put in place after the 2002 drought helped Aurora Water ensure that the 2012–2013 drought did not impact water supplies and service to the extent experienced during the previous drought. In response to the 2002 drought, Aurora Water established a dedicated budget for conservation activities and initiated several efforts to mitigate the impacts of the drought. The activities include:

- Increasing the number of staff dedicated to conservation.
- Implementing mandatory water restrictions.
- Expanding conservation programs. Aurora Water's conservation initiatives included education and outreach, leak detection and main repair to minimize water loss, and rebate programs for efficient fixtures and clothes washers.
- Creating an overarching Water Management Plan (WMP). Developed in 2003, the WMP includes water use goals, watering time limit and day restrictions, and information on fines. The document also outlines the utility's goals and initiatives

[17] Information in this case study was obtained through personal communication with Denver Water and Aurora Water staff unless otherwise indicated.

related to public education and outreach and conservation initiatives. The document is updated annually (Whitney 2014, Mikesell 2012).

- Developing more sophisticated models to assess the impact of drought and mitigation activities on the utility. Aurora Water's model allows the utility to calculate the reduction in water use that would be required under the four stages of drought. It can also calculate the ability of the utility's reservoirs to supply customers under varying drought conditions and other source supplementation or conservation scenarios. These projections take into account potential increases in population, potential drought duration, water quality goals, water loss across the system, and other factors (Whitney 2014).
- Initiating a major water re-use project. The Prairie Waters project, which currently provides 10 million gallons of water per day (and will be expanded to 50 million gallons per day as the city grows), was initiated in response to the 2002 drought. In this project, water is pumped from 17 wells on the South Platte River banks into an aquifer recharge and recovery basin, where it is allowed to filter naturally by passing over sand and gravel. The filtered water is then piped over 34 miles to three pumping stations and then sent to a treatment facility, from where it is pumped and distributed to customers (Water Technology 2015).
- Purchasing additional water rights. Aurora Water has access to major reservoirs with varying levels of system ownership. For example, the utility has 2 percent ownership of the Twin Lakes reservoir, which has a capacity of approximately 2,724 acre-feet, or about 888 million gallons. They have 100 percent ownership of the Aurora reservoir, which has a capacity of approximately 31,679 acre-feet, or about 10,323 million gallons (Aurora Water 2011). In addition, Aurora Water also purchases additional water rights to supplement the reusable supplies in the Prairie Waters project.

Aurora Water continued to improve its drought mitigation efforts in response to the 2012–2013 drought. In addition to expanding the Prairie Waters facility in 2014, Aurora Water updated the Sand Creek Water Reclamation Facility (Meyer 2007, Mitchell 2014, Whitney 2014). Since 1964, the City of Aurora has operated the Sand Creek Water Reclamation Facility, which treats wastewater for use in irrigation, thus reducing the demand on Aurora's drinking water supplies. The facility underwent expansions and upgrades in 2001 (WERF 2015).

Similar to Aurora Water, Denver Water implemented a wide variety of initiatives in response to the 2002–2004 drought and improved upon them for the 2012–2013 drought after examining their effectiveness. In 2013, Denver Water implemented mandatory watering restrictions for the first time since the 2002–2004 drought. The overall impact of the 2012–2013 drought was less severe than the impact of the 2002–2004 drought, due largely to wet weather that arrived in the spring of 2013 and the long-term conservation and planning initiatives that had been implemented in response to the 2002–2004 drought. Denver Water's drought management activities include:

- Updating the Drought Response Plan. The plan is updated regularly and provides an overview of drought severity indicators, response actions, and communication activities (Denver Water 2014).

- Using a drought management tool to assess drought conditions. Denver Water uses a modified version of Surface Water Supply Index (SWSI) to gauge the severity of drought conditions. The index relies on reservoir storage data, real-time streamflow observations, and Ensemble Streamflow Prediction (ESP) probabilistic water supply forecasts (Volckens et al. 2014).
- Developing five guiding principles for response to drought. In response to the 2002–2004 drought, Denver Water developed the following principles to serve as a framework for responding to drought conditions and restricting water use:
    - Avoiding irretrievable loss of natural resources.
    - Restricting less essential uses before essential uses.
    - Protecting public spaces.
    - Minimizing adverse financial effects.
    - Implementing extensive public information and media relations programs.

The guiding principles described above and lessons learned from the 2002–2004 drought led to several key improvements to how Denver Water responded to the 2012–2013 drought (Weber 2014):

- Established a water budget program for large properties. Denver Water provided certain large irrigators, such as schools and parks, a water budget, rather than specifying day-of-the-week watering restrictions. This provided flexibility as to when and where such entities watered, which avoided irretrievable loss of natural resources.
- Recaptured flushed water. Water flushed from the distribution system was recaptured and used for irrigation purposes.
- Established guiding principles for drought pricing. Drought pricing is used for defined purposes that can be communicated clearly to customers.
- Examined the utility's financial model. Denver Water is studying a new financial model that could provide more revenue stability across various weather scenarios.

Source: **Courtesy of Denver Water**

Figure 3-4. Example of the playful public outreach campaign conducted by Denver Water in 2013

Finally, Denver Water ramped up its public outreach campaign in 2013, initiating an engaging and playful message (Figure 3-4). The campaign's tag line was changed from "Use Only What You Need" to "Use Even Less" to indicate the severity of drought conditions. The utility later took steps to remove outreach materials quickly when the region experienced historic flooding in September 2013. Overall, the 2013 public outreach campaign cost Denver Water about $700,000; the budget for public outreach fluctuates annually depending on internal and external conditons.

3.4.4 The Cost of Drought Mitigation and Response

In addition to the costs of these drought-related activities, Table 3-4 provides the costs of these utilities' water management practices. Note that although the programs listed in Table 3-4 may improve the ability of these utilities to mitigate or respond to drought impacts, many of these programs would be in place as part of their overall resource management strategy to address issues unrelated to drought, such ongoing conservation activities and outreach campaigns. The discussion below focuses only on the costs of those activities that have a major impact on the utilities' resilience to drought.

Aurora Water's investments in drought management efforts have been significant. The utility's Office of Water Conservation has grown from three full-time equivalents (FTEs) in 2001 to ten FTEs, six contract staff, and six interns in 2014. Between 2007 and 2014, the Office's annual budget more than doubled, from $747,540 ($853,516 in 2014$) to nearly $1.7 million (Whitney 2014).

The budget for the rebate program is approximately $500,000 a year, and the program is managed by three staff members. The utility offers toilet, irrigation modification, xeriscaping, and, until 2012, clothes washer rebates. In 2012, Aurora Water evaluated the rebate program through a survey conducted by both Aurora Water and Denver Water. Aurora Water determined that customers were choosing to purchase high-efficiency clothes washers regardless of rebates offered, which led the utility to discontinue washer rebates. Aurora Water also found that the return on investment for most rebates was three years, although this was harder to quantify for xeriscaping because of the length of time necessary to see water savings. The utility did note, however, that when one customer installed a xeriscape landscape their neighbors tended to follow suit (Whitney 2014).

Aurora Water's education and outreach initiatives include irrigation and indoor water audits, adult and youth education classes, a volunteer program, and a smartphone app. Through its volunteer program, the utility encourages city residents to learn more about xeriscaping by maintaining Aurora's Xeriscape Demonstration Garden. The smartphone app helps the utility transmit critical information, such as drought declarations, to customers immediately and allows customers to enter information on their indoor and outdoor water use and compare it to usage rates across other customers. The utility also distributes a monthly newsletter and annual postcard in addition to other water use-related messaging throughout the year. Four staff members, four interns, and two contractors oversee these efforts in addition to their other responsibilities, which include adult and youth education, xeriscape garden maintenance, indoor water audits, water waste monitoring, and permit inspections. The utility spends approximately $800,000 per year on public outreach and $500,000 per year on its leak detection program (Whitney 2014).

The cost of the Prairie Waters reuse project was approximately $650 million, and water rights purchasing costs the utility $7 million per year. The cost of the 2001 upgrades to the Sand

Creek Water Reclamation Facility was approximately $11 million ($14.7 million in 2014$) (WERF 2015).

Due to key management interventions, Aurora's water use has declined significantly from its peak (total water deliveries in 2003 were down 26 percent over 2001) and has remained consistently below previous averages (Kenney et al. 2008). In addition, per capita water use has declined 20 percent since 2002 (Aurora Water 2015). After 2012, overall water use reached an all-time 30-year low. The utility has had to adjust to the corresponding reduction in revenue, but planning for revenue declines has mitigated those impacts. For example, Aurora Water doubled its rates from 2005 through 2010, which funded several projects including the Prairie Waters system. These projects have saved water, allowing Aurora Water to plan for future demand in a growing community. Although water use continues to decline, the rate of decline has slowed considerably. In addition, during periods of drought, Aurora Water has invested in additional monitoring staff (four in response to the 2012 drought) and outreach ($50,000 in additional expenses in response to 2012) (Whitney 2014).

Denver Water has spent more than $26 million in 2002$ ($34.2 million in 2014$) on water quality improvements, sediment and debris removal, reclamation techniques, and infrastructure projects since the 1996 and 2002 forest fires, and it works in partnership with the Rocky Mountain Region of the U.S. Forest Service to protect and improve forest and watershed conditions (Denver Water 2015a).

Denver Water's communications and outreach budget is less than 1 percent of the total budget for the utility, and attributing drought-specific costs to communications and outreach is difficult. However, because of Denver Water's conservation efforts, customers are using 21 percent less water than before the 2002 drought, even with a 10 percent increase in population.

Table 3-4 provides examples of costs Denver Water and Aurora Water have incurred for key water resource management and drought mitigation and response activities. Although this is not an exhaustive list of drought-related activities, it presents some of the utilities' more significant efforts.

Table 3-4
Costs of water resource and drought management practices for Denver Water and Aurora Water

	Activity	Cost
Denver Water	Long-term ongoing outreach campaign	$700,000 in 2013
	Ongoing Rebate Program	$2,200,000 in 2013
	Water Budget program implementation	$40,000 in 2013
	Ongoing pipe improvement and replacement	$7,800,000 (5-year average from 2010-2014); recent annual average
	Ongoing Leak detection program	$250,000; recent annual average
	Activity	Cost
Aurora Water	Long-term ongoing outreach	$800,000 per year
	Rebates and other incentives for conservation	$500,000 per year
	Leak detection program	$500,000 per year
	Water rights purchasing	$7,000,000 per year
	Recycled water (storage, distribution, and operations and maintenance)	$661,000,000

Source: L. Weber (Denver Water), pers. comm. and L. Whitney (Aurora Water), pers. comm.

Costs shown above reflect costs of water resource management practices, which include costs of programs designed to mitigate or respond to drought. The precise amounts dedicated to drought mitigation and response are not always discernable from costs associated with other water resource management activities.

3.4.5 Looking Forward

Aurora Water's approach to drought management has evolved over time in response to consumer feedback and results. Aurora Water uses innovative technologies, such as the smartphone app, to stay at the forefront of customer outreach initiatives.

One of the more significant changes to be introduced in 2015 by Aurora Water is a reduction in the number of drought stages from six to four and an increase in the extent of restrictions between each stage. The utility also instituted smaller initial fines ($50, down from $250), surcharges, and day of the week restrictions, and they implemented what are considered to be more realistic conservation goals (Whitney 2014).

Denver Water continues to place a significant emphasis on adaptation and being prepared to provide a reliable supply of water to customers in the face of a wide range of potential future weather conditions that affect temperature and precipitation (Kaatz 2014). The experiences of large drinking water utilities such as Denver Water and Aurora Water demonstrate how continued investment in and improvement of drought management efforts can yield long-term benefits. Establishing drought mitigation efforts early and improving them over time has helped both utilities respond to the 2012–2013 drought.

CHAPTER 4
THE VALUE OF COST-BENEFIT ANALYSES FOR EVALUATING DROUGHT MANAGEMENT PRACTICES

Drinking water utilities face difficult choices as they plan their responses to droughts in a changing global climate. Global climate change may increase the severity, duration, and frequency of droughts, increasing the potential impacts of drought. They will need to consider the short-term impacts and long-term implications of their decisions in a changing climate. The theory of welfare economics provides a framework for evaluating alternative practices and the decisions to be made; in principle, utilities should analyze their unique conditions and choose the drought management practice that provides the largest net increase in social welfare. In practice, however, a great deal of information is required to implement this framework fully, and utilities may not have all the information readily available. Some information may be difficult, if not impossible, to quantify. Cost-benefit analysis can still be a useful tool that utilities can use to catalogue and collect the necessary information for evaluating alternative plans within a welfare economics framework.

The basic approach is relatively simple. The steps for a cost-benefit analysis of drought management practices are outlined in Figure 4-1. Cost-benefit analyses systematically assign values to the costs and benefits of a practice. If a practice's benefits are greater than its costs, it is worth pursuing. When comparing several options, the practice with the largest net benefit is the best alternative.

Competitive markets, under limited conditions, will allocate resources to a project as long as the marginal social benefit exceeds the marginal social cost. In the jargon of welfare economics, this is considered an efficient outcome. Cost-benefit analysis allows policy makers to accomplish the same goal of efficiently allocating resources if the costs include all of the economic costs to society and the benefits include all of the economic benefits to society. To select the option that provides the largest net benefit to society, it is not sufficient for a utility to look at the impact on its bottom line alone; the utility must also estimate the net benefit to society. Therefore, the cost-benefit analysis should expand beyond just economic factors to focus on the triple bottom line:

1. The economic impact on the utility and its customers, including changes in revenue and expenses associated with the project.
2. The environmental impact, which includes the effects on water quality, pollution, changes in habitat, and carbon emissions.
3. The social impact, which includes the effects on public health, changes in community attractiveness, and property values.

By focusing on the triple bottom line, the analysis will help identify efficient drought management practices and evaluate the impacts of such practices on various decision makers. This, in turn, can help utility managers understand the obstacles and opportunities they may face when implementing the practices. For example, the City of San Diego Public Utilities Department has addressed the economic and environmental impacts of its water resource management plan in a cost-benefit analysis (see Appendix B).

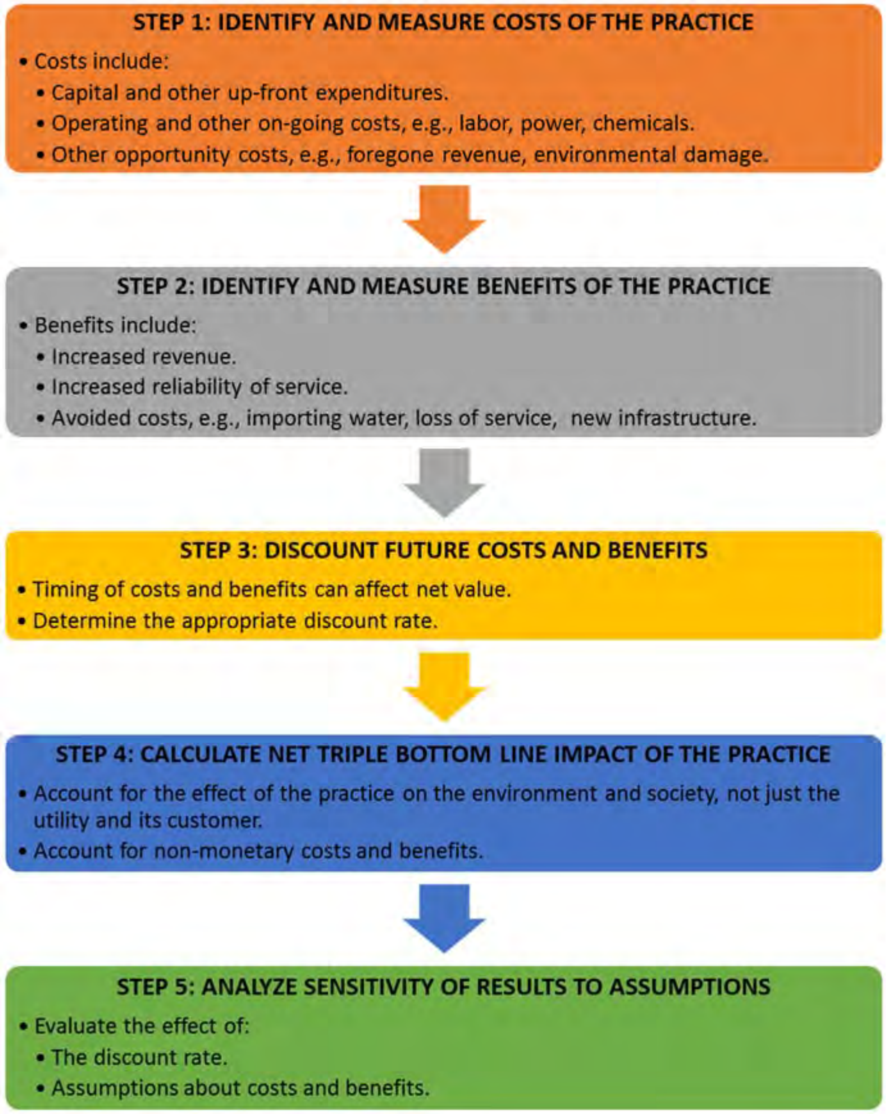


Figure 4-1. Steps in a cost-benefit analysis to evaluate drought management practices.

Although the basic approach is simple, the details of the analysis can be quite complex. Utilities face diverse circumstances, and these circumstances change over time. Planning tools must be both flexible and robust to ensure that they can be adapted to meet each utility's needs while providing accurate assessments of alternative plans. The information available for planning may vary greatly across utilities and can change over time for an individual utility. Fortunately, cost-benefit analysis is a flexible process that can be adapted to changing conditions. Rather than develop a one-size-fits-all strategy, this report outlines an approach (or general guidance) that can be applied under many circumstances. The approach can also be revised and updated as more information becomes available.

Utilities may need a great deal of information to value and ascribe the costs and benefits of a drought mitigation plan, further adding to the complexity of an analysis. Carefully documenting cost data consistently at the requisite level of detail (Step 1 in Figure 4-1) is often challenging for utilities, as such efforts may require additional labor hours and other resources that may not be available. Further, quantifying benefits and, in particular, assigning dollar values to social and environmental benefits (Step 2) is challenging, as there is no single standard method for doing this. One will likely need to develop estimates, rely on models, or make some general assumptions to conduct the analysis. Determining who pays the costs and who receives the benefits also adds to the complexity of the analysis. Therefore, the final step of the analysis—conducting sensitivity analyses (Step 5)—is necessary to ensure the analysis provides meaningful results under a range of alternative assumptions.

To illustrate the use of a cost-benefit analysis in drought management planning, we present an example cost-benefit analysis for a hypothetical utility in two parts. Appendix C explains our methodology, assumptions, and the results. The details of the analysis are contained in a MS Excel file that is published separately as the 4546 Example Cost-Benefit Analysis. The cost data used in the example are a combination of data provided by partner utilities (presented in Appendix D) and additional data identified in the literature. While the 4546 Example Cost-Benefit Analysis is in MS Excel, it is not a template that can be used by a utility to evaluate drought management alternatives. It illustrates the concepts discussed in this chapter and highlights the type of data and supplemental information needed to calculate the value of different drought management practices.

4.1 MULTIPLE PERSPECTIVES

The net benefit of a practice may look quite different from different perspectives. For example, an individual customer may bear most of the costs associated with improving water-use efficiency, but the benefits may be shared with others. Because the analysis must identify not only the costs and benefits, but also who pays the costs and who receives the benefits, there are at least three perspectives to consider: (1) society as a whole, (2) the customer (or ratepayer), and (3) the water utility.

Ideally, analyses are conducted from each perspective. The net social benefit includes the effects of the drought management practice on the utility, its customers, the environment, as well as other stakeholders that may be affected by the policies. If a practice provides positive social net benefits, then a utility can conduct a customer-level analysis to understand how the customer will value the program to determine whether incentives will be needed to encourage customer participation. Finally, the utility can evaluate the value the project will provide to the utility given its costs and benefits.

4.1.1 Societal Perspective

From the societal perspective, cost-benefit analyses weigh the aggregate costs and benefits of the project or program to the greater community and the environment as well as to customers, ratepayers, and utilities. An analysis at this level is the widest in scope. It captures all costs and benefits to society, including effects on parties not directly involved in the program. For example, the City of San Diego Public Utilities Department cost-benefit analysis considered both positive and negative impacts of its water resource management options through 2035, such as reduction of greenhouse gas emissions and contamination of local habitats (see Appendix B). The potential effects—both positive and negative—of drought management practices on the environment are substantial, and the analysis must explicitly account for these impacts to assess the net societal benefit of alternative drought management practices accurately. This type of analysis is useful for high-level policy making because it allows comparison among programs and projects.

Conducting an analysis from the societal perspective is more likely to include costs and benefits that are difficult to quantify. Measuring and valuing the environmental, security, and social benefits of reduced water and energy use is complex and often associated with great uncertainty. Furthermore, this analysis does not distinguish among the net effects for each of the parties involved. Some parties may have costs that outweigh benefits, even if society as a whole is better off from the program. There may be social, economic, or political reasons for treating the costs or benefits to various parties differently.

4.1.2 Customer Perspective

Customer-level cost-benefit analyses identify each change in equipment or process and develop estimates of the implications of the change in water use by the customer. One important advantage of conducting a cost-benefit analysis from the customer's perspective is the ability to compare the evaluation among different drinking water utilities. Customer characteristics vary across utilities; analyses by customer class can capture these differences and facilitate comparisons of the impact of programs across utilities. A cost-benefit analysis from the customer's perspective also allows for greater coordination among utilities, enables them to present consistent evaluations to customers, and allows them to determine any assistance or incentives required to encourage customers to undertake or otherwise support the project.

4.1.3 Utility Perspective

A cost-benefit analysis from the utility's perspective provides an estimate of the value of the drought management practice to the utility. An analysis from this perspective allows the utility to focus limited resources on projects that will provide the greatest benefits to the utility. Costs and benefits may be different for the utility than for the individual customer for a number of reasons. One critical difference is the cost of capital. A utility may be able to borrow at a lower cost than its customers. The lower cost of capital will, in turn, lower the cost of a project. Of equal importance, utilities will discount future benefits at a lower rate than their customers because of the utilities' lower cost of capital, potentially increasing the value of the project (*ceteris paribus*). (See the discussion of discount rates in section 4.3.)

A second potential difference between utilities and their customers is that the utility may have explicit water efficiency goals that it needs to achieve to comply with state or other public objectives. The utility may place value on efficiency gains over and above the savings available to the customer because the efficiency measures help the utility achieve its water efficiency goals. Because of these differences, the net present value (NPV) of potential drought management practices may be positive for the utility even though it is zero or negative for the customer.

4.2 CATALOGING COSTS AND BENEFITS

It is crucial that a cost-benefit analysis include all potential costs and benefits, and it must evaluate them in a consistent manner. Some costs are easier to quantify than others. Monetary costs and benefits are the traditional measures used in most cost-benefit analyses and are often relatively easy to quantify. (Nevertheless, monetary values are sometimes difficult to obtain. Costs specific to drought may be difficult to segregate from costs for more general planning and for standard operations.) Monetary costs include the costs incurred by implementing the drought management practice, such as the capital expenditures; the cost of labor, power, water, and routine maintenance; forgone revenue; and others. Benefits include reduced expenditures on water, avoided costs such as buying water from neighboring communities or acquiring new sources of water, lower utility bills, etc.

In addition to these standard costs and benefits, some costs and benefits cannot be quantified or monetized. For example, environmental benefits such as the protection of wildlife habitat may not have clear monetary values. A complete analysis will identify each of these non-monetary benefits, assign qualitative measures of their importance, and draw conclusions about their impacts on the bottom line.

The costs and benefits of a drought management practice must also be evaluated in light of what would have occurred absent the project. Only incremental costs and benefits resulting from the project should be included in the cost-benefit analysis. An example of such an incremental cost would be a customer that replaces an inefficient piece of equipment with a water-efficient one as part of a larger drought management program. If the customer would only have installed the high efficiency equipment through the utility's program, then the benefits of this action should be included in the analysis. (If the customer is only likely to have installed the equipment through the program, a portion of the benefits can be included.) Similarly, only the incremental costs of the equipment should be included. If the equipment had been replaced with less efficient equipment, the difference in costs between the two alternatives, rather than the total cost of the new equipment, would be used for the analysis.

The analysis must account for the timing of the costs and benefits. Most analyses will focus on annual costs and benefits. The analysis may use quarterly or monthly data (e.g., monthly data used for billing), but such detail is usually not necessary. For our purposes, we assume the analysis will use annual cost and benefit data.

The analysis must account for all costs and benefits, but the level of detail required will depend on the quality and amount of information available. For example, one analysis may have dozens of clearly defined components of costs, each with established and accepted values. Another may have a handful of broad costs that are based on a set of assumptions or models. Both analyses can be useful. The key is to make the best use of the information available and to revise the analysis as additional information is gathered.

4.2.1 Accounting for Costs

Costs can include one-time, up-front investments as well as recurring costs. Some costs, such as labor and energy costs, may vary with the scale of the project, while others may be fixed. The analysis should estimate the costs for each year of the project. For example, a project may require an upfront investment in physical equipment, followed by annual operations and maintenance (O&M) expenses. The City of San Diego Public Utilities Department example (see Appendix B) provides an illustration of how these up-front and recurring costs can be incorporated into a cost-benefit analysis. The City of San Diego Public Utilities Department evaluated the up-front capital costs of new water supply development and upgrades, as well as long-term costs, such as O&M costs for drinking water supply and distribution and wastewater systems. Furthermore, the City of San Diego Public Utilities Department's analysis estimated fixed and variable costs for eight distinct water resources management approaches (portfolios). The first five years of a simplified example of costs are displayed in Table 4-1.

This is a very simple example, and additional detail may be needed for further analysis. The analysis may divide the costs into categories based on who will bear them. For example, costs may be divided among those borne by utilities or taxpayers. (See the discussion of accounting for different perspectives below.) In addition, both the cost of the initial investment and the annual O&M costs may need to be further divided into their components to estimate the annual cost of the project. The interest on any bonds or loans associated with the initial investment will be added to the annual cost as well. O&M costs can be divided into labor, materials, and other costs. The analysis would then sum these costs to estimate the total annual cost of implementing the plan.

Table 4-1
Example of annual cost

Year	Plant and equipment	Operations and Maintenance	Total
2015	$1,000,000	$0	$1,000,000
2016	$0	$10,000	$10,000
2017	$0	$10,000	$10,000
2018	$0	$10,000	$10,000
2019	$0	$10,000	$10,000

To evaluate the net impact of the plan on customers, utilities, and society, the analysis will need to consider the costs from multiple perspectives. It is helpful to build the model by component. The analysis begins by identifying the costs facing customers and the utility. These can then be combined with other costs to develop the estimate of the impact on the environment and society as a whole.

Costs borne by the customer can include:

- Incremental one-time costs to purchase and install equipment. (Only the additional costs of the efficient equipment should be included in the analysis if less efficient equipment would have been installed absent the program.)
- Additional O&M costs, including the value of the time the customer spends administering the response to the management plan.
- Any increases in the customer's utility bills. (For example, both water and wastewater rates may increase under a drought management program. Utilities may increase water rates to encourage water conservation. Reduced water use may lead to higher contaminant concentrations in wastewater, which may result in higher wastewater rates.)

The costs of a drought management practice from the utility's perspective are calculated by evaluating changes in utility revenues and operating costs. Costs can include:

- Costs to administer the project or program.
- Incentives paid to the customer.
- Any additional source, storage, treatment, or transmission and distribution costs.
- Forgone revenue.

The analysis should not consider changes in revenue for the district or utility as costs because they likely will result in rate changes. Typically, a loss in revenue will be recovered through increases in rates; there will be no net loss to the utility.

The costs to society include the cost to customers and utilities as well as costs borne by others, including the impact on the environment. Economists refer to these costs as externalities and they can include:

- Reduced in-stream flows and effects on wildlife.
- Environmental damage caused by new or expanded dams.
- Increased energy consumption and carbon emissions associated with increased pumping, treatment, etc.
- Increased costs to taxpayers and customers of other utilities.

4.2.2 Accounting for Benefits

Benefits can be realized once or recur over time. They may include fixed and variable components. As with costs, benefits should be catalogued based on multiple perspectives because some benefits accrue to the utility, some to its customers, and some to society as whole.

A drought management practice may generate more than one benefit, and the benefits may be constant, or they may change over time. As an example, the first five years of a program that ramps up over three years may result in benefits such as those outlined in Table 4-2:

Table 4-2
Example of annual benefits

Year	Avoided Costs of New Supplies	Increased Local Control	Total
2015	$100,000	$10,000	$110,000
2016	$200,000	$20,000	$220,000
2017	$300,000	$30,000	$330,000
2018	$300,000	$30,000	$330,000
2019	$300,000	$30,000	$330,000

As with costs, the analysis will need to consider the benefits from multiple perspectives to evaluate the net impact of the practice on customers, utilities, the environment, and society at large. The same approach used for costs should be used for benefits, building the model by component. We identify the benefits for customers and the utility and then combine them with other benefits to develop the estimate of the impact on society as a whole. The City of San Diego Public Utilities Department's analysis provides an aggregate benefit to society, including benefits for the utility, ratepayers, and other stakeholders. For example, objectives included protecting quality of life and managing costs and affordability. A complete list of the City of San Diego Public Utilities Department's 11 objectives in this analysis can be found in Figure B-1.

Benefits to the customer due to a drought management practice can include:

- Reductions in the customer's utility bills (beyond those that would have occurred without participation in the project) due to reduced water use.
- Reductions in other costs as a result of the drought management practice.
- Incentives or tax credits received.

The benefits to utilities can include:

- Avoided costs of acquiring water sources, including purchases or production.
- Avoided water storage costs.
- Avoided costs to treat water and wastewater.
- Avoided transmission and distribution costs.
- Incentives, tax credits, or revenue from sales of conserved water to other customers.
- Increased local control.
- Maintaining customer trust.

The drought management practice may have other impacts as well. Although they do not accrue to the utility or the customers, these should be included in estimates of the social benefit of the program, and can include:

- Avoided costs incurred by other districts or utilities providing water to the utility serving the customer.
- Potentially more stable demand, increased utility reliability, and reduced price volatility.
- Benefits created through reduced water and energy use. These include improved air and water quality, reduced greenhouse gas emissions, and improved wildlife habitats.

Other potential benefits that are important to consider but may be difficult to quantify include increased productivity, enhanced green image, and increased morale of employees that value improved efficiency.

Benefits can be more difficult to measure than costs. For example, utilities are likely to know the labor costs required for implementing a drought management practice, but they may not be able to place a monetary value on the benefits. Utilities may need to rely on contingent valuation studies, models, or qualitative assessments to measure the benefits of their practices. An important measure of the benefits of a practice is the cost of activities that can be avoided if it is in place. For example, in the absence of a drought management plan, a utility may purchase finished water from other sources. In that case, one of the benefits would be the avoided cost of the purchased water. The City of San Diego Public Utilities Department incorporated avoided costs into its benefits analysis by including a cost management and affordability objective in its plan (see Appendix B).

4.2.3 Escalating Future Costs and Benefits

Utilities may have sound information on the costs and benefits of a practice for the current year, but they must estimate future costs and benefits. The analysis must account for changes in relative prices over time as well as general changes in the price level or inflation. It is important to distinguish between relative price changes, which reflect real changes in the value of goods and services, and inflation.

In describing change in relative price, the analysis should include factors that measure the change over time. Costs and benefits in year *t* are given by Equation 4.1:

$$C_{t=}C_0(1+p)^t \quad (4.1)$$

where C_t is the cost or benefit in year t, C_0 is the cost or benefit in the current year, and p is the annual rate of change in the relative price. For example, if the price of energy is expected to increase in real terms by 3 percent per year, one would assume that the energy costs associated with one's program will be 3 percent higher next year, 6.09 percent higher in two years, 9.27 percent higher in three years, and so on.

Global climate change can affect relative prices, including for water. If future climates will be drier and will include more frequent droughts of longer durations, the relative value of water would increase over time, relative to other costs. Planners will need to estimate this increase and incorporate it into their planning models. In other words, rather than assume the benefit of water efficiency is constant in real terms, they can apply Equation 4.1 and increase the value of water savings over time.

A general increase in price is described in Equation 4.2. If the analysis is to measure net benefit in nominal dollars—the actual benefits generated and expenses that will be incurred—in each year, then the costs and benefits must be increased to account for inflation. The net benefit in year t is given by Equation 4.2:

$$N_{t=}N_0(1+i)^t \quad (4.2)$$

where N_t is the net benefit in year t, N_0 is the net benefit in the current year, and i is the annual inflation rate. In most cases, cost-benefit analyses present their results in real terms, usually reflecting current price levels. In other words, they assume price levels are constant and no further adjustment is needed.

For its cost analysis, the City of San Diego Public Utilities Department estimated that all costs would increase at the rate of inflation with the exception of imported water rates, which it estimated would increase at a higher rate. These assumptions can be found in Appendix B.

4.2.4 Qualitative Measures of Non-Quantitative Costs and Benefits

Many benefits and some costs are intangible. Although it may not be possible to place a dollar value on intangible benefits and costs, they can be discussed qualitatively. The analysis should indicate whether intangible costs and benefits exist. It also may describe their magnitude in qualitative terms. Ultimately, their value is subjective. The goal of the analysis is to provide enough information to decision makers so they can decide on the relative importance of these intangible costs and benefits.

Utilities have several ways to account for non-quantified costs and benefits. One approach is to measure people's willingness to pay for a benefit. (In the case of costs, we would measure people's willingness to pay to avoid the costs.) Contingent valuation studies are designed to measure the monetary value of program impacts that do not themselves have a dollar value. Another approach is to use proxies that are similar to the cost or benefit, including the costs avoided as a result of the drought management practice.

If alternative measures of the value of costs and benefits are not available, the analysis can rely on qualitative assessments of their potential impact. The analysis would first account for costs and benefits that can be valued. The analysis would then add a qualitative assessment of the non-monetary costs and benefits, showing whether their net impact is positive or negative. Stoplight charts, plus or minus signs, or other graphics can be simple, effective means of showing the potential impacts of these non-monetary factors.

4.3 DISCOUNTING

4.3.1 Purpose of Discounting

The costs and benefits of drought management plans may occur over many years. For example, infrastructure such as dams and reservoirs built today will provide water storage for many years into the future. Future costs and benefits must be discounted to compare them to present values for two reasons. First, most people would place higher values on current costs or benefits than on future costs or benefits due to the *time value of money*. That is, most people would choose to receive $100 today rather than in one year, because (in principle) they could invest the $100 they receive today and have more than $100 next year. Second, there is a risk that future costs and benefits will not occur. Discounting adjusts future costs and benefits to reflect their present value (i.e., what they are worth today). The higher the discount rate applied, the lower the present value of future costs and benefits.

Equation 4.3 is used to calculate the present value of future costs or benefits:

$$PV = \frac{FV}{(1 + r)^t} \tag{4.3}$$

where *PV* is the present value, *FV* is the future value, *r* is the annual discount rate, and *t* is the number of years until the future cost is incurred or the future benefit is realized. The discount rate can be in nominal or real (i.e., inflation-adjusted) terms. It can be risk free or adjusted for risk, depending on the needs of the analysis.

4.3.2 Determining the Discount Rate

Careful consideration should be made when choosing a discount rate because the rate can influence the outcome of the cost-benefit analysis. For example, the present value of $1,000 dollars saved in 10 years at a discount rate of five percent is nearly $614 (Equation 4.4). In contrast, a discount rate of 10 percent would yield a present value of less than $386 (Equation 4.5):

$$PV = \frac{\$1,000}{(1 + .05)^{10}} = \$613.91 \tag{4.4}$$

$$PV = \frac{\$1,000}{(1 + .10)^{10}} = \$385.54 \tag{4.5}$$

The appropriate discount rate to apply depends on the perspective of the analysis. If the analysis is conducted at the customer level, then the market rate of return for private investments or the customer's weighted average cost of capital should be applied. Analyses at the utility level should use the utility's cost of capital.

Analyses conducted from the societal perspective will typically apply lower discount rates than are used at the customer or utility perspective. This is due, in part, to the role of risk. Individual customers must pay a risk premium when they borrow funds. The risk premium is a transfer payment and nets to zero from society's perspective. Further, some have argued that the societal discount rate is below the risk-free market rate because of imperfections in capital markets.[18] The California Urban Water Conservation Council (CUWCC) cost-effectiveness guidelines recommend using the discount rates published by the Executive Office of the President, Office of Management and Budget (OMB) for the societal discount rate. These rates are based on the U.S. Treasury borrowing rate on marketable securities. The rate with maturity comparable to the length of analysis should be used. The OMB discount rates for 2013 are presented in Table 4-3.

Table 4-3
2014 interest rates on treasury notes and bonds of specified maturities (percent)

	3-Year	5-Year	7-Year	10-Year	20-Year	30-Year
Nominal Interest Rates	1.7	2.2	2.5	2.8	3.1	3.4
Real Interest Rates	0.1	0.4	0.7	0.9	1.2	1.4

Source: OMB 2014.

OMB uses a real rate of 7 percent to discount future costs and benefits. Many studies use a real rate of 2 percent for long-term projects. This approximates the after-tax rate of return (Rosen 2005). If the costs and benefits are to be expressed in real (inflation-adjusted) terms, then the real discount rate should be applied rather than the nominal discount rate. The real discount rate is calculated from the nominal discount rate using Equation 4.6:

$$r = (d - i) + (1 + i) \tag{4.6}$$

where r is the real discount rate, d is the nominal discount rate, and i is the expected inflation rate.

The City of San Diego Public Utilities Department calculated the present value of its cost estimates by applying a 5 percent annual discount rate over a 25-year period (Appendix B).

4.4 EVALUATION MEASURES

The suggested best approach for completing a cost-benefit analysis is to calculate the NPV of a drought management practice. The NPV is the suggested best measure, but there are times when it is appropriate to use other measures. These include benefit-cost ratios, cost-effectiveness ratios, and internal rates of return. It is often important to consider also payback periods for projects because this metric is often used by customers for decision-making. The following provides a description of these measures, guidance on how they are calculated, and a discussion of their advantages and disadvantages compared to NPV.

4.4.1 Net Present Value

NPV allows for the expression of streams of costs and benefits over time in their equivalent present day value and for comparison to one another. NPV sums the discounted value of net benefits, which are accrued over a specified period. An NPV greater than zero indicates that the benefits outweigh the costs of the project. A project is considered admissible if its NPV is greater than zero. Among admissible projects, the preferred project is the one with the highest NPV. A

[18] See, for example, Rosen H. S. and T. Gayer, *Public Finance*, 8th Edition (New York: McGraw-Hill/Irwin 2008), 158.

utility may not always be able to implement the preferred option because of political or other constraints. Ideally, these constraints would be incorporated in the analysis as an additional set of costs. In practice, they may be applied separately from the analysis as a limit on the choice of policies available to the utility.

The NPV is calculated using Equation 4.7:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+r)^t} \tag{4.7}$$

where B_t is the benefit in year t, C_t is the cost in year t, r is the discount rate, and n is the period of years in the analysis. The period of the analysis, n, is typically equal to the expected life of the new/replacement equipment that is installed as part of the efficiency project.

The advantage of using NPV is that it calculates the total value of the project. Because NPV reflects the actual net benefits that will be earned over time, it allows for a direct comparison of the values of alternative projects. NPV does not, however, reveal the relative advantage of investing a given amount of money in one project over another. Another disadvantage of using NPV is that it may not adequately capture all the factors that play a role in decision-making. NPV does not indicate when benefits begin to outweigh costs, a particularly important consideration for customers.

Combining our examples of costs and benefits from Table 4-1 and Table 4-2, Table 4-4 shows the calculation of NPV, assuming a discount rate of three percent; the resulting NPV is $192,675.

Table 4-4
Example of net present value (in 2015$)

Year	Costs	Benefits	Net	Discounted Net
2015	-$1,000,000	$110,000	$-890,000	-$890,000
2016	-$10,000$420,000	$220,000	$630,000	$203,883
2017	-$10,000	$330,000	$320,000	$301,631
2018	-$10,000	$330,000	$320,000	$292,845
2019	-$10,000	$330,000	$320,000	$284,316
Total	$-30,000	$1,320,000	$1,590,000	$192,675

4.4.2 Benefit-Cost Ratio

The benefit-cost ratio is the ratio of the sum of discounted benefits to the sum of discounted costs of a program over time. A benefit-cost ratio greater than one indicates that the total benefits of the project are greater than the costs.

The benefit-cost ratio (B/C) is calculated using Equation 4.8:

$$B/C = \frac{\sum_{t=1}^{n} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+r)^t}} \tag{4.8}$$

where B_t is benefit in year t, C_t is the cost in year t, r is the discount rate, and n is the period of years in the analysis.

The advantage of using a benefit-cost ratio is that it allows for a quick comparison of the benefits relative to the costs. It also provides a general rate of return for the project, which enables comparisons of the return's alternative investments. The disadvantage of using a benefit-cost ratio is that it does not indicate the magnitude of the total value of the project. A project may have a very large benefit-cost ratio, but a small NPV compared to alternative projects.

4.4.3 Cost-Effectiveness Ratio

The cost-effectiveness ratio provides a measure of the costs associated with saving a specified amount of water. Just as monetary values can be discounted, so can units of water. The cost-effectiveness ratio is the sum of discounted costs over the sum of the discounted water saved (as measured in gallons, cubic feet, acre-feet, etc.) over time.

Cost effectiveness (CE) is calculated using Equation 4.9:

$$CE = \frac{\sum_{t=1}^{n} \frac{C_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{U_t}{(1+r)^t}} \qquad (4.9)$$

where C_t is the cost in year t, U_t the units of water saved, r is the discount rate, and n is the period of years in the analysis.

The cost-effectiveness ratio is a good measure to identify the lowest cost option for reducing resource use. The alternative with the lowest cost per unit of water saved can be identified. The cost-effectiveness ratio does not allow comparison among the total resource savings for each of the alternatives, nor does it include the overall benefits associated with the projects.

4.4.4 Internal Rates of Return

The internal rate of return calculates the discount rate that would make the NPV of the project equal to zero. It is calculated through an iterative process where different discount rates are applied to the NPV equation until the NPV is zero. If market interest rates are less than the internal rate of return, then the project is beneficial.

The internal rate of return finds the value of r that satisfies Equation 4.10:

$$NPV = \sum_{t=1}^{n} \frac{B_t - C_t}{(1+r)^t} = 0 \qquad (4.10)$$

where B_t is the benefit in year t, C_t is the cost in year t, r is the discount rate, and n is the period of years in the analysis.

The advantage of calculating an internal rate of return is that it allows for comparison of the efficiency project with the returns of other investment alternatives. Like the benefit-cost ratio and the cost-effectiveness ratio, the internal rate of return does not provide the total value of the project.

4.4.5 Payback Period

A simple payback period indicates the number of years it takes until the cumulative benefits exceed the cumulative costs of a project. The shorter the payback, the more attractive the project is, particularly for customers with limited funding for capital investment.

The simple payback period is the n that satisfies Equation 4.11:

$$IC = \sum_{t=1}^{n} B_t - AC_t \tag{4.11}$$

where IC represents the initial capital costs, B_t is the benefit in year t, AC_t is the annual cost in year t, and n is the period of years.

If the annual net benefits ($B_t - AC_t$) are the same every year, then Equation 4.12 is used to calculate the simple payback period (SP):

$$SP = \frac{IC}{B - AC} \tag{4.12}$$

The discounted payback is the n that satisfies Equation 4.13:

$$IC = \sum_{t=1}^{n} \frac{B_t - AC_t}{(1+r)^t} \tag{4.13}$$

where r is the discount rate. A discounted payback more accurately reflects the value of future costs and benefits, though the simple payback is the common method currently used by many customers.

4.5 ANALYZING UNCERTAINTY

Water utility planning always has involved some uncertainty—about population growth, climate, input prices, etc.—but uncertainty will likely increase as climate change leads to different hydrological conditions in the future than utilities have faced in the past (Groves et al. 2013). Cost-benefit analyses often require a great deal of information, some of which may not be available. Some future costs may not be known, and the amount of water that can be saved and its value may depend on unknown future conditions. Analysts may be able to estimate the cost of capital, but it may vary over some range. With additional time and resources, the missing information might be obtained. Without those resources, the analyst may need to make assumptions about costs, benefits, and discount rates in order to evaluate a project. Even full-scale analyses conducted over many years, however, will not have perfect information. Therefore, cost-benefit analyses need to include an evaluation of the effects of uncertainty on the results.

These analyses are known as sensitivity analyses because they evaluate whether the conclusions are sensitive to the underlying assumptions. The analysis should address the following assumptions.

- Costs. Good cost data is often easier to obtain than benefit data. The cost of new equipment is often known, and organizations may have good information about labor costs now and in the future. If there is uncertainty about the cost of a project, the analysis should include estimates of the NPV and other measures of the effectiveness of the project over the range of possible costs.

- Benefits. Benefits are often more uncertain. For example, the amount of water a program can save may depend on usage rates in the economy or customer behavior, which can vary over time. In other cases, benefits may not be easily quantified. The analysis may use assumptions for the dollar value of these benefits. As with costs, the analyses should include estimates of the NPV and other measures of effectiveness of the project over a range of possible benefits.
- Discount rates. The cost of capital for a specific organization may not be available. There also may not be a consensus on the value of the social discount rate. The discount rate is a critical value in the analysis and can have a substantial impact on the results. NPV should be calculated over a reasonable range of discount rates.

Given the best information available about costs and benefits, and given an agreed-upon discount rate, the NPV of a project may be positive and greater than the NPVs of alternative projects. But a sensitivity analysis may indicate that the project's NPV may be negative under some circumstances. This may indicate where additional information is needed to improve the analysis, or it may illustrate risks inherent in the project that utilities may be able to overcome with proper incentives.

Sensitivity analysis involves re-running the analysis using alternative assumptions. If a small number of assumptions are to be evaluated, this can be done by changing the individual inputs into the model. For example, the analysis can be run using a discount rate of 2, 3, 4, 5, 6, or 7 percent to explore the impact of the discount rate on the NPV. If, on the other hand, the analysis needs to assess the sensitivity of the results to a large number of assumptions, more advanced software may be required. (Crystal Ball and Analytica are two software packages that can build sensitivity analyses into cost-benefit models.)

4.6 THE TRIPLE BOTTOM LINE

Traditional cost-benefit analyses have focused on the bottom line facing the decision makers: the business, agency, or utility. By also including costs and benefits from the viewpoint of customers and society, the analysis can provide additional perspectives on the impacts of the proposed drought management practices. Another related approach is to evaluate the impact of practices on the triple bottom line. The triple bottom line is an accounting framework that can be used with cost-benefit analyses to promote sustainable policies. In addition to the traditional bottom line of the profit or loss for the utility, a full accounting of the impacts of a drought management practice will also consider impacts on the environmental and society. Environmental concerns include impacts on water and air quality, energy consumption, wildlife, and greenhouse gas emissions. Social concerns include the impact of policies on labor (i.e., utility employees), customers, and the community at large.

A cost-benefit analysis that tracks costs and benefits by perspective can also evaluate the impact of drought management practices on the triple bottom line. To do so, costs and benefits must be assigned to the appropriate "account" (i.e., environmental and social) as well as perspective. The perspectives we consider—customer, utility, and society—overlap with the accounts of the triple bottom line, but they are not identical.

- The customer perspective is a component of social accounts.
- The utility perspective includes labor concerns, which the triple bottom line includes in the social accounts.
- The societal perspective includes environmental accounts as well as the impact of the practices on people other than the utility's customers.

Incorporating both the triple bottom line and multiple perspectives into a cost-benefit analysis can be complex. Potential costs and benefits can be divided by perspective and account, but most analyses will likely use one of these two approaches. The approach used and the level of detail required to evaluate the impact of a plan will depend on the amount of information available; the scope of the plan; and the requirements of the analysis. An example cost-benefit analysis for evaluating alternative drought management practices at a hypothetical utility is presented in Appendix C.

CHAPTER 5
SUMMARY AND CONCLUSIONS

Drought management under a changing climate presents challenges for drinking water utilities; without adequate planning, droughts can reduce water quality, reduce levels of service, and necessitate service cutoffs. Due to climate change, utilities are more likely to face drought, as widespread drought becomes more common, and are more likely to experience increasingly intense droughts, which may affect available supplies and increase demand. Fortunately, drinking water utilities can use a number of tools to help plan for droughts and mitigate their impacts on the utility, customers, and the environment. Cost-benefit analyses let utilities compare approaches and choose a strategy that is best suited for their individual circumstances. A cost-benefit analysis can help utilities choose among best practices, but its results are only as good as its inputs. Utilities need reliable data on the potential impacts of drought, its costs, and the impacts and costs of alternative mitigation strategies. With this information, cost-benefit analyses can be powerful tools to help utilities manage droughts.

This report describes how a cost-benefit analysis may be used in drought planning and the issues and challenges that drinking water utilities face in implementing drought management practices. This summary reviews the three main components of cost-benefit analysis for drought planning: measuring the impacts and costs of drought, evaluating the effects of best practices for mitigating drought, and conducting a cost-benefit analysis. Drawing on the case studies of utility experiences with drought management (but not a cost-benefit analysis), this report then reviews some of the challenges utilities face when planning for droughts. It concludes with suggestions for additional research.

To illustrate the use of a cost-benefit analysis in drought management planning, we present an example cost-benefit analysis for a hypothetical utility in two parts. Appendix C explains our methodology, assumptions, and the results. The details of the analysis are contained in a MS Excel file that is published separately as the 4546 Example Cost-Benefit Analysis. The cost data used in the example are a combination of data provided by partner utilities (presented in Chapter 3 and Appendix D) and additional data identified in the literature. While the 4546 Example Cost-Benefit Analysis is in MS Excel, it is not a template that can be used by a utility to evaluate drought management alternatives. It illustrates the concepts discussed in Chapter 4 and highlights the type of data and supplemental information needed to calculate the value of different drought management practices.

5.1 COST-BENEFIT ANALYSIS OF DROUGHT PLANNING

5.1.1 The Impacts and Costs of Drought

Droughts involve a broad range of impacts and associated costs for water utilities and their customers. These impacts can include reduced water availability, degradation of water quality, and fluctuations in water demand. The effects of drought on water utilities can be divided into five categories:

- Reduced supply of water.
- Increased demand for water.

- Changes in water infrastructure, including water main breaks.
- Degraded water quality.
- Unreliable utility revenue.

Local and regional economies can be affected negatively by drought. Drought can also create or exacerbate public health risks and increase the frequency and size of wildfires. Water utilities may need to modify existing infrastructure or build new infrastructure to ensure reliable water intake and transmission, treat water to meet federal and state drinking water standards, or draw from new water sources, depending on the severity of conditions. Water utilities may see their revenue decline as conservation measures take hold, unless they modify their rates or add drought surcharges to ensure they meet their revenue requirements. Customers may see their water-related charges increase as the costs associated with these impacts are passed on in the form of surcharges or rate increases. New infrastructure projects to alleviate the impact of droughts, such as development of new (or modifications to existing) water conveyances, dams, and levees, can add to the total social cost of water services.

It is unlikely that any one water utility will experience all of these impacts. Drought will affect some areas of the country more than others, and the types of impacts will vary according to the vulnerabilities of those areas. For example, a water utility that draws from a coastal aquifer may need to consider the likelihood of saltwater intrusion, whereas an inland water utility drawing from surface water may be more concerned about declines in the snowpack. When undertaking an assessment of the potential impacts of a drought, it is critical that the water utility addresses the specific issues that affect it, develop accurate cost estimates, and identify who bears the costs. The utility can then incorporate this information into a cost-benefit analysis to represent the unmitigated costs of drought.

5.1.2 Leading Practices in Drought Management

Individuals, utilities, communities, tribes, and states, as well as local, state, or federal government entities, may engage in drought planning and decision-making. In the United States, a majority of the states has developed or is currently developing drought management plans. However, to address drought effectively at the utility scale, utilities themselves must be involved because they are responsible for providing safe and reliable water supplies. Drought management measures are generally most effectively implemented in four stages:

- Mitigation
- Preparedness
- Response
- Recovery

Many of these stages may occur concurrently. To manage drought proactively, utilities need to prioritize risk management, which is precautionary, over crisis management, which is reactionary. Many utilities implement best practices for water resource management even when drought is not occurring. Incorporating risk management into daily operations and regular planning processes can help utilities better prepare for and respond to drought as well as other extreme weather events. Specific actions to mitigate drought include those that increase the water supply, reduce demand for water, and alleviate the impacts of drought. Utilities can opt for different practices within each of these broad categories. A compilation primarily from online sources of about forty examples of demand and supply management practices for addressing drought undertaken by water utilities across the United States is presented in Appendix A. This appendix shows the diversity of drought management practices as well as the wide variation in their costs from utility to utility.

The value of the benefits provided by these practices is often hard to measure. Because effective management helps utilities avoid higher costs due to drought, these avoided costs are a useful measure of the benefits of the practices and can be used as a proxy for benefits in a cost-benefit analysis. Avoided costs could include desalination, imported water, damage to aquifers from overdraw, water hauling, and full elimination of service.

5.1.3 Conducting a Cost-Benefit Analysis

The basic approach of cost-benefit analysis is simple: values are systematically assigned to the costs and benefits of a plan. If a plan's benefits are greater than its costs, it is worth pursuing. When comparing several options, the plan with the largest net benefit is the best alternative. It is crucial that the analysis accounts for all potential costs and benefits, determines when they will occur, and evaluates them in a consistent manner. Utilities will often find it easier to quantify the cost of management practices (e.g., labor hours, equipment, imported water) than the value of the benefits, which may be vague and difficult to measure. A useful measure of the benefits of a drought management practice is the avoided costs associated with the practice. For example, a marketing campaign to encourage residential customers to save water can avoid the need to purchase expensive imported water. The value of the imported water is the benefit of the campaign; if the campaign costs less than the imported water, it should be considered.

The costs and benefits of drought management plans may occur over many years. Future costs and benefits must be discounted to compare them to present values. Discounting adjusts future costs and benefits to reflect their present value (i.e., what they are worth today). The higher the discount rate applied, the lower the present value of future costs and benefits. The discount rate used should reflect borrowing rates on marketable securities of comparable maturity. U.S. Treasury rates are commonly used. The analysis should show how sensitive the results are to the chosen discount rate.

Utilities can use several measures of the value of a drought management practice. The best approach is to calculate the NPV, or the difference between the discounted benefits and costs. Utilities may find other measures useful as well, including the ratio of benefits to costs, cost-effectiveness ratios, and internal rates of return. They also may want to calculate the payback period because this metric often is used by their customers.

To select the option that provides the largest net benefit to society, it is not sufficient for a utility to consider only the impact on its bottom line alone. A more comprehensive approach estimates the net benefit to society as represented by the triple bottom line:

1. The economic impact on the utility and its customers, including changes in revenue and expenses associated with the project.
2. The environmental impact, which includes the effects on water quality, pollution, changes in habitat, and carbon emissions.
3. The social impact, which includes the effects on public health, changes in community attractiveness, and property values.

5.2 CHALLENGES UTILITIES FACE IN IMPLEMENTING COST-BENEFIT ANALYSES

5.2.1 The Cost of Drought Management

Although drought management and planning can avoid the substantial impacts of drought, they are not free. Aurora Water, the Cobb County Water System, Denver Water, the El Dorado Irrigation District, and the City of San Diego all incurred costs in planning for and mitigating the potential impacts of droughts. Utilities may need to pay for customer outreach, reporting and enforcement, increased staff time for planning and other activities, rebates and incentives, forecasting, drinking water and wastewater treatment, and purchasing water from other sources. These utilities also lost revenue and delayed needed maintenance and repairs. The cost of drought planning and mitigation highlights the need for cost-benefit analyses so that utilities can (1) compare approaches; (2) evaluate the trade-offs among preparedness, mitigation, response, and recovery activities; and (3) choose the most cost-effective approach to drought management.

5.2.2 Uncertainty and Lack of Data

As with any tool or model, cost-benefit analyses are only as good as the information and data they use. Utilities may need to commit resources to gathering data, developing new sources of information, and producing estimates for many of their inputs. Information about both the potential impacts of drought and the costs of mitigation efforts is essential.

The cost of drought mitigation can include equipment, material, energy, and labor. Although utilities will generally have good data on their annual operating and maintenance expenses and capital costs, they may not be able to determine the share of the costs incurred by the drought management practice. For example, a marketing campaign used by the City of San Diego to encourage conservation required additional labor hours by utility staff. El Dorado Irrigation District in California committed labor hours to tracking, reporting, and enforcement efforts to ensure that customers met the mandatory water use restrictions. Ideally, the cost-benefit analysis would include only those additional hours (the marginal cost of the plan), but the utility's accounting system may not distinguish between hours spent on the marketing plan from other activities. Utilities may need to estimate these costs, often using rules of thumb rather than precise measures.

Several factors complicate the characterization of drought impacts. Unlike hurricanes, earthquakes, and other natural disasters, there is no universal, quantifiable definition of a drought. The conditions defining drought vary by location. Each sector that relies on water resources will have different thresholds to determine when there is a drought. This lack of clear and consistent criteria makes it difficult to identify the beginning and end of a drought and poses a challenge for collecting and analyzing data that could help characterize drought impacts. The duration and extent of a drought is also uncertain. In some cases, the uncertainty inherent in defining when a drought is occurring and thus when or for how long a response is necessary can be minimized by taking advantage of lessons learned during past droughts affecting a specific utility. The Cobb County Water System in Georgia was forced to react to the 2006–2009 drought, but the utility was able to use lessons learned to help plan responses to the 2010–2012 drought. Another way to overcome uncertainty is through modeling to understand relevant trends. El Dorado Irrigation District in California used a sophisticated model to evaluate fluctuations in supply and demand as well as other factors. Not all utilities will have access to such models, however.

The value of the drought mitigation efforts depends on the potential impacts of the drought. These impacts are uncertain and difficult to measure. Placing a dollar value on risk reduction is difficult, and utilities may need to rely on softer, qualitative measures of the value of their drought plans.

5.2.3 External Constraints

When collaborating with other utilities or local, regional, or state agencies to implement a drought management practice, utilities may find it challenging to separate their share of the costs and benefits from those incurred by collaborating agencies. For example, the City of San Diego Public Utilities Department is one of many utilities in San Diego County that will be augmenting their water supply with water from the Carlsbad desalination plant. Because the plant is being constructed by the San Diego County Water Authority, documentation of capital and operating costs exist only at the county scale. The City of San Diego does not have costs associated with this project, but it will receive part of the benefits. One potential way to apportion the costs and benefits would be based on the number of service connections or population served. This method, however, does not account for other factors that may influence costs and benefits, such as whether the utility has abundant existing supplies or is relying on a dwindling water supply.

Utilities are also subject to social and political constraints that lie outside the limits of a cost-benefit analysis. Upon selecting an appropriate drought management practice using a cost-benefit analysis, a utility may still be limited in its ability to implement that practice due to political pressures or social perspectives. For example, a direct potable reuse project, which may be a viable option for addressing water shortages under long-term drought, may be challenging for a utility to implement due to the generally low social acceptance of potable reuse. Similarly, political conditions may constrain public utilities' options. Elected officials may have promised not to implement drought restrictions until drought worsens to a certain stage, potentially forcing the utility to eliminate a drought management practice with the maximum net benefit. Similarly, state or regional mandates during drought periods may require utilities to prioritize practices that their analysis indicates do not have the highest net benefit.

5.2.4 Planning for the Future

Successful drought planning and mitigation can be integrated into normal operations, promoting long-term efficient water use, as in El Dorado Irrigation District and at many other utilities. Long-term conservation efforts potentially lock in place lower water sales that are a result of drought-related conservation plans. Water sales may remain below pre-drought levels after the drought ends due to short-term drought response, as in Cobb County Water System. Therefore, although utilities may be able to reduce costs, they likely will need to restructure their rates to ensure that they continue to meet their revenue requirements.

As states and other regional agencies develop their own drought management plans, utilities may need to align their own plans with the state, other utilities, and other authorities, as the Cobb County Water System and the City of San Diego must do. They also need to adapt to and take advantage of emerging technologies, including new means of communicating with their customers.

5.3 AREAS FOR FUTURE RESEARCH

This study identified gaps in available information, policy approaches, and challenges facing utilities that warrant additional research. Potential topics for future research include:

- Additional case studies on specific issues facing utilities and their policy responses.
    - One set of case studies should focus on short-term responses to droughts, including temporary service shut-offs, trucking water, or use of interconnections to purchase water from other suppliers.
    - Another set of studies should focus on long-term responses. These may include the development of alternative water sources such as direct potable reuse or desalination as well as long-term market transformations, including the permanent removal of lawns or the elimination of service to some sectors.
- The short- and long-term impacts of droughts on agriculture and how agricultural demand affects urban water service in times of shortages.
- The roles played by municipal, state, and regional drought management plans and their impacts on the ability of local utilities to plan for and respond to droughts.
- Using the lessons learned from our case studies of utility experiences with drought management (but not a cost-benefit analysis), identify the specific information required to conduct a full analysis of drought management practices, identify a utility with sufficient data, and implement a full cost-benefit analysis.
- Conduct a more thorough exploration of regional issues related to drought planning and assess how best practices can be shared among utilities in a region.
- Collect data from regional or national samples of utilities regarding their drought management practices to paint regional and national pictures of best practices. The information to collect would address the following questions:
    1. Which programs and projects do utilities implement that are specifically designed to address drought?
    2. Which programs and projects do utilities use that may be a part of an overall water resource management strategy (i.e., not specifically designed to address drought) but that may improve the utility's resilience to drought?
    3. Do utilities collaborate with other utilities, or state, local, or regional entities to implement drought management initiatives? The survey should explore which practices are collaborative efforts; the names of the collaborators; and the contributions to the drought practice (i.e., financial resources, labor/manpower, materials, etc.) in each case.
- Explore ways to get utilities to interact and share information, perhaps by developing a set of brief but direct questions that a larger sample of utilities could be asked.

This study explored the use of cost-benefit analysis for evaluating alternative drought management practices. It identified best practices and the types of projects and activities utilities use to plan for and respond to drought and the issues that they face. The proposed additional research would help develop a more complete picture of challenges and opportunities utilities face when planning for drought and the role that cost-benefit analyses can play in promoting sustainable polices in the face of global climate change.

APPENDIX A
EXAMPLES OF COSTS OF UTILITY-SPECIFIC DROUGHT MANAGEMENT PRACTICES

The following table is a compilation of examples of drought management practices employed by drinking water utilities across the United States as identified in the literature (mostly online sources). The examples are identified as either demand management or supply management, and are categorized by type of drought practice (e.g., voluntary conservation, public outreach) according to the topics discussed in Chapter 2. Costs reported in the following tables are presented as real values in 2014 dollars.

Table A-1
Examples of costs of utility-specific drought management practices

Water System	Location (City, State)	Drought Management Practice	Description	Cost to Utility	References
Demand Management					
Desert Water Agency (and/or Coachella Valley Water District)	Palm Springs, CA	Voluntary conservation	Utility offers rebates to customers who replace turf with desert landscaping.	Cost of rebate program: $1 million	James 2014
Edwards Aquifer Authority (EAA)	San Antonio, TX	Voluntary conservation	Authority has created a Voluntary Irrigation Suspension Program Option, which offers cash payments for either 5- or 10-year agreements from large irrigators to not pump water. EAA has secured agreements to conserve 39,000 acre-feet annually. This option is triggered when well levels within the aquifer hit pre-determined levels.	Cost of rebate program: $8 million (during 2014)	Huddleston 2014
El Paso Water Utility	El Paso, TX	Voluntary conservation	City is paying citizens $1 per square foot of lawn removed and replaced with gravel, cement, or desert plants.	Cost of rebate program: $11 million (since 1979)	Ball 2011
Metropolitan Water District	Southern CA	Voluntary conservation	Water district offered rebates for residents and businesses to replace turf with drought-tolerant landscaping and for installing water-efficient fixtures.	Cost of running conservation program: $18.6 million (July 2013-July 2014); $17.1 million (July 2014-December 2014)	Stevens 2014

(continued)

Table A-1 (Continued)

Water System	Location (City, State)	Drought Management Practice	Description	Cost to Utility	References
Metropolitan Water District	Southern CA	Public outreach	Water district created outreach campaign promoting conservation on radio, TV, and in print.	Cost of conservation outreach campaign: $5.5 million	Zimmerman 2014
Santa Clara Valley Water District	San Jose, CA	Voluntary conservation	Utility is targeting a 10 percent reduction in water usage.	Cost of outreach and enforcement: $5.9 million	Rogers 2014a
Santa Clara Valley Water District (SCVWD)	San Jose, CA	Public outreach	SCVWD conducted public outreach to ask people to conserve water.	Cost of public outreach conservation effort: $1 million	Rogers 2010
Supply Management					
Aurora Water	Aurora, CO	Investment in infrastructure or water sources	City utility constructed a purification plant to take water from the South Platte River, downstream of the Denver Metro, and treated it with filtration and ultraviolet light.	Cost of constructing purification plant: $709 million	Illescas 2010
Cambria Community Services District	Cambria, CA	Alternative supply augmentation approaches	Utility is constructing a desalination plant.	Cost of constructing desalination plant: $9.13 million	Covarrubias 2014
Central Arizona Water Conservation District (CAWCD)	AZ	Alternative supply augmentation approaches	CAWCD conducted cloud seeding by blasting silver iodide into clouds to increase snowfall over CO, UT, and WY, and to ultimately contribute to the snowpack feeding the Colorado River.	Cost of cloud seeding: $800,000	Dale 2014
City of Aurora	Aurora, CO	Alternative supply augmentation approaches	City constructed a water recycling system that can treat 50 million gallons of water daily.	Cost of constructing water recycling system: $710 million	Lynn 2013
City of Hays	Hays, KS	Alternative supply augmentation approaches	City implemented a cloud seeding project in the spring of 2014 to improve the chance of rainfall by an estimated 10–15 percent.	Cost of cloud seeding: $300,000	City of Wichita Falls 2014

(continued)

Table A-1 (Continued)

Water System	Location (City, State)	Drought Management Practice	Description	Cost to Utility	References
City of Las Vegas	Las Vegas, NM	Investment in infrastructure or water sources	City built a new diversion on the Gallinas River (primary source water supply) that can access lower river flows more efficiently than the original structure (built in 1890). The diversion screens out debris that would otherwise enter the City's intake pipe.	Cost of building new diversion: $1.5 million	Matlock 2012
City of Odessa	Odessa, TX	Investment in infrastructure or water sources	City is expanding production from well fields from 45 MGD to 65 MGD.	Cost of expanding well fields: $38 million	Miller 2014
City of Odessa	Odessa, TX	Investment in infrastructure or water sources	City spent $1.475 million on study on well drilling to tap Capitan Reef Aquifer in Fort Stockton. The City will determine water quality to see if it will be cheaper to treat this source of brackish groundwater than other available sources.	Cost of drilling well(s) and associated treatment study: $1.475 million	Toledanes 2012
City of Round Rock	Round Rock, TX	Purchasing or hauling water	City is purchasing water from the Brazos River Authority to further diversify water sources.	Cost of purchasing water: $1.7 million for fiscal year 2015	Pena 2014
City of San Angelo	San Angelo, TX	Investment in infrastructure or water sources	City invested in new wells, well field upgrades, and treatment upgrades to expand activity in the Hickory Aquifer. This will allow the City to take full advantage of its annual allocation and banked water. A total of 12 new wells are to be drilled.	Cost of drilling wells and constructing treatment plants: $120 million	City of San Angelo 2015
City of Wichita Falls	Wichita Falls, TX	Alternative supply augmentation approaches	Awaiting approval to recapture 5 MGD of treated wastewater effluent to mix with 5 MGD of reservoir water, which will then be retreated and used as drinking water.	Cost of pipeline to connect wastewater treatment facility to existing treatment plant: $9 million	Campbell 2014
City Utilities	Springfield, MO	Purchasing or hauling water	City constructed the Nuccitelli Pipeline to draw water from Stockton Lake.	Cost of constructing pipeline: $40 million	Johnson 2012
Colorado River Municipal Water District (CRMWD)	Big Spring, TX	Alternative supply augmentation approaches	CRMWD constructed new water reclamation plant in Big Spring and a new pipeline to increase its available water supply.	Cost of constructing water reclamation plant and related pipeline: $79 million	Mueller 2012

(continued)

Table A-1 (Continued)

Water System	Location (City, State)	Drought Management Practice	Description	Cost to Utility	References
East Bay Municipal Utility District	Oakland, CA	Purchasing or hauling water	Utility district, in partnership with a nearby county, built a pipeline to tap water from the Sacramento River in order to diversify its raw water sources.	Cost of constructing pipeline: Nearly $1 billion	Weiser 2014
East Bay Municipal Utility District	Alameda and Contra Costa counties, CA	Purchasing or hauling water	Utility district is using pipeline to divert 16,000 acre-feet of water from the Sacramento River for 2 months, May and June.	Cost of pumping and treating water from the pipeline: $8 million	Weiser 2014
El Paso Drinking water utilities	El Paso, TX	Alternative supply augmentation approaches	In order to diversify raw water supplies and continue to meet demand, the constructed the Kay Bailey Hutchison Desalination Plant, which treats water from a saline aquifer.	Cost of constructing desalination plant: $91 million	Galbraith 2012
Escondido City	Escondido, CA	Alternative supply augmentation approaches	City is building an indirect potable reuse (IPR) system to treat all of the city's wastewater for use in irrigation. Wastewater is treated using ultrafiltration and ultraviolet light.	Cost of constructing indirect potable reuse system: $285 million	Sangree 2014
Hendersonville Utility District	Henderson-ville, TN	Investment in infrastructure or water sources	Utility constructed new water treatment plant.	Cost of constructing water treatment facility plant: $25 million	Yankova 2014
Illinois American Water	East St. Louis, IL	Investment in infrastructure or water sources	Utility is extending the raw water intake, which will allow the water treatment plant access to raw water if the water level in the Mississippi River falls during drought.	Cost of investing in water treatment plant: $400,000	JournalStar Staff 2012
Irvine Ranch Water District	Irvine, CA	Alternative supply augmentation approaches	Utility is constructing a recycled water storage facility to store excess recycled water that is not used during the winter (due to lower demand) for use in irrigation during the summer, when irrigation demand is high.	Cost of constructing recycled water storage facility: $70 million	Madans 2014
Laguna Madre Water District	South Padre Island, TX	Alternative supply augmentation approaches	Water district built a 1 MGD desalination plant. The plant will be the first in Texas to use seawater as a raw water source.	Cost of constructing desalination plant: $13 million	Mashhood 2012

(continued)

Table A-1 (Continued)

Water System	Location (City, State)	Drought Management Practice	Description	Cost to Utility	References
Long Beach	Long Beach, CA	Purchasing or hauling water	City is constructing a well to tap the West Coast Groundwater Basin, which will decrease the city's dependence on imported water from 40% to 30%.	Cost of constructing well: $2 million	Madans 2014
Long Beach Water Department	Long Beach, CA	Investment in infrastructure or water source	Since 1998, utility invested approximately $100 million to replace older cast iron piping, which is prone to breaks than more reliable ductile iron piping. On average, the department replaces 107,000 linear feet of cast iron piping per year. The average number of water main breaks per year has fallen from over 130 to 30.	Cost of infrastructure upgrades: $100 million	Long Beach Water Department 2015a
Long Beach Water Department	Long Beach, CA	Alternative supply augmentation approaches	Utility drilled 4 aquifer storage and recovery (ASR) wells, which can both inject and withdraw water from an aquifer. The project will store up to 4.2 billion gallons of water in wet years for use in drought years. The project also helps prevent saltwater intrusion into groundwater supplies.	Cost of drilling well(s): $4.5 million	Long Beach Water Department 2015b
Lower Colorado River Authority (LCRA)	Austin, TX	Alternative supply augmentation approaches	Utility is constructing a reservoir to capture and store rainwater from parts of state where there is greater rainfall. The reservoir will add 90,000 acre-feet per year of supply.	Cost of constructing reservoir: $215 million	Urbaszewski 2014
LCRA	Austin, TX	Investment in infrastructure or water source	LCRA is building five new wells at Lone Pines Power Park.	Cost of drilling well(s): $15 million	KVUE Staff 2014
Northern Water Conservation District	Northern CO	Investment in infrastructure or water source	A regional water supply project, this project would add 215,000 acre-feet of storage by building new reservoirs and diverting surface water sources.	Cost of constructing reservoir: $490 million	Finley 2012

(continued)

Table A-1 (Continued)

Water System	Location (City, State)	Drought Management Practice	Description	Cost to Utility	References
Orange County Water District	Orange County, CA	Alternative supply augmentation approaches	Utility district is using recycled water to recharge groundwater. Improvements at the recycled water plant will provide an additional 30 MGD for recharge and other uses.	Cost of constructing new infrastructure: N/A	Madans 2014
Sacramento Metropolitan Utility District	Sacramento, CA	Alternative supply augmentation approaches	Utility deployed planes to seed clouds with chemicals in an effort to increase precipitation. Officials estimate a 7–10 percent increase in precipitation from spring storms from the effort.	Cost of cloud seeding: $250,000 in 2014 and 139,500 in 2015	DuHain 2014 and Weiser 2013
San Antonio Water System	San Antonio, TX	Purchasing or hauling water	Water system is entering an agreement with two private companies, who will construct a wellfield, pipeline, and associated treatment to tap an aquifer in Burleson County (140 miles away) and deliver 16 billion gallons of treated water per year. The pipeline is needed to diversify water sources and allow for population growth.	Cost of constructing wellfield, pipeline, and treatment: $3.4 billion	Satija 2014a
San Diego County Water Authority	San Diego, CA	Investment in infrastructure or water sources	Water authority enlarged the San Vicente Dam and reservoir to hold an additional 152,000 acre-feet to decrease region's dependence on Metropolitan Water District by storing water in wet years, as well as to provide a backup in case an emergency such as an earthquake disrupts other supplies.	Cost of enlarging the San Vincente dam and reservoir: $838 million	Perry 2014
South Coast Water District	Dana Point, South Laguna, San Clemente, and San Juan Capistrano, CA	Alternative supply augmentation approaches	Utility is constructing a new seawater desalination plant that will provide 5 MGD, with potential to expand the plant to 15 MGD. This project will help reduce the reliance of the utility on imported water.	Cost of constructing plant and wells: $50-70 million initially + $75-100 million for expansion	Madans 2014

APPENDIX B
SAN DIEGO USES COST-BENEFIT ANALYSIS FOR WATER RESOURCES MANAGEMENT

The City of San Diego Public Utilities Department manages one of the largest water treatment and supply systems in the nation, delivering 200 million gallons of water per day (MGD) to its 1.3 million customers. The City of San Diego Public Utilities Department's wastewater system serves over 2 million users in San Diego County. Approximately 74 percent of the drinking water delivered to consumers originates from imported sources purchased from the SDCWA. One of these sources is the Colorado River Basin, which is suffering from a 12-year drought and record low water levels. The second source is the Sacramento-San Joaquin River Delta, where water withdrawals have been significantly reduced since 1991 by court rulings to protect valuable fisheries and accommodate other agricultural, urban, and environmental demands. Together, these factors have resulted in allocation limits that add a strain to SDWA's water supply.

Given its heavy reliance on imported water, an ongoing statewide drought, and projected climate change source water impacts, the City of San Diego Public Utilities Department published the 2012 Long Range Water Resources Plan (LRWRP) to help decision makers manage the city's water resources through 2035. The City of San Diego Public Utilities Department has assessed costs and benefits, which illustrate many of the elements necessary for evaluating drought management practices identified in this report.

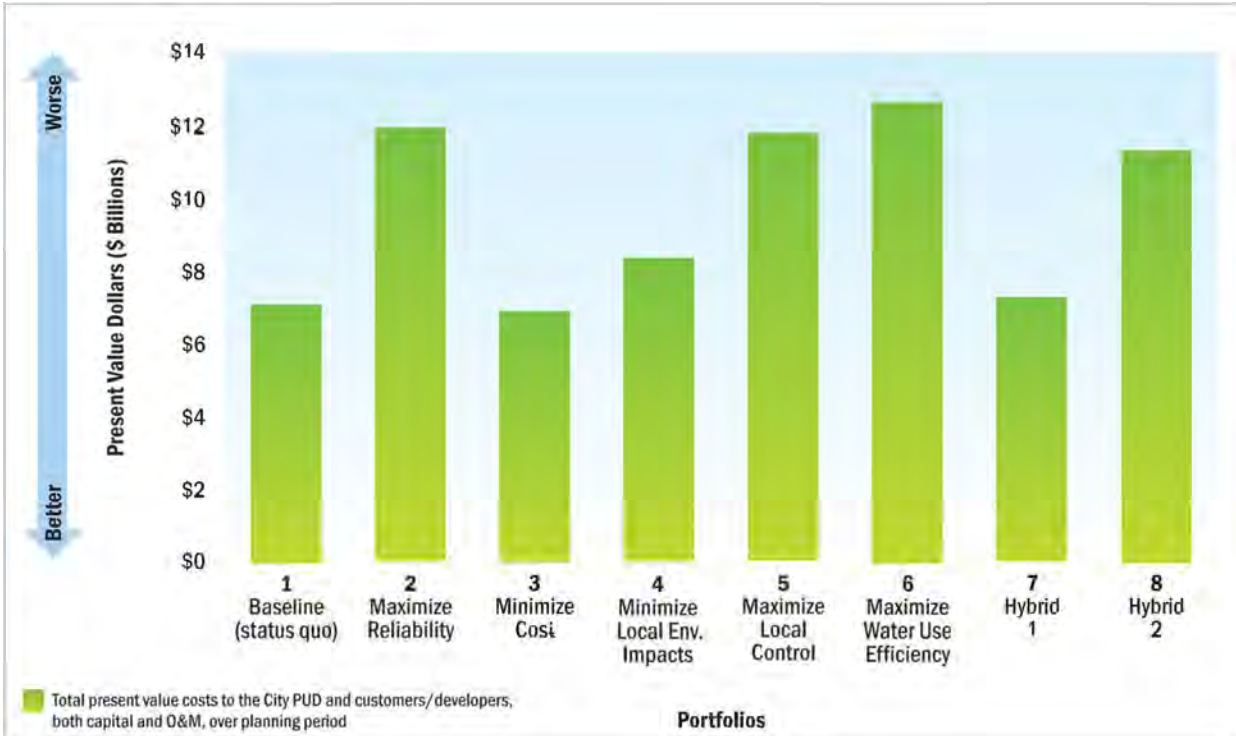
Table B-1
Key economic values used to calculate annual costs of each portfolio

Economic Assumption	Value	Exceptions
Inflation rate	3% annually	Expected annual increases for imported water rates: 6% through 2016; 4.5% from 2014–2020; 3% from 2021–-2035
Capital loan interest rate	5% annually	--
Capital loan repayment period	30 years (amortized at 5.5%)	--
Capital cost amortization rate	5.5% over 30 years	--
Capital discount rate	5% annually	--
Discount period	25 years	--

Source: Data from City of San Diego Public Utilities Department 2013.

The City of San Diego Public Utilities Department evaluated monetary costs only and compared the costs of all portfolios against the cost of the status quo. Table B-1 shows key economic metrics used to calculate annual costs of each management portfolio.

Figure B-1 provides the final costs for each portfolio in present value (PV). The City of San Diego Public Utilities Department conducted sensitivity and climate change analyses to determine the robustness of each cost estimate in Figure B-1. Based on the results of these analyses, the City of San Diego Public Utilities Department determined that portfolios 7, 8, and 6 (Hybrid 1, Hybrid 2, and Maximum Water Use Efficiency, respectively) consistently scored highest in the cost-benefit analysis. The City of San Diego Public Utilities Department developed a strategy that uses a phased approach to implement these three options.



Source: Figure developed by CDM Smith for City of San Diego Public Utilities Department 2013.

Conservation portfolios are labeled 1 through 8. Portfolio 7 ("Hybrid 1") is equal to Portfolio 3 with an additional indirect potable reuse project. Portfolio 8 ("Hybrid 2") is equal to Portfolio 6 with an additional groundwater project, but removing non-potable reuse with satellite treatment plants, graywater, and centralized stormwater capture.

Figure B-1. Portfolio scores for total present value costs over planning horizon

APPENDIX C
EXAMPLE COST-BENEFIT ANALYSIS FOR EVALUATING DROUGHT MANAGEMENT PRACTICES FOR A FICTONAL UTILITY

Introduction

To demonstrate the feasibility of using the cost-benefit analysis framework to evaluate and compare drought mitigation practices, the study team developed a stylized example, called the Example Cost-Benefit Analysis. The cost data used in the example are a combination of data provided by partner utilities (presented in Chapter 3 and Appendix D) and additional data identified in the literature. The majority of costs and benefits used in the analysis were reported by the participating utilities[19] and modified to provide a coherent cost-benefit analysis example for a fictional utility. When the utilities were unable to provide specific information required for a cost-benefit analysis,[20] the study team made assumptions based on publicly available information to provide a reasonable estimate of costs and benefits. The specific assumptions for each drought mitigation practice are described below.

The Example Cost-Benefit Analysis for a hypothetical utility is presented in two parts. Appendix C explains the methodology, assumptions, and the results. The details of the analysis are contained in a MS Excel file that is published separately as the 4546 Example Cost-Benefit Analysis. The Example Cost-Benefit Analysis is in MS Excel format, but it is not a template that can be used by any utility to evaluate its proposed practices. Drought management planning using a cost-benefit analysis usually requires substantial amounts of utility specific information, which may not be readily available, and the data needs and availability can vary a great deal across utilities. The goal of the Example Cost-Benefit Analysis spreadsheet is to demonstrate how the concepts described in the Chapter 4 can be used to select a drought management practice, the type of data and information needed, and the calculations required to measure the value of the projects.

The Example Cost-Benefit Analysis includes costs and benefits over a 30-year period. For programs or assets that will last longer than 30 years, such as reservoirs, our analysis includes the present value of the costs and benefits for the full life of the program or asset. The spreadsheet shows the costs and benefits in the year in which they occur. The analysis is conducted in real terms, removing the effect of inflation, which is a change in the overall price level. The spreadsheet allows for real growth in costs and benefits over time, i.e., the spreadsheet will increase the value of a cost or benefit over time if it grows faster than inflation. It discounts future costs and benefits to calculate the net present value (i.e., what it is worth today) of each option. It also calculates the cost per gallon and the benefit-cost ratio of each drought management practice. In addition to these quantitative measures, the spreadsheet includes qualitative measures of the impacts of drought

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[19] Cost data on water resource management practices were collected from participating water utilities between December 2014 and March 2015. The data collected included costs of programs designed to mitigate or respond to drought. The precise amounts dedicated to drought mitigation and response were not always discernable from costs associated with other water resource management activities.

[20] No single utility was able to provide cost information for all the drought management practices evaluated in this example cost-benefit analysis. Therefore, cost data used in the example cost-benefit analysis are a combination of data from different utilities (presented in Appendix D) and have not been specifically attributed to any of the utilities that provided data. Rather, a hypothetical utility is used in this cost-benefit analysis example.

management practices that are difficult to quantify (e.g., service reliability, sustainability, employment). The analysis evaluates the impacts (costs and benefits) of drought management practices on the utility, its customers, and society as a whole and shows the impact on the triple bottom line (i.e., the impact on the utility, the environment, and society as a whole, as discussed in Chapter 4). The spreadsheet also includes an analysis of the sensitivity of the results to the discount rate.[21]

The Fictional Water Utility

The example cost-benefit analysis is conducted for a fictional utility that serves a large city, serving 1 million persons. The city relies on two sources of water: a local surface water source and a groundwater source. It can purchase water from a regional wholesale supplier. In response to projections of a drier climate in the future than in the past, the utility is considering implementing several water efficiency measures. It also expects a drought of 1 year in duration or longer in the next 10 years that would affect both its local surface water supply and the safe yield of its aquifers. (Our analysis assumes a drought occurs in 5 years and again every 10 years afterwards.) Without drought mitigation activities or alternative sources, the utility plans to address anticipated water shortages by purchasing additional water from the regional wholesaler.

The cost-benefit analysis weighs each alternative drought practice against the cost of purchasing treated water from the regional wholesaler. The cost of the purchased water is $1,100 per acre-foot or $3,376 per million gallons (MG). The utility can avoid this cost if it implements drought management practices. The cost-benefit analysis assumes the base demand for water (i.e., absent any conservation or water efficiency programs) is an average of 540,000 MG per year.

Proposed Drought Mitigation Practices

The utility is considering several responses to future droughts. These include developing alternative sources of water and encouraging conservation. The following list describes the basic features of each proposed drought management practice.

- **The Water Storage Reservoir** is a new off-stream storage reservoir, intended to supplement the utility’s water supply during drought. It can provide 32 MGD for 30 days (or 960 MG total) and refills during non-drought years. It is assumed that annual O&M cost is 5 percent of the initial capital cost to build the reservoir and that the reservoir will have a life of 50 years before significant retrofit expenses are required. The utility would fill the reservoir over a 5-year period using local supplies. (The drought years, when the utility would draw down the water in the reservoir, are highlighted in bold in the 4546 Example Cost-Benefit Analysis spreadsheet.)
- **The Leak Detection/Repair Program** requires start-up costs that include purchasing leak detection and other equipment, developing a system map, and developing a program plan. Costs per repair include costs of infrastructure (pipes, etc.), material, and labor. The program is ongoing, and the benefit of the program

[21] The discount rate accounts for the time value of money (see Chapter 4), i.e., a dollar earned in the future is worth less than a dollar earned today. The discount rate allows us to calculate the present value of goods and services in the future.

is the water efficiency achieved by the water main repairs. The repairs last for 20 years and the benefits accumulate over the life of the repairs. Reinvestment in the equipment will occur after 20 years.

- **Rebate Programs** are assumed to require no start-up costs. Annual O&M costs cover labor and materials (e.g., program outreach and rebates) to the utility as well as to the customers, who pay a portion of the cost of the product that is not covered by the rebate. The program is ongoing, and benefits consist of improved water efficiency and conservation by the utility's customers. Benefits accumulate over all 30 years of the analysis.
- **The Rainwater Harvesting Program** requires no start-up funding. Annual O&M costs are the cost of purchasing barrels, which are provided by the utility to customers free of charge. Barrel capacity is 55 gallons, and a barrel refills approximately 25 times during a drought year. In order to receive a rain barrel, customers must attend an informational meeting about water conservation. Thus, the program is primarily used by the utility to educate customers and promote awareness of water conservation, rather than to harvest large quantities of water. The program is ongoing, and the benefits consist of minor water savings and improved awareness of conservation options. It is assumed that the barrels will last for 20 years.
- **The Purchase of Reclaimed Water** from existing wastewater treatment plants would supplement the utility's water supply. The cost-benefit analysis includes an option to purchase reclaimed water from existing water reuse plants operated by the wastewater treatment agency. The analysis uses only the costs to conduct tertiary treatment and delivery of the water for beneficial use. In the example, more water is treated annually than is delivered during non-drought years. It is assumed that the water utility will purchase the reclaimed water at a price that reflects the unit cost of production of all water undergoing tertiary treatment, but will only pay for the water actually delivered. It is assumed the balance of the unused reclaimed water is returned to surface sources, thereby providing a social benefit. We assume the value of this benefit is equal the cost of treating the water. The cost and benefit of this additional water are reflected in the social costs, but are not borne by the utility. The analysis assumes the utility will purchase all of the reclaimed water during drought years. (These years are highlighted in bold in the 4546 Example Cost-Benefit Analysis spreadsheet.) The analysis also assumes the cost of the additional treatment includes additional energy costs and costs of related increases in carbon emissions. The cost of these emissions is not borne by the utility, but does affect the environment. (See below for a discussion of how the analysis estimates the cost of carbon emissions.)
- **The Conversion of an Existing Wastewater Treatment Plant into a Water Reuse Plant** is another potential source of supply. This option includes an initial capital expense to convert the plant, which will produce approximately 6 MGD. During drought years, the utility will use all of the reclaimed water produced by the plant. (As with the existing plants, drought years are highlighted in bold in the 4546 Example Cost-Benefit Analysis spreadsheet.) In other years, the utility will use 1 MGD for non-potable use. As with the existing water reuse plants operated by the wastewater treatment agency (discussed above), the remaining 5 MGD is

discharged into the local surface supply, which is considered a social benefit in the cost-benefit analysis. The analysis also assumes the cost of the additional treatment includes additional energy costs and costs related to increased carbon emissions.

- **A Desalination Plant** provides another alternative source of water. The option to purchase water from a desalination plant includes the amortized capital cost and annual O&M cost of purchasing 18,248 MG of water per year. Capital costs include costs of constructing the plant and a conveyance pipeline, and pumping costs. O&M costs include costs of treatment, labor, and ongoing maintenance. The analysis assumes that the utility enters an agreement with the desalination plant to purchase an agreed-upon quantity of water over a 30-year period. As with the water reuse plants, the analysis assumes the desalination plant will increase carbon emissions. As with treatment for water reuse, the cost of these emissions is not borne by the utility, but does affect the environment.
- **Ongoing Outreach** consists of activities that the utility would regularly conduct to promote water efficiency and conservation among its customers. The program includes promoting ongoing rebate, retrofit, and landscaping programs, and the development and implementation of water conservation education programs. Benefits of ongoing outreach consist of a reduction in water demand, which will accumulate over the 30 years of the analysis.
- **Emergency Outreach** activities are specific temporary measures that are implemented during a drought and include costs related to labor, materials, and enforcement. Examples of activities that fall under emergency outreach are development of outreach materials, communication, enforcement of water use restrictions, and implementation of advertising campaigns. Benefits of emergency outreach consist of a reduction in water demand, and they are only realized during the years in which the outreach program is implemented.
- In **the Commercial Conservation Program**, the utility conducts water audits of commercial customers to identify potential improvements in water efficiency. The process is labor intensive for the utility and includes on-site inspections and phone calls. Following the program, businesses implement retrofits or improve their processes to achieve water savings. The cost to the utility is the cost of labor for conducting the audits, but the cost to commercial customers to implement the changes is unknown. Benefits consist of a reduction in water demand and accumulate over all 30 years of the analysis.
- **The Residential Retrofit Program** includes the distribution of retrofit kits to residential customers. The kits include simple supplies to improve water efficiency, such as low-flow showerheads and faucet aerators, and provide water-saving tips. Benefits consist of a reduction in water demand and accumulate over all 30 years of the analysis.
- **The Landscaping Program** promotes water-efficient landscapes by paying customers to replace turf with native plants, mulch, or permeable pathways. The utility pays $3.75 per square foot for the first 1,500 square feet of turf replaced, and $2.00 per square foot thereafter for every additional square foot that is converted. The analysis assumes the cost of landscaping is $4.00 per square foot, with the balance of the cost paid by the customers. Each square foot converted from turf is estimated to save approximately 25 gallons per year, and the average plot is

estimated to be 2,400 square feet. Benefits consist of a reduction in water demand and accumulate over all 30 years of the analysis. The customer also receives aesthetic value from the landscape, which is assumed to equal the cost of the landscaping, less the water savings. This benefit is included in the social value of the program.

- **The Conservation Rate Design** consists of a one-time cost for the cost-of-service and rate analysis. The benefit of the rate change is the total expected reduction in water sales and carries over all 30 years of the analysis. The analysis assumes the rate design is revenue neutral—i.e., it does not increase average costs for customers.

Drought management practices that provide alternative water sources also incur energy costs to treat and distribute water. Therefore, carbon emissions resulting from water reuse and desalination are included in the cost-benefit analysis example as environmental costs. Carbon emissions were estimated using industry-generated energy use estimates per MG for each type of water treatment and the typical output of carbon representative of a power provider in Southern California. It is estimated that tertiary wastewater treatment produces approximately 1.4 to 2.0 metric tons of carbon dioxide (CO_2) per MG of water produced and that a desalination plant produces approximately 2.7 to 3.8 metric tons of CO_2 per MG of water produced. These emissions are monetized using EPA's social cost of carbon of $41.50 per metric ton of CO_2 (EPA 2013).

Evaluation of Costs and Benefits from Three Alternative Perspectives

The analysis evaluates the costs and benefits of each drought management practice from three different perspectives:

- **The utility perspective** includes all costs and benefits that accrue to the utility. Costs include the cost of labor and capital costs, as well as subsidies or rebates the utility may pay to encourage customers to use water efficiently. The benefits include the value of water saved, which is expressed as the avoided cost of water purchased from a regional supplier. Future costs and benefits are discounted using the utility's weighted average cost of capital. (The real cost of capital is assumed to be 3 percent per year for this analysis.)
- **The customer perspective** includes costs and benefits of the program for the customer. If the customer pays for drought-resistant landscaping, for example, the cost to the customer includes the material and labor costs of the new plants. The benefits include the water savings, priced at the average rates charged to customers. We assume the discount rate for customers is higher than for utilities because their borrowing costs are higher. (The discount rate is assumed to be 4 percent for customers in the analysis.) Some utility costs or benefits may be passed on to the customer by the utility; in that case, the cost shows up in both perspectives. For example, the price the utility pays for reclaimed water may be passed through to the customer. The analysis includes the cost in both perspectives to understand the impact it has in each case.
- **The social perspective** includes all costs and benefits borne by society. It includes costs and benefits borne by both the utility and the customers, as well as other social effects, including impacts on the environment. Costs and benefits passed from the

utility to the customer are not double counted. For example, while the cost of reclaimed water appears in both the utility and customer perspectives, it is counted only once for society as whole. The social discount rate is used to calculate present values. The social discount rate is generally a risk-free rate that represents the time value of money for society as a whole. (See the discussion regarding discounting, below. The analysis assumes the social discount rate is 2 percent.)

The Triple Bottom Line

The example cost-benefit analysis also shows the impact of each drought management practice on the triple bottom line. The utility's bottom line is largely equal to the utility perspective described above. The environmental bottom line, which is a component of the social perspective, includes environmental damage (like carbon emissions) and benefits (like improved water quality). The social bottom line includes other impacts on customers, labor, or other elements of society.

Table C-1 summarizes the impact of each drought management practice on the utility's bottom line. The amount of water associated with each option is shown in the second column in MG per year. The table contains the present value of the water saved or supplied over the next 30 years.[22] The third and fourth columns in Table C-1 show the present value of costs and benefits of each drought management practice. The final column shows the net present value of each practice. Future water quantities, costs, and benefits are discounted at 2 percent per year.

Table C-1
Cost-benefit analysis of alternative drought management practices for the utility

Drought Management Practice	Water Supplied or Saved (MG)	Present Value of Costs	Present Value of Benefits	Net Present Value
Water Storage (Reservoir)*	2,498	$8,366,458	$8,432,078	$65,620
Leak Detection/Repair	23,880	$4,541,983	$95,608,044	$91,066,061
Rebates	20,346	$7,570,670	$79,860,522	$72,289,852
Rainwater Harvesting*	24	$121,131	$95,066	($26,065)
Purchase Reclaimed Water*	49,075	$39,876,459	$187,963,104	$148,086,645
Build Water Reuse*	22,119	$172,135,190	$85,706,230	($86,428,960)
Purchase Desalinated Water*	368,392	$2,123,156,781	$1,410,779,265	($712,377,516)
Ongoing Outreach	6,096	$760,666	$23,346,028	$22,585,362
Emergency Outreach	2,345	$43,890	$8,318,663	$8,274,774
Commercial Conservation Measures	56,505	$122,526	$226,231,893	$226,109,367
Residential Retrofit	1,894	$78,664	$7,040,798	$6,962,134
Landscaping	385	$2,681,512	$1,298,900	($1,382,611)
Conservation Rates	30,358	$152,433	$116,259,343	$116,106,909

** Practices providing additional water supply. The other practices conserve water.*

According to this analysis, commercial conservation measures have the largest net present value for the utility, indicating that they provide the greatest benefits relative to costs. In contrast,

[22] Although water is a physical quantity and not a dollar value, the analysis discounts future flows to reflect society's time preferences. The analysis discounts water volumes using the same discount rate it uses for dollar amounts.

desalination has the lowest net present value in this example. Although it provides a large and reliable volume of water (i.e. the greatest volume supplied relative to other drought management practices), its up-front investment costs are significantly greater than any of the other practices. Landscaping, which provides relatively less water savings in this example, is also expensive. The net present value of landscaping to the utility is negative. However, water savings are not the only value provided by landscaping; customers also benefit from the aesthetic value of the new landscaping. Because customers receive value from the new landscaping, the utility in this example may consider scaling back the subsidy for landscaping, as customers may be inclined to invest in landscaping themselves. If the water saved per square foot is higher than assumed in this analysis, landscaping would be a more cost-effective drought management practice. Measures to encourage water efficiency, including residential retrofit programs and conservation rates, are cost effective. Building a water reuse plant, by converting an existing wastewater facility, however, is not worthwhile because, like desalination, of the large up-front capital costs of the plant are very high.

While most of the costs and benefits of drought management practices are captured by the utility, such practices also affect the environment. Water reuse treatment and desalination increase carbon emissions. Table C-2 summarizes the costs of these additional impacts.

Table C-2
Environmental impacts of drought management practices

Drought Management Practice	Water Supplied or Saved (MG)	Present Value of Costs	Present Value of Benefits	Net Present Value
Purchase Reclaimed Water	49,075	$15,075,691	$0	($15,075,691)
Build Water Reuse	22,119	$3,198,908	$0	($3,198,908)
Purchase Desalinated Water	368,392	$56,020,675	$0	($56,020,675)

Some drought management practices have social impacts, the costs and benefits of which are not borne by the utility. For example, the residential rebate program includes costs paid by customers in addition to the rebates. The water reuse plants provide improved source water quality, which is a benefit to society. However, the utility does not pay the full cost of reclaiming the water; a portion of that cost may be borne by others (e.g., passed on to taxpayers). Customers must pay a portion of the landscape program, but they also receive the benefit of the new plants and materials. These additional costs and benefits are shown in Table C-3.

Table C-3
Other social impacts of drought management practices

Drought Management Practice	Water Supplied or Saved (MG)	Present Value of Costs	Present Value of Benefits	Net Present Value
Rebates	N/A	$1,395,964	$0	($1,395,964)
Purchase Reclaimed Water	8,939	$7,263,535	$7,263,535	$0
Build Water Reuse	19,936	$0	$26,780,693	$26,780,693
Landscaping	N/A	$759,665	$0	($759,665)

In addition to their dollar value, drought management practices may also have impacts that can only be measured qualitatively. Figure C-1 shows several potential impacts of each practice on several factors:

- **Service reliability.** The impact of the drought management practice on the utility's ability to continue to provide drinking water service during the drought.
- **Employment.** The drought management practice may provide jobs for the community. While generally considered a cost of a plan, policy makers often value the impact of measures on employment, especially during recessions.
- **Awareness.** The drought management practice may raise awareness of the cost of water in general and the challenges facing the community during the drought.
- **Environmental sustainability.** The impact of the drought management practice on the environment and the sustainability of the water utility.
- **Implementation costs.** Some implementation costs were not available or cannot be measured. For example, the costs to commercial customers of upgrades were not available, but will affect the relative value of the commercial conservation measures.

Utility planners and stakeholders would review each drought management practice and evaluate its potential impact in each area. For this study, the research team engaged in a round table discussion of the potential impact of the plans in each areas. The final score reflects the consensus view, and is subjective. Plans that have a potential positive impact are represented by a green circle in Figure C-1. Plans with negative impacts have a red circle. Plans with neutral impacts are shown with yellow.

	Service Reliability	Employment	Awareness	Environ-mental Sustain-ability	Implemen-tation Costs
Water Storage	Green	Yellow	Yellow	Yellow	Yellow
Leak Detection/Repair	Yellow	Green	Yellow	Green	Yellow
Rebates	Red	Yellow	Green	Green	Yellow
Rainwater Harvesting	Red	Yellow	Green	Green	Yellow
Purchase Reclaimed Water	Green	Yellow	Yellow	Green	Yellow
Build Water Reuse	Green	Green	Red	Green	Yellow
Purchase Desalinated Water	Green	Yellow	Yellow	Yellow	Yellow
Ongoing Outreach	Red	Yellow	Green	Green	Red
Emergency Outreach	Red	Yellow	Green	Yellow	Red
Commercial Conservation Measures	Yellow	Yellow	Green	Green	Red
Residential Retrofit	Yellow	Green	Green	Green	Yellow
Landscaping	Green	Green	Green	Green	Yellow
Conservation Rates	Yellow	Yellow	Green	Green	Yellow

Figure C-1. Other impacts of drought management practices

While the net present value of building additional water storage is small (at the discount rate of 3 percent), the increase in service reliability may offset the cost and make this option more viable. While landscaping's net present value is negative, its impact on service reliability, employment, awareness, and sustainability is positive. If these factors are critical, they may offset the cost of the plan.

Discounting

As discussed in Chapter 4, future costs and benefits need to be discounted to account for time preferences. In principle, the utility would use its weighted average cost of capital to discount future streams of costs and benefits because it measures the utility's opportunity cost of resources required to fund the drought management practices. For this analysis, we used a 3 percent discount rate for the utility.

There is a substantial body of literature on the social discount rate—i.e., the rate we should use to evaluate the impact of a program for society as a whole. (See Rosen and Gayer 2008 for a textbook explanation of the social discount rate. Bazelon and Smetters 1999, Howe 1990, Hartman 1990, Lind 1990, Lyon 1990, Moore and Viscusi 1990, Portney 1990, Scheraga 1990, and Kambhu 1990 all describe the use of discounting by government agencies.) This analysis assumed the social discount rate is 2 percent. (This is somewhat conservative—current real interest rate on 30-year U.S. Treasury securities is 1.4 percent.) The net present value of some of the results is sensitive to the discount rate. We explored the impact of the discount rate by evaluating each drought management practice using discount rates from 0 to 10 percent. Figure C-1 summarizes the results of this analysis.

The 4546 Example Cost-Benefit Analysis

The analysis discussed above is implemented in the 4546 Example Cost-Benefit Analysis Microsoft Excel spreadsheet. The spreadsheet uses Excel's present value functions to discount future costs and benefits.[23] The spreadsheet has multiple tabs that contains the data inputs, interim calculations, annual cost and benefit data, and the calculation of net present value and other measures of the impact of each drought management practice. These tabs (whose names appear in bold below) are described here in further detail. The tabs are color coded in the spreadsheet to group similar tabs together for ease of use; colors are mentioned in parentheses below.

The **Assumptions** tab (pink) in the spreadsheet contains the basic assumptions of the analysis. It includes the discount rate for each perspective, the term of the analysis (i.e., 30 years), and real escalation rates for future costs and benefits. The next several tabs summarize the results of the analysis, using the data and calculations that are in subsequent tabs.

ImpactByPerspective (blue) summarizes the present value of the costs, benefits, and net value of each drought management practice for the utility, its customers, and society as whole. It also includes a stoplight chart that qualitatively describes the potential impact of other effects that are difficult to measure quantitatively.

The next three tabs show the impact of each plan on the triple bottom line. **Utility** (blue) shows the impact on the utility's bottom line. **Environment** (blue) shows the impact on the environment. **Social** (blue) shows other social effects. Each tab shows the volume of water saved

[23] Excel uses a series of related functions to calculate present value (PV), future value (FV), and amortized annual payments (PMT). These include the PV, FV, PMT, and Net Present Value (NPV) functions. For example, the present value of a constant annual payment of $1.00 at the end of the year for 30 years assuming a discount rate of 2 percent is given by PV(.02,20,1), or $22.40.

or supplied by each drought management practice and the present value of the costs, benefits, and net value of that practice. Each tab also shows the cost per MG of each practice and the benefit-cost ratio. Finally, each tab shows a stoplight chart that summarizes the impact of the drought management practices on other measures.

DiscountSensitivity (yellow) calculates the net present value of each drought management practice for society as whole using alternative discount rates. The discount rates considered range from 0 to 10 percent. The tab **Sensitivity-All** (yellow) shows the results of the analysis in a line chart (same as Figure C-1 above), plotting the net present value of each plan against the discount rate. Because the net present value of desalination is so much larger than the other options, it is shown on the right hand vertical axis; the value of the remaining options are on the left hand vertical axis. The tab **Sensitivity-Choose** (yellow) shows the effect using a line chart for a single drought management practice. A user can choose the practice they want to display in the graph by using slider bar on the right hand side of the chart.

The tab **Costs and Benefits** (orange) contains the annual data for each option: its cost, the water each option saves (in MG), and the benefit. It includes data for 30 years (2014–2043). For each plan, it distinguishes between the utility, environmental, and social impacts. It also shows the impact on customers (which is included in the social bottom line). It also shows the impact for society as whole. This is the central component of the cost-benefit analysis, calculating the costs and benefits of the program by year for each drought management practice. The previous tabs use these data to calculate the net present value, the cost per MG, and the benefit-cost ratio of each option.

The inputs for these annual data are in the remaining tabs. **DataSummary** (orange) collects much of the information from the other tabs for use in **Costs and Benefits**. The tab **DescriptionCostsAndBenefits** (orange) provides a qualitative overview of the cost and benefit data and how they are used in the analysis. The tab **WaterCosts** (green) calculates the annual cost of water from the utility's three sources: groundwater, purchase of local surface water, and purchase of surface water from a regional supplier. The real cost of each is escalated by a fixed percentage. The current analysis assumes the cost of the regional supplier will increase 1 percent per year while local costs remain constant in real terms.

The tab **Reservoir** (green) contains the cost and capacity information for the emergency storage option. It shows the water stored and used, the cost of the reservoir, and its benefits by year for 50 years, which is the expected life of the reservoir.

The tab **Landscaping** (green) contains the data on the costs and benefits associated with the replacement of lawns with drought-resistant plants. It shows annual costs and benefits of a program to replace lawns at 67 homes per year for 5 years, which is the number of lawn replacements the current funding can pay for each year. It includes the cost of replacing lawns and the water the program saves. It assumes the value to the homeowner of the new landscaping is equal to its cost. It calculates the annual value by amortizing the cost over 30 years.

The following tabs contain the cost and benefit assumptions for the remaining options. Unlike **WaterCosts** (green), **Reservoir** (green), and **Landscaping** (green), these tabs do not contain data by year; rather, they show the cost and benefits in a single year. **Costs and Benefits** (red) then distributes these costs and benefits by year.

- **Rates** (green) contains the data on costs and benefits of conservation-based water rates.

- **Outreach** (green) contains data on the costs and benefits of emergency and on-going outreach measures.
- **Conservation** (green) contains data on the costs and benefits of water efficiency and conservation programs.
- **Rainwater** (green) contains data on the costs and benefits of rainwater harvesting.
- **Rebates** (green) contains data on the costs and benefits of residential rebate programs.
- **Leaks** (green) contains data on the cost and benefits of a program to locate and repair leaks in the distribution network.
- **Reuse** (green) contains data on the costs and benefits of purchasing reclaimed water from an existing water reuse facility. It also contains the costs and benefits of building a plan by converting an existing wastewater treatment facility.
- **Desal** (green) contains data on the costs and benefits of purchasing desalinated water from an existing facility.
- **CO2** (green) contains the data used to calculate the volume of carbon emissions from reuse and desalination plants. (The **Reuse** and **Desal** tabs use these data.)

The analysis is conducted in real terms; in other words, it allows for real changes in costs and benefits, excluding changes in the overall price level. Historical cost data are presented in 2014 dollars. The analysis uses the consumer price index for all urban consumers, CPI-U, to adjust historical nominal cost and benefit data to 2014 dollars. The tab **Inflation** (cyan) contains the CPI-U index.

Conclusions

Cost-benefit analyses require a large amount of information about the costs of drought management practices, their impact on water supply and demand, and the value of the practices for the utility, the environment, and society as a whole. The partner utilities were able to provide a great deal of good information, but a full-scale analysis would require more details about each practice, as well as additional assumptions about future conditions. However, the relatively simple analysis demonstrated in the 4546 Example Cost-Benefit Analysis shows the potential value of a cost-benefit analysis, in selecting drought management practices as well as potential pitfalls.

- The quality of the data drives the quality of the analysis. Additional resources are needed to collect good cost and benefit data to ensure that the analysis provides meaningful results.
- The analysis shows that not all drought practices are worthwhile. Some inexpensive and easy steps may have little impact and, therefore, have little or no value. On the other hand, relatively expensive options may provide the largest net benefit.
- Although not all costs and benefits can be measured by their dollar value, they can have a substantial impact on the triple bottom line. The value of the service provided by the utility—or what the impact would be if the utility could not supply water—is not captured in the example cost-benefit analysis. The value of reliable drinking water service in the context of climate change will likely be important for utility customers, especially if the number and duration of droughts increase.

The last bullet point raises an important issue underlying all drought planning in the context of global climate change. The length and duration of droughts will affect both the options that utilities must consider in response to droughts and the value of alternative drought management practices. If longer-term droughts lead to interruptions of service, some relatively expensive drought management practices may become financially viable. For example, the cost of turf replacement in this example is greater than the value of the purchased water it saves. However, if the drought lasts for more than 1 year, the net present value of the landscape program for the utility's bottom line may be positive and large if it helps avoid an interruption in service.

APPENDIX D
COST OF DROUGHT MANAGEMENT PRACTICES

Introduction

The cost data on drought management practices presented in this file were collected between December 2014 and May 2015 via a short survey of drinking water utilities participating in this research project. The five utilities that provided data are: El Dorado Irrigation District, CA; Cobb County Water System, GA; City of San Diego Public Utilities Department, CA; Denver Water, CO; Aurora Water, CO; and City of Oklahoma City Utilities Department, OK.

The following tables are organized by utility and present cost data and supporting information on each utility's drought management practices, as well as on their overall water resource management practices, which may improve their resilience to drought. The precise amounts dedicated to drought mitigation and response were not always discernable from costs associated with other water resource management activities. Note that not all drought management practices were implemented by all of the utilities. The information presented in this appendix was used to inform the example cost-benefit analysis presented in Appendix C.

Cost information for El Dorado Irrigation District

Background	
1. How many people and connections do you serve?	2013 numbers: EID Main: 117,700 people (39,389 connections) Outingdale: 487 people (191 connections) Strawberry: 345 people (136 connections)
2. What was your overall revenue loss due to decreased demand during drought and over what time frame?	2014 foregone water sales - approximately $2.3 million 2014 foregone power sales - approximately $3.0 million 2014 foregone recycled water sales - approximately $250,000

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
6. Hauling water			
a. Cost of buying wholesale water	$0 (2014$)	See column to left	Since we transferred water from one of our systems to the other. Population impacted = 487
b. Cost of moving water from one location to another	$0.4 per gallon (2014$)	See column to left	6500 gallon tanker trucks, costing $0.4 per gallon. Population impacted = 487
c. Cost of buying bottled water	n/a	n/a	Population impacted = 487
d. Length of time water was hauled	n/a	n/a	One month, Sept 9th to Oct 11th. Population impacted = 487
7. Legal/administrative			
a. Cost of buying water from farmers in dry years (per gallon or other volume measure)	n/a	n/a	n/a
b. Cost of transferring or acquiring new water rights (indicate volume of water acquired)	n/a	n/a	n/a

Supply Augmentation

Cost information for El Dorado Irrigation District

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
8. New dams, reservoirs, and other major storage			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
c. Anticipated revenue (e.g., from hydropower)	n/a	n/a	n/a
9. New or deeper wells			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
10. Lower intakes			
a. Capital costs	n/a	n/a	Population impacted = 487
b. Operations & maintenance costs	$1,500 (2014$)	See column to left	n/a
11. Inter-connections with other utilities			
a. Costs of establishing infrastructure for inter-connections	$10,000 (2014$)	See column to left	Improvements for water transfer. Population impacted = 487
b. Costs of buying water (per gallon or other volume measure)	n/a	n/a	n/a
12. Leaks detection			
a. Costs of detection technologies	n/a	n/a	Approximately $200,000 to establish program and purchase equipment.
b. Costs of repair	n/a	n/a	
13. Repair and/or replace water mains			
a. Costs of repair	$1,537 per event, average events per year 568 ($873,290 annually) (2014$)	See column to left	n/a
b. Costs of replacement	$250,000 for 1,200 LF of pipe replaced ($208/LF) (2014$)	See column to left	n/a
14. Prevent evaporation			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
15. Groundwater recharge/"water banking"			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a

Cost information for El Dorado Irrigation District

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
16. Rainwater harvesting			
a. Communication costs	n/a	n/a	n/a
b. Costs of providing rebates or other incentives	n/a	n/a	n/a
17. Greywater reuse			
a. Communication costs	n/a	n/a	n/a
b. Costs of providing rebates or other incentives	n/a	n/a	n/a
18. Water reuse (recycling)			
a. Additional treatment costs	n/a	n/a	Discharge requirements are same as recycle requirements for us. 4,000 connections
b. Capital costs	n/a	n/a	n/a
c. Storage costs	$724,578 for 60 MG storage pond (2014$)	See column to left	Current book value.
d. Costs of separate distribution network	$22,601,494 (2014$)	See column to left	Current book value.
e. Operations & maintenance costs	$1,200,000 (2014$)	See column to left	2015 O&M budget.
f. Communication costs (e.g., signage, outreach)	n/a	n/a	Included in general district cost.
19. Desalination			
a. Capital costs	n/a		n/a
b. Operations & maintenance costs	n/a		n/a

Cost information for El Dorado Irrigation District

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
20. Ongoing/long-term outreach campaign			
a. Outreach costs (labor and materials)	$50,000 (2014$)	See column to left	Population = 118,532 (all systems)
b. Enforcement costs (labor and materials)	n/a	n/a	n/a
c. Costs of providing rebates and other incentives	$25,000 (2014$)	See column to left	2015 Budget
21. Temporary conservation measures, especially related to outdoor water use (voluntary or mandatory)			
a. Emergency outreach costs (labor and materials)	$295,000 (2014$)	See column to left	n/a
b. Enforcement costs (labor and materials)	n/a	n/a	n/a
c. Costs of providing rebates and other incentives	$25,000 (2014$)	See column to left	2015 Budget
22. Retrofitting programs, use of low-flow fixtures			
a. Outreach costs (labor and materials)	included in question 20	n/a	n/a
b. Enforcement costs (labor and materials)	included in question 20	n/a	n/a
c. Costs of providing rebates and other incentives	included in question 20	n/a	n/a
23. Encourage climatically appropriate planting (e.g., Xeriscaping ordinances, HOA covenants)			
a. Outreach costs (labor and materials)	included in question 20	n/a	n/a
b. Enforcement costs (labor and materials)	included in question 20	n/a	n/a
c. Costs of providing rebates and other incentives	included in question 20	n/a	n/a
24. Meter water deliveries			
a. Outreach costs (labor and materials)	n/a	n/a	n/a
b. Monitoring costs (labor and materials)	n/a	n/a	n/a
c. Enforcement costs (labor and materials)	n/a	n/a	n/a
d. Costs of providing rebates and other incentives	n/a	n/a	n/a
25. Encourage business/industry users to reuse and recycle			
a. Outreach costs (labor and materials)	n/a	n/a	n/a
b. Costs of providing rebates and other incentives	n/a	n/a	n/a

Cost information for El Dorado Irrigation District

Rate Adjustment

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
26. Rate Structure			
a. Please provide your rate structure (to encourage conservation during drought and to protect revenue during drought)	n/a	n/a	Website link has all of the information: http://www.eid.org/customers/drought-information
b. Were there additional costs associated with developing a new rate structure during drought conditions (e.g., did you hire a consultant)?	n/r	n/r	n/r

n/r = No response; utility did not provide response

n/a = Not applicable; utility marked this item as not applicable

Source: **El Dorado Irrigation District**

Date of Information Submitted: **1/14/2015**

Cost information for Cobb County Water System

Background	
1. How many people and connections do you serve?	650,000 people and 172,000 connections
2. What was your overall revenue loss due to decreased demand during drought and over what time frame?	$18.4 million; Oct 2007 – Dec 2008

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
6. Hauling water			
a. Cost of buying wholesale water	$2.68/1,000 gallons (2014$)	See column to left	All of our water is purchased wholesale current price.
b. Cost of moving water from one location to another	n/a	n/a	n/a
c. Cost of buying bottled water	n/a	n/a	n/a
d. Length of time water was hauled	n/a	n/a	n/a
7. Legal/administrative			
a. Cost of buying water from farmers in dry years (per gallon or other volume measure)	n/a	n/a	Riparian water law does not permit that practice.
b. Cost of transferring or acquiring new water rights (indicate volume of water acquired)	n/a	n/a	Riparian water law does not allow the transferring of water.
8. New dams, reservoirs, and other major storage			
a. Capital costs	$100 million (2012$)	$103 million	Wholesaler completed off stream storage project for $100 million (project was underway before 2007 drought in response to 2001 drought completed in 2013).
b. Operations & maintenance costs	n/a	n/a	Currently not being used and have not received a permit from Army Corps of Engineers. There is a fulltime operator at the Dam. The cost is born by wholesaler.
c. Anticipated revenue (e.g., from hydropower)	$0	$0	n/a

Cost information for Cobb County Water System

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
9. New or deeper wells			
a. Capital costs	n/a	n/a	This is a surface water system. With granite bedrock, there is no reliable groundwater.
b. Operations & maintenance costs	n/r	n/a	n/r
10. Lower intakes			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/r	n/r	n/r
11. Inter-connections with other utilities			
a. Costs of establishing infrastructure for inter-connections	n/a	n/a	Purchase system.
b. Costs of buying water (per gallon or other volume measure)	n/r	n/r	n/r
12. Leaks detection			
a. Costs of detection technologies	$200,000	n/a	Approximately $200,000 to establish program and purchase equipment.
b. Costs of repair	$1,035/per repair (2009$)	$1,142/per repair	
13. Repair and/or replace water mains			
a. Costs of repair	$1,035/per repair (YEAR$)	$1,142/per repair	See question 12.
b. Costs of replacement	n/a	n/a	Postponed much of this to mitigate revenue shortfall.
14. Prevent evaporation			
a. Capital costs	n/a	n/a	Purchase system.
b. Operations & maintenance costs	n/r	n/r	n/r
15. Groundwater recharge/"water banking"			
a. Capital costs	n/a	n/a	No groundwater.
b. Operations & maintenance costs	n/r	n/r	n/r

Cost information for Cobb County Water System

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
16. Rainwater harvesting			
a. Communication costs	n/a	n/a	Not additional to our communications, related to drought part of messaging.
b. Costs of providing rebates or other incentives	$6,000/year (2008$)	$6,597/year	Ran a rain barrel program for $6,000/year. We did not incentivize large rainwater harvesting projects. Residential accounts (167,000).
17. Greywater reuse			
a. Communication costs	n/a	n/a	n/a
b. Costs of providing rebates or other incentives	n/r	n/r	n/r
18. Water reuse (recycling)			
a. Additional treatment costs	n/a	n/a	Already had a reuse plant online.
b. Capital costs	n/r	n/r	n/r
c. Storage costs	n/r	n/r	n/r
d. Costs of separate distribution network	n/r	n/r	n/r
e. Operations & maintenance costs	$2,500 (2008$)	$2,749	Additional cost to truck reuse water to protect trees (Government/public sites 300 accounts).
f. Communication costs (e.g., signage, outreach)	n/a	n/a	This is a surface water system. With granite bedrock, there is no reliable groundwater.
19. Desalination			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/r	n/r	n/r

Cost information for Cobb County Water System

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
20. Ongoing/long-term outreach campaign			
a. Outreach costs (labor and materials)	$33,000 (2009$)	$36,414	All 172,000.
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	$375,000 (2008$)	$412,330	Residential Customer, 167,000 accounts.
21. Temporary conservation measures, especially related to outdoor water use (voluntary or mandatory)			
a. Emergency outreach costs (labor and materials)	~$10,000 (2009$)	$11,035	Outdoor Ban all 172,000 accounts.
b. Enforcement costs (labor and materials)	$144,000 (2008$)	$158,335	Water ban.
c. Costs of providing rebates and other incentives	n/a	n/a	Part of conservation program above.
22. Retrofitting programs, use of low-flow fixtures			
a. Outreach costs (labor and materials)	n/a	n/a	Part of other efforts.
b. Enforcement costs (labor and materials)	$27,000 (2008$)	$29,687	172,000 accounts
c. Costs of providing rebates and other incentives	n/a	n/a	n/a
23. Encourage climatically appropriate planting (e.g., Xeriscaping ordinances, HOA covenants)			
a. Outreach costs (labor and materials)	n/a	n/a	Part of other communication efforts, can't parse out.
b. Enforcement costs (labor and materials)	$17,000 (2007$)	$19,410	Outdoor kits and Give Them an Inch Materials – 172,000 accounts.
c. Costs of providing rebates and other incentives	n/r	n/r	n/r
24. Meter water deliveries			
a. Outreach costs (labor and materials)	n/a	n/a	n/a
b. Monitoring costs (labor and materials)	n/r	n/r	n/r
c. Enforcement costs (labor and materials)	n/r	n/r	n/r
d. Costs of providing rebates and other incentives	n/r	n/r	n/r
25. Encourage business/industry users to reuse and recycle			
a. Outreach costs (labor and materials)	n/r	n/r	n/r
b. Costs of providing rebates and other incentives	n/r	n/r	n/r

Cost information for Cobb County Water System

Rate Adjustment

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
26. Rate Structure			
a. Please provide your rate structure (to encourage conservation during drought and to protect revenue during drought)	Provided below	n/a	n/a
b. Were there additional costs associated with developing a new rate structure during drought conditions (e.g., did you hire a consultant)?	No, done in house	n/a	n/a

n/r = No response; utility did not provide response

n/a = Not applicable; utility marked this item as not applicable

Source: **Cobb County Water System**

Date of Information Submitted: **1/6/2015**

Cost information for Cobb County Water System

COBB COUNTY WATER SYSTEM
RATES, CHARGES AND FEES
EFFECTIVE DATE: January 1, 2007

MONTHLY SERVICE CHARGES

The monthly service charge is assessed by meter size. This charge is to recover administrative, customer service, billing and meter-related cost, bond interest and some depreciation expenses. This fee is billed to all active accounts and does not include any water consumption.

METER SIZE	RESIDENTIAL	NON-RESIDENTIAL	IRRIGATION
5/8" & ¾"	$7.00	$7.00	$19.00
1"	$15.00	$15.00	$22.00
1½"	$26.00	$26.00	$41.00
2"	$45.00	$45.00	$63.00
3"	$66.00	$66.00	$120.00
4"	$99.60	$99.60	$185.00
6"	$206.40	$206.40	$325.00
8"	$321.60	$321.60	$450.00
10"	$463.20	$463.20	$650.00
12"	$463.20	$463.20	$800.00

Cost information for Cobb County Water System

FIRE PROTECTION SERVICE

This fee is for water availability on demand for fire protection. It is associated with DDC and backflow devices and other metering devices for fire protection. This is typically for commercial facilities where domestic water demands are low, but must have fire flow capacity available to meet fire code requirements.

LINE SIZE	DOUBLE DETECTOR CHECK DEVICES	DOMESTIC or MFM METERS USED AS DDC DEVICES	UNMETERED FIRE LINES
5/8" & ¾"		$19.00	
1"		$19.00	
1½"		$19.00	
2"		$24.00	
3"		$32.00	
4"		$40.00	
6"	$50.00	$151.00	$200.00
8"	$60.00	$201.00	$250.00
10"	$80.00	$251.00	$300.00
12"	$110.00		$350.00

Cost information for Cobb County Water System

COMMODITY CHARGES

The commodity charges are for the recovery of costs associated with water purchases and distribution or wastewater collection and treatment expenses. These are billed to the consumer on a per thousand gallon basis.

Retail Rates

RESIDENTIAL - WATER	Tier 1 (1,000 to 8,000 gallons):	$2.29 per 1,000 gallons
	Tier 2 (9,000 to 15,000 gallons):	$2.64 per 1,000 gallons
	Tier 3 (16,000 to 29,000 gallons)	$2.98 per 1,000 gallons
	Tier 4 (30,000 to 49,000 gallons)	$3.50 per 1,000 gallons
	Tier 5 (50,000 and above)	$5.00 per 1,000 gallons
	Tier 2 and tier 3 rates are calculated at 115% and 130% respectively of tier 1 per 1,000 gallon rate. Tier 4 and Tier 5 were effective as of November 1, 2007.	
NON-RESIDENTIAL - WATER	$2.59 per 1,000 gallons	
IRRIGATION - WATER	$3.26 per 1,000 gallons	

Cost information for City of San Diego Public Utilities Department

Background	
1. How many people and connections do you serve?	1,345,895 people (279,226 connections)
2. What was your overall revenue loss due to decreased demand during drought and over what time frame?	n/a

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
6. Hauling water			
a. Cost of buying wholesale water	$829 per acre-foot	n/a	For untreated water.
b. Cost of moving water from one location to another	$1,103 per acre-foot	n/a	For treated water.
c. Cost of buying bottled water	n/a	n/a	n/a
d. Length of time water was hauled	n/a	n/a	n/a
7. Legal/administrative			
a. Cost of buying water from farmers in dry years (per gallon or other volume measure)	n/a	n/a	n/a
b. Cost of transferring or acquiring new water rights (indicate volume of water acquired)	n/a	n/a	n/a
8. New dams, reservoirs, and other major storage			
a. Capital costs	n/r	n/r	n/r
b. Operations & maintenance costs	n/r	n/r	n/r
c. Anticipated revenue (e.g., from hydropower)	n/r	n/r	n/r
9. New or deeper wells			
a. Capital costs	n/r	n/r	n/r
b. Operations & maintenance costs	n/r	n/r	n/r

Cost information for City of San Diego Public Utilities Department

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
10. Lower intakes			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
11. Inter-connections with other utilities			
a. Costs of establishing infrastructure for inter-connections	n/a	n/a	n/a
b. Costs of buying water (per gallon or other volume measure)	$1,103 per acre-foot	n/a	n/a
12. Leaks detection			
a. Costs of detection technologies	n/a	n/a	n/a
b. Costs of repair	n/a	n/a	n/a
13. Repair and/or replace water mains			
a. Costs of repair	Rehab - Hard cost (82% of Total Cost): $656,000 Soft cost (18% of Total Cost): $144,000 Total cost/mile: $800,000 (2013$)	n/a	These are the costs for replacing pipeline that we are currently using. AC pipe disposal estimated at 23$/ft.

Supply Augmentation

Cost information for City of San Diego Public Utilities Department

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
13. Repair and/or replace water mains			
b. Costs of replacement	8" CI - Hard cost: $1.2M 8" CI - Soft cost: $400,000 8" CI - Cost/mile: $1.6M 12" CI - Hard cost: $1.4M 12" CI - Soft cost: $466,667 12" CI - Cost/mile: $1,866,667 16" CI - Hard cost: $1.6M 16" CI - Soft cost: $533,333 16" CI - Cost/mile: $2,133,333 8" AC - Hard cost: $1,321,400 8" AC - Soft cost: $440,467 8" AC - Cost/mile: $1,761,867 12" AC - Hard cost: $1,521,400 12" AC - Soft cost: $507,133 12" AC - Cost/mile: $2,028,533 16" AC- Hard cost: $1,721,440 16" AC - Soft cost: $573,813 16" AC - Cost/mile: $2,295,253	n/a	These are the costs for replacing pipeline that we are currently using. AC pipe disposal estimated at 23$/ft.
14. Prevent evaporation			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
15. Groundwater recharge/"water banking"			
a. Capital costs	n/r	n/r	n/r
b. Operations & maintenance costs	n/r	n/r	n/r
16. Rainwater harvesting			
a. Communication costs	n/r	n/r	n/r
b. Costs of providing rebates or other incentives	n/r	n/r	n/r
17. Greywater reuse			
a. Communication costs	n/r	n/r	n/r
b. Costs of providing rebates or other incentives	n/r	n/r	n/r

Cost information for City of San Diego Public Utilities Department

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
18. Water reuse (recycling)			
a. Additional treatment costs	North City Water Reclamation Plant FY 2014 - Total tertiary treatment cost: $2,333,319 (2014$) South Bay Water Reclamation Plant FY 2014 - Total tertiary treatment cost: $1,721,841 (2014$)	n/a	Received spreadsheet containing WWTD's information for the North City and South Bay Water Reclamation Plant.
b. Capital costs	n/r	n/r	n/r
c. Storage costs	n/r	n/r	n/r
d. Costs of separate distribution network	n/r	n/r	n/r
e. Operations & maintenance costs	North City Water Reclamation Plant FY 2014 - O&M: $8,552,931 (2014$) South Bay Water Reclamation Plant FY 2014 - O&M: $7,536,492 (2014$)	n/a	Received spreadsheet containing WWTD's information for the North City and South Bay Water Reclamation Plant.
f. Communication costs (e.g., signage, outreach)	n/a	n/a	n/a

Cost information for City of San Diego Public Utilities Department

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
19. Desalination			
a. Capital costs	$881 per acre-foot (2013$)	n/a	These unit costs are for the purchase of water from Poseidon and include the cost of the plant and the 10 mile conveyance pipeline (including the costs for pumping into the Water Authority system). These unit costs are based on the purchase of 56,000 acre-feet per year, the most likely purchase scenario. The Water Authority has a minimum purchase commitment of 48,000 acre-feet per year. These unit costs are based on 2013$. Note that we are currently in the process of updating the unit costs for Carlsbad (using the specified indices and cost references in the Water Purchase Agreement) for its planned commercial operations start in the fall of this year, but that data is not yet available.
b. Operations & maintenance costs	$967 per acre-foot (2013$)	n/a	See above.

Cost information for City of San Diego Public Utilities Department

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
20. Ongoing/long-term outreach campaign			
a. Outreach costs (labor and materials)	$450,000 ($250,000 for media buys+$200,000 for consultant services) (2014$)	n/a	For 2014, outreach cost - $250,000 for media buys and $200,000 for consultant services for public outreach. The $250,000 in media buys started in FY 2014 (Jul 2013 to June 2014), and continued to FY 2015. As the drought worsens, we can add to the FY 2016 budget. Prior to FY 2014, there really was not media buy budget, except in FY 2009 ($750,000) and FY 2010 ($500,000) when the City first went to mandatory use restrictions ever. The consultant contract of $200,000 per year is ongoing as it provide support back and forth between both programs and drought response.
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	n/r	n/r	n/r
21. Temporary conservation measures, especially related to outdoor water use (voluntary or mandatory)			
a. Emergency outreach costs (labor and materials)	n/r	n/r	n/r
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	n/r	n/r	n/r
22. Retrofitting programs, use of low-flow fixtures			
a. Outreach costs (labor and materials)	n/r	n/r	n/r
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	n/r	n/r	n/r

Cost information for City of San Diego Public Utilities Department

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
23. Encourage climatically appropriate planting (e.g., Xeriscaping ordinances, HOA covenants)			
a. Outreach costs (labor and materials)	n/r	n/r	n/r
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	n/r	n/r	n/r
24. Meter water deliveries			
a. Outreach costs (labor and materials)	$200 per acre foot	n/a	In the City of San Diego, all water services are metered. Outdoor water use is measured on approximately 7,000 irrigation meters representing approximately 2.5% of our total (approx. 270,000) meters. This metering took place at the time of initial connection of service and has not incurred additional labor since then. Irrigation meter customers are offered a Water Survey and a monthly water budget is automatically provided and listed on their water bill giving these customers a target water use. The cost of a Water Survey is estimated at $200/acre. No enforcement is required as this is voluntary at this time. New construction is required to install a separate irrigation meter as follows: Dedicated landscape irrigation meters shall be required in all new development with a landscape area greater than or equal to 5,000 square feet; except that this requirement shall not apply to new single dwelling unit development or to the commercial production of agricultural crops or livestock.

Cost information for City of San Diego Public Utilities Department

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
24. Meter water deliveries			
(continued)	n/a	n/a	Landscape irrigation submeters shall be required in the following developments: (A) New single dwelling unit development; (B) Improvements to existing industrial, commercial and multiple dwelling unit development when: (i) The improvement requires a building permit as identified in Table 142-04A; and (ii) The landscape area is 1,000 square feet and greater. We are currently developing an Alternative for Large Landscapes variance that will set monthly water use limits for large landscapes with irrigation meters. If a customer stays below their limit they are exempt from watering restrictions. We do not currently have costs for monitoring or enforcement as this is not in place.
b. Monitoring costs (labor and materials)	n/r	n/r	n/r
c. Enforcement costs (labor and materials)	$0 - since voluntary	$0	The City of San Diego has never provided a rebate for customers to install separate irrigation meters from interior water use.
d. Costs of providing rebates and other incentives	n/r	n/r	n/r
25. Encourage business/industry users to reuse and recycle			
a. Outreach costs (labor and materials)	n/r	n/r	n/r
b. Costs of providing rebates and other incentives	n/r	n/r	n/r

Cost information for City of San Diego Public Utilities Department

Rate Adjustment

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
26. Rate Structure			
a. Please provide your rate structure (to encourage conservation during drought and to protect revenue during drought)	Old rate structure: increased from 8% to 12% from tier 1 to 2, and tier 2 to 3. New rate structure: increases of 12%, 43%, and 40% from tier 1 to 2 to 3.	n/a	We did hire a consultant (B&V) to devise the new rate structure that went into effect January 1, 2014. The new rate structure went from 3 relatively flat tiers to 4 much steeper tiers, i.e. the old structure increased ~ 8% and 12%, respectively from tier 1 to 2, and tier 2 to tier 3. The new structure has increases of ~12%, 43% and 40%, respectively. The total cost to produce the rate case, along with the COSS was about $150,000, a significant portion of which went to cover consultant time spent preparing presentations for meetings with Council members to get them comfortable with the rate increases, and presentations to IROC.
b. Were there additional costs associated with developing a new rate structure during drought conditions (e.g., did you hire a consultant)?	$150,000	n/a	The total cost to produce the rate case, along with the COSS, was about $150,000 with a significant portion covering cost of consultant. Hired a consultant to devise new rate structure that went into effect 1/1/14. Consultant also prepared presentations for meetings with Council members to get them comfortable with rate increases and presentations to IROC.

n/r = No response; utility did not provide response

n/a = Not applicable; utility marked this item as not applicable

Source: **City of San Diego Public Utilities Department**

Date of Information Submitted: **1/27/2015; 2/4/2015**

Cost information for Denver Water

Background	
1. How many people and connections do you serve?	Denver Water serves 1.3 million people in the city of Denver and many surrounding suburbs. At the end of 2013, Denver Water had 312,228 active taps (2013 CAFR, III-15). Denver Water serves water inside its service area, and outside of its service area through fixed-amount contracts.
2. What was your overall revenue loss due to decreased demand during drought and over what time frame?	Denver Water's original forecasted revenue for 2013 was $269 million; Denver Water's 2013 actual revenue came to $231 million (Billed Revenue Reports, Jan. & Dec. 2013). Thus, Denver Water's 2013 revenue was about $37 million (2013$) lower than originally projected. Denver Water saw a decrease in both demand and revenue in 2013 from a variety of reasons, including: mandatory watering restrictions in the spring and early summer, wet conditions from heavy spring snowfall, and wet conditions from historic flooding in September 2013. Denver Water does not have a revenue shortfall number that is specifically related to drought in 2013, since it is nearly impossible to separate out the effect of drought restrictions from weather and other variables.

Cost information for Denver Water

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
6. Hauling water			
a. Cost of buying wholesale water	n/a	n/a	Denver Water did not make major supply augmentation efforts (like the ones listed in questions 6 through 19) during the 2012-2013 drought. Denver Water carefully considers supply augmentation as part of its regular long-range planning efforts that are performed in all years, not just drought years.
b. Cost of moving water from one location to another	n/a	n/a	n/a
c. Cost of buying bottled water	n/a	n/a	n/a
d. Length of time water was hauled	n/a	n/a	n/a
7. Legal/administrative			
a. Cost of buying water from farmers in dry years (per gallon or other volume measure)	n/a	n/a	n/a
b. Cost of transferring or acquiring new water rights (indicate volume of water acquired)	n/a	n/a	n/a
8. New dams, reservoirs, and other major storage			
a. Capital costs	$10,000-$40,000 per acre-foot of firm yield	n/a	Denver Water is considering several new water supply projects for a secure long-term future. We are seeing a range of $10,000-$40,000 per acre-foot for firm yield. Of course, new supply costs will be specific to the utility and to the individual water supply project.
b. Operations & maintenance costs	n/a	n/a	n/a
c. Anticipated revenue (e.g., from hydropower)	n/a	n/a	n/a
9. New or deeper wells			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a

Cost information for Denver Water

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
10. Lower intakes			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
11. Inter-connections with other utilities			
a. Costs of establishing infrastructure for inter-connections	n/a	n/a	Denver Water is the state's largest water utility.
b. Costs of buying water (per gallon or other volume measure)	n/a	n/a	n/a
12. Leaks detection			
a. Costs of detection technologies	$250,000 for leak-detection program (2013$)	$254,056 for leak-detection program	Denver Water has a leak-detection program as part of regular utility operations. The average annual program cost is approximately $250,000. See page III-91 of the 2013 CAFR to see estimated savings generated from saving lost water and from pinpointing leaks. Finding a water leak before it becomes a main break conserves water, reduces repair costs, and eliminates unscheduled outages. (http://www.denverwater.org/docs/assets/63FF0223-0ACA-A877-7B4D0892FD5E1317/2013_annual_report.pdf)
b. Costs of repair	n/a	n/a	n/a

Supply Augmentation

Cost information for Denver Water

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
13. Repair and/or replace water mains			
a. Costs of repair	$7.8 million (2014$)	See column to left	Denver Water performs proactive infrastructure maintenance and repair. The average annual cost for Denver Water's pipe improvement and replacement is $7.8 million (5-year average of 2010-2014). The average annual pipe footage replaced/improved is about 51,000 feet per year (5-year average of 2010-2014). It should be noted that pipe repair and replacement is a good utility practice, not necessarily a useful drought management tool.
b. Costs of replacement	n/a	n/a	n/a
14. Prevent evaporation			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
15. Groundwater recharge/"water banking"			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
16. Rainwater harvesting			
a. Communication costs	n/a	n/a	Rainwater harvesting is not allowed in Colorado except for a select few pilot projects.
b. Costs of providing rebates or other incentives	n/a	n/a	n/a
17. Greywater reuse			
a. Communication costs	n/a	n/a	n/a
b. Costs of providing rebates or other incentives	n/a	n/a	n/a

Cost information for Denver Water

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
18. Water reuse (recycling)			
a. Additional treatment costs	n/a	n/a	n/a
b. Capital costs	n/a	n/a	n/a
c. Storage costs	n/a	n/a	n/a
d. Costs of separate distribution network	n/a	n/a	n/a
e. Operations & maintenance costs	n/a	n/a	n/a
f. Communication costs (e.g., signage, outreach)	n/a	n/a	n/a
19. Desalination			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a

Cost information for Denver Water

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
20. Ongoing/long-term outreach campaign			
a. Outreach costs (labor and materials)	$700,000 (2013$)	$711,355	Denver Water originally started its long-term public outreach campaign in 2006 as a result of drought conditions in 2002-2004. The public outreach campaign has become part of regular operations and not solely drought management. Costs for the program vary across years depending on conditions, budget constraints, and the specific goal and targeting of the year's campaign. In 2013 (drought conditions), the cost of the public outreach campaign was approximately $700,000. The annual budget for this campaign decreased in 2014 and was further decreased for 2015. The average annual program cost for 2013-2015 is about $585,000. It should be noted that advertising/outreach campaigns don't last forever and have a "shelf life." Denver Water's public outreach campaign is internationally recognized. Denver Water has a strong, proactive Conservation program that is part of regular operations and not just used in times of drought. Because of our strong conservation programming and long-term planning, Denver Water is well prepared to manage a drought. Denver Water is using our experience in the 2013 drought to help plan future conservation programming.
b. Enforcement costs (labor and materials)	n/r	n/r	n/r

Cost information for Denver Water

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
20. Ongoing/long-term outreach campaign			
c. Costs of providing rebates and other incentives	n/a	n/a	n/a
21. Temporary conservation measures, especially related to outdoor water use (voluntary or mandatory)			
a. Emergency outreach costs (labor and materials)	n/a	n/a	n/a
b. Enforcement costs (labor and materials)	4 staff - $40,000; 1 car $20,000	n/a	Denver Water has had an education and enforcement program, called Water Savers, since 2008. In 2013 we hired 4 more enforcement staff than we did in 2014 to help cover the greater need for education and enforcement during the drought. The cost of the additional salary for these four staff was about $40,000. Additionally, one additional car was leased in 2013 compared to 2014, and more vehicle miles driven in 2013 because there were more shifts for the Water Savers. Conservation staff were on-call during the drought, and as a result there was an additional cost of about $20,000 for this overtime and vehicles and miles. Denver Water created a water budget program for large irrigation customers during the 2012-2013 drought. This water budget program has continued after the drought and is now part of our regular Conservation programming. The cost of the water budget program would be the staff time to develop and run the program – about $40,000.
c. Costs of providing rebates and other incentives	n/r	n/r	n/r

Cost information for Denver Water

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
22. Retrofitting programs, use of low-flow fixtures			
a. Outreach costs (labor and materials)	n/a	n/a	n/a
b. Enforcement costs (labor and materials)	n/a	n/a	n/a
c. Costs of providing rebates and other incentives	$2.2 million (2013$)	$2.2 million	Denver Water has a rebate program as part of our regular Conservation programming. Denver Water did not alter the rebate program as a result of the 2012-2013 drought. Annual rebate program costs can vary slightly depending on conditions and budget. In 2013, the cost of Denver Water's rebate program for residential, commercial, industrial and governmental customers was approximately $2.2 million. It should be noted that a rebate program is a long-term water management tool and it not a short-term drought management tool.
23. Encourage climatically appropriate planting (e.g., Xeriscaping ordinances, HOA covenants)			
a. Outreach costs (labor and materials)	n/a - But estimated $25,000 cost savings (2013$)	n/a - But estimated $25,405 cost savings	Denver Water promotes outdoor irrigation efficiency and xeriscaping as part of our regular Conservation programming. In 2013 Denver Water conservation staff developed a pilot program that sent letters to single family residential customers that were highly inefficient in outdoor water use. The cost of this pilot program is staff time and small printing and mailing costs.

Cost information for Denver Water

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
23. Encourage climatically appropriate planting (e.g., Xeriscaping ordinances, HOA covenants)			
(continued)	n/a	n/a	In 2013 Denver Water did not offer a Garden-in-a-Box program (http://www.denverwater.org/AboutUs/PressRoom/9FE9E7C0-EA66-2AB4-3ECB2261B847275C/) because staff were concerned about establishing new plantings in the second year of a drought. The cost savings from not implementing this program are estimated to be $25,000. We did not increase outdoor programming as a result of the 2012-2013 drought.
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	n/a	n/a	n/a
24. Meter water deliveries			
a. Outreach costs (labor and materials)	n/a	n/a	n/a
b. Monitoring costs (labor and materials)	n/a	n/a	n/a
c. Enforcement costs (labor and materials)	n/a	n/a	n/a
d. Costs of providing rebates and other incentives	n/a	n/a	n/a
25. Encourage business/industry users to reuse and recycle			
a. Outreach costs (labor and materials)	$17,000 (2013$)	$17,276	Encouraging commercial customers to use water efficiently, reuse and recycle is part of our regular Conservation programming. In 2013, Denver Water spent about $17,000 on commercial and industrial efficiency contracts.
b. Costs of providing rebates and other incentives	n/a	n/a	n/a

Cost information for Denver Water

Rate Adjustment

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
26. Rate Structure			
a. Please provide your rate structure (to encourage conservation during drought and to protect revenue during drought)	n/a	n/a	Denver Water's rates can be found at: http://www.denverwater.org/BillingRates/RatesCharges/.
b. Were there additional costs associated with developing a new rate structure during drought conditions (e.g., did you hire a consultant)?	n/a	n/a	Denver Water did not change its rate structure as a result of the 2012-2013 drought. While Denver Water considered implementing drought pricing in 2013, conditions improved so drastically in April and May that we did not need to implement drought pricing. The only cost for this work would be staff time spent on developing the drought pricing methodology and recommendation. However, Denver Water has since hired a consultant to perform a rate structure study to look at ways to provide more revenue stability across various weather scenarios.

n/r = No response; utility did not provide response
n/a = Not applicable; utility marked this item as not applicable

Source: **Denver Water**
Date of Information Submitted: **1/9/2015; 2/6/15**

Cost information for Aurora Water

Background	
1. How many people and connections do you serve?	340,000 people
2. What was your overall revenue loss due to decreased demand during drought and over what time frame?	n/r

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
6. Hauling water			
a. Cost of buying wholesale water	n/a	n/a	n/a
b. Cost of moving water from one location to another	n/a	n/a	n/a
c. Cost of buying bottled water	n/a	n/a	n/a
d. Length of time water was hauled	n/a	n/a	n/a
7. Legal/administrative			
a. Cost of buying water from farmers in dry years (per gallon or other volume measure)	n/a	n/a	Currently not legal in Colorado.
b. Cost of transferring or acquiring new water rights (indicate volume of water acquired)	$10,000/acre-foot	n/a	Currently, in the South Platte.
8. New dams, reservoirs, and other major storage			
a. Capital costs	About $2,500/acre-foot	n/a	
b. Operations & maintenance costs	About $500,000/year for each structure	n/a	
c. Anticipated revenue (e.g., from hydropower)	n/r	n/r	n/r
9. New or deeper wells			
a. Capital costs	n/a	n/a	Currently no plans to drill more wells.
b. Operations & maintenance costs	n/r	n/r	n/r
10. Lower intakes			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a

Cost information for Aurora Water

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
11. Inter-connections with other utilities			
a. Costs of establishing infrastructure for inter-connections	n/a	n/a	Connections already exist.
b. Costs of buying water (per gallon or other volume measure)	$400/acre-foot	n/a	
12. Leaks detection			
a. Costs of detection technologies	n/r	n/r	n/r
b. Costs of repair	n/r	n/r	n/r
13. Repair and/or replace water mains			
a. Costs of repair	n/r	n/r	n/r
b. Costs of replacement	n/r	n/r	n/r
14. Prevent evaporation			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
15. Groundwater recharge/"water banking"			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a
16. Rainwater harvesting			
a. Communication costs	n/a	n/a	Currently not legal in Colorado.
b. Costs of providing rebates or other incentives	n/a	n/a	See above.
17. Greywater reuse			
a. Communication costs	n/a	n/a	Currently not legal in Colorado.
b. Costs of providing rebates or other incentives	n/a	n/a	n/a

Cost information for Aurora Water

Supply Augmentation

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
18. Water reuse (recycling)			
a. Additional treatment costs	n/r	n/r	n/r
b. Capital costs	n/r	n/r	n/r
c. Storage costs	n/r	n/r	n/r
d. Costs of separate distribution network	n/r	n/r	n/r
e. Operations & maintenance costs	n/r	n/r	n/r
f. Communication costs (e.g., signage, outreach)	n/r	n/r	n/r
19. Desalination			
a. Capital costs	n/a	n/a	n/a
b. Operations & maintenance costs	n/a	n/a	n/a

Cost information for Aurora Water

Demand Management

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
20. Ongoing/long-term outreach campaign			
a. Outreach costs (labor and materials)	n/r	n/r	n/r
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	n/r	n/r	n/r
21. Temporary conservation measures, especially related to outdoor water use (voluntary or mandatory)			
a. Emergency outreach costs (labor and materials)	n/r	n/r	n/r
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	n/r	n/r	n/r
22. Retrofitting programs, use of low-flow fixtures			
a. Outreach costs (labor and materials)	n/r	n/r	n/r
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	n/r	n/r	n/r
23. Encourage climatically appropriate planting (e.g., Xeriscaping ordinances, HOA covenants)			
a. Outreach costs (labor and materials)	n/a	n/a	n/r
b. Enforcement costs (labor and materials)	n/r	n/r	n/r
c. Costs of providing rebates and other incentives	n/r	n/r	n/r
24. Meter water deliveries			
a. Outreach costs (labor and materials)	n/r	n/r	n/r
b. Monitoring costs (labor and materials)	n/r	n/r	n/r
c. Enforcement costs (labor and materials)	n/r	n/r	n/r
d. Costs of providing rebates and other incentives	n/r	n/r	n/r
25. Encourage business/industry users to reuse and recycle			
a. Outreach costs (labor and materials)	n/r	n/r	n/r
b. Costs of providing rebates and other incentives	n/r	n/r	n/r

Cost information for Aurora Water

Rate Adjustment

Drought Management Practice	Costs (as originally reported)	Costs in 2014$	Notes
26. Rate Structure			
a. Please provide your rate structure (to encourage conservation during drought and to protect revenue during drought)	n/r	n/r	n/r
b. Were there additional costs associated with developing a new rate structure during drought conditions (e.g., did you hire a consultant)?	n/r	n/r	n/r

n/r = No response; utility did not provide response

n/a = Not applicable; utility marked this item as not applicable

Source: **Aurora Water**

Date of Information Submitted: **3/19/2015**

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ABBREVIATIONS

4CORE	Four Corners Office for Resource Efficiency
AC_t	annual cost in year t
ACWA	Association of California Water Agencies
AMEC	AMEC Earth and Environmental
ASR	aquifer storage and recovery
AWE	Alliance for Water Efficiency
AWWA	American Water Works Association
B/C	benefit-cost ratio
B_t	benefit in year t
CAWCD	Central Arizona Water Conservation District
CCWS	Cobb County Water System
CCMWA	Cobb County-Marietta Water Authority
CE	cost-effectiveness
CPI	Consumer Price Index
CPO	Climate Program Office
CRMWD	Colorado River Municipal Water District
CRWA	Canyon Regional Water Authority
C_t	cost in year t
CUWCC	California Urban Water Conservation Council
CVM	contingent valuation method
EAA	Edwards Aquifer Authority
EID	El Dorado Irrigation District
EPA	U.S. Environmental Protection Agency
EPD	Georgia Environmental Protection Division
ESP	Ensemble Streamflow Prediction
FTE	full-time equivalent
FY	Fiscal year
GA DNR	Georgia Department of Natural Resources
GCPD	Gallons per capita daily
HB	House Bill
IC	initial capital costs
IPR	indirect potable reuse

LADWP	Los Angeles Department of Water and Power
LCRA	Lower Colorado River Authority
LRWRP	Long Range Water Resources Plan
MG	million gallons
MGD	million gallons per day
MUD	Municipal Utility District
MWCOG	Metropolitan Washington Council of Governments
MWD	Metropolitan Water District of Southern California
n	period of years
NASA	National Aeronautics and Space Administration
NDMC-UNL	National Drought Mitigation Center, University of Nebraska-Lincoln
NIDIS	National Integrated Drought Information System
NOAA	National Oceanic and Atmospheric Administration
NPV	net present value
NRDC	Natural Resources Defense Council
O&M	operations and maintenance
OMB	Office of Management and Budget
PAWSD	Pagosa Area Water and Sanitation District
PV	present value
r	discount rate
RCP	Representative Concentration Pathway
SARP	Sectoral Applications Research Program
SAWS	San Antonio Water System
SCVWD	Santa Clara Valley Water District
SCWA	Sonoma County Water Agency
SDCWA	San Diego County Water Authority
SNWA	Southern Nevada Water Authority
SP	simple payback period
SWRCB	State Water Resources Control Board
SWSI	Surface Water Supply Index
USGCRP	United States Global Change Research Program
USGS	United States Geological Survey
U_t	units of water saved

WERF	Water Environment Research Foundation
WMP	Water Management Plan