# Chapter 10

# Water: Impacts, Risks, and Adaptation


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## Executive Summary


This chapter focuses on societal vulnerabilities to impacts from changes in sources, timing, quantity, and quality of the Southwest's water supply. It addresses both vulnerabilities related to environmental factors (such as wildfire risk and increased stream temperatures) and issues related to water management (such as water and energy demand, and reservoir operation). The chapter describes water management strategies for the coming century, including federal, regional, state, and municipal adaptation initiatives.

- The water cycle is a primary mechanism by which the earth redistributes heat. Climate change has already altered the water cycle and additional changes are expected. A large portion of the Southwest is expected to experience reductions in streamflow and other water stresses in the twenty-first century (Bates et al. 2008; Karl, Melillo and Peterson 2009; Seager and Vecchi 2010; Reclamation 2011d). (high confidence)
- Changes in water supplies lead to a wide range of societal vulnerabilities that impact almost all human and natural systems, including agriculture, energy, industry, domestic, forestry, and recreation (Westerling et al. 2006; Ray et al. 2008; Williams et al. 2010). (high confidence)
- Considerable resources are now being allocated by larger water entities to understand how to adapt to a changing water cycle. A full range of solutions involving both supply and demand are being examined. Most smaller utilities have not begun the process of adapting. To date, adaptation progress has been modest (Reclamation 2011a; WUCA 2010). (high confidence)



**Chapter citation:** Udall, B. 2013. "Water: Impacts, Risks, and Adaptation." In *Assessment of Climate Change in the Southwest United States: A Report Prepared for the National Climate Assessment*, edited by G. Garfin, A. Jardine, R. Merideth, M. Black, and S. LeRoy, 197–217. A report by the Southwest Climate Alliance. Washington, DC: Island Press.

- There is a mismatch between the temporal and spatial scales at which climate models produce useful outputs and the scales that are useful to water decision makers. Differing temperature and precipitation responses across models, lack of realistic topography, lack of realistic monsoon simulation, and lack of agreement about the future characteristics of the El Niño-Southern Oscillation (ENSO) all provide significant uncertainty. It is not clear if this uncertainty can be reduced (Nature Editorial Board 2010; Kerr 2011a, 2011b; Kiem and Verdon-Kidd 2011). (high confidence)
- Water supplies in the Southwest are already stressed due to many non-climatic factors. Population growth, endangered species, expensive infrastructure, and legal and institutional constraints all impede solutions. Both climate and non-climate stresses and barriers must be addressed to achieve practical solutions (Reclamation 2005; Lund et al. 2010). (high confidence)
- Twentieth-century water management was based in part on the principle that the future would look like the past. Lack of a suitable replacement for this principle, known as *stationarity*, is inhibiting the process of adaptation and the search for solutions (Reclamation 2005; Milly et al. 2008; NRC 2009; Means et al. 2010; Kiem and Verdon-Kidd 2011). (high confidence)
- Data collection, monitoring, and modeling to support both science and management are critical as the water cycle changes (WestFAST 2010). (high confidence)

## 10.1 Introduction

This chapter breaks with traditional climate change assessments of the water sector by focusing primarily on emerging adaptation activities being pursued by water providers rather than on either the changes to water cycle or impacts and risks to, and vulnerabilities of, human and natural systems. This altered focus occurs because the mandate of this assessment was to identify important new findings since 2009, the date of the last U.S. national assessment on climate change (Karl, Melillo and Peterson 2009). In most cases, the science about water-cycle changes and human and natural system impacts, risks, and vulnerabilities has changed little over the last three years. During this same period, however, numerous adaptation initiatives have been pursued by water managers and providers in the West. These activities are predominantly new, important, and pertinent to this assessment. It is critical to note that these nascent efforts have produced important documents and networks of knowledgeable experts, but few other tangible products or projects.

In the interest of providing a broader context to these adaptation initiatives, this chapter also summarizes some important information from traditional water-sector assessments about water-cycle changes, impacts, risks, and vulnerabilities. Much of this information is also present in other chapters of this assessment but is repeated here for completeness.

This chapter provides a broad historical overview of water development in the Southwest; briefly discusses the physical impacts to the water cycle that occurred prior to the twentieth century (as deduced from paleoclimate proxies), have occurred during the twentieth century, and are projected to occur in the twenty-first century (material covered in more detail in Chapters 4, 5, 6 and 7); provides a survey of the impacts, risks, and associated vulnerabilities to human and natural systems deriving from changes to the water cycle; and then presents in detail adaptation activities being pursued at different levels of government. Boxes within the chapter discuss the SECURE Water Act, and vulnerabilities to the Colorado River and the Sacramento-San Joaquin Bay Delta complex (see also discussion of Rio Grande Basin in Chapter 16, Section 16.5.1).

THE SUPER SECTOR. For more than 100 years, Southwestern water managers at all levels of government have managed to deliver water to homes, industry, and agriculture through periods of excess and of shortage. These deliveries occurred reliably despite population growth in the six Southwestern states from approximately 5 million persons in the early 1900s to about 56 million in 2010. The passage of the federal 1902 Reclamation Act and numerous state, regional, and municipal actions led to the development of substantial water infrastructure in the West. This infrastructure now serves many purposes, including for agricultural and municipal supplies, recreation, flood control, and environmental needs.

Interstate compacts apportioned the flow of rivers among and between states, while throughout most of the West the doctrine of prior appropriation[i] determined how water was allocated within states (Wilkinson 1992; Hundley 2009). As increases in consumptive use (water that is not returned to a water system after use, as for example water lost through evapotranspiration of crops) occurred during the twentieth century, environmental conflicts arose on almost all Western rivers (Reisner 1993). Water demands for endangered species and other environmental purposes in recent years also have altered water management practices (NRC 2004; Adler 2007; NRC 2010). During the twentieth century, water diversions by humans have substantially reduced flows at river mouths (Pitt et al. 2000; Lund et al 2010; Sabo et al. 2010).

In recent years, municipal per capita water demand has been on a downward trend over large portions of the Southwest. Many discussions are occurring throughout the West on how to manage water in the twenty-first century under conditions of multiple stresses (Isenberg et al. 2007; Colorado Interbasin Compact Committee 2010; Blue Ribbon Committee of the Metropolitan Water District 2011; Reclamation 2011a).

Water is a "super sector" that has direct and indirect connections to perhaps all natural and human systems. In many cases water has no substitute. Agriculture relies on water provided by irrigation. Energy production usually needs water for cooling, just as the transport of water often requires substantial energy. Native Americans rely upon water for agriculture and also to fulfill traditional cultural and spiritual needs. Ecosystems depend critically on the quality, timing, and amounts of water. It is difficult to overstate the importance of water, especially in the arid Southwest.

## 10.2 Physical Changes to the Water Cycle

The water cycle is an important physical process that transports and mixes heat globally and locally. Widespread changes to the water cycle are anticipated as the earth warms and many changes have already been noted that are related to precipitation patterns and intensity; incidence of drought; melting of snow and ice; atmospheric vapor, evaporation, and water temperatures; lake and river ice; and soil moisture and runoff (Karl, Melillo and Peterson 2009). Global climate models have consistently shown such changes—including the magnitude and direction (increases or decreases) and spatial patterns of these changes—since the earliest days of climate modeling (Manabe and Wetherald 1975).

Widespread changes to the climate of the Western United States have occurred over the last fifty years. These include higher temperatures, earlier snowmelt runoff, more rain, less snow, and shifts in storm tracks. Some of these changes have been directly attributed to human activities, such as greenhouse gas (GHG) emissions (Barnett et al. 2008). During the same period, no changes have been detected in the region's total annual precipitation or in daily extreme precipitation (Chapter 5).

As discussed in Chapter 5, paleoclimate studies indicate that the period since 1950 has been warmer in the Southwest than during any comparable period in at least 600 years. Reconstructions of drought (from tree rings and other "proxy" records) indicate that the most severe and sustained droughts during the period 1901 through 2010 were exceeded in severity and duration by several paleodroughts in the preceding 2,000 years.

Recent research suggests that the deposition of airborne dust on snowpack in the Colorado River Basin has reduced runoff by 5% on average (Painter et al. 2010). Such dust has become more prevalent since European settlement of the American West.

In addition, recent research confirms a long-standing concern that the large spatial scales in the current generation of global climate models (GCMs) poorly represent the effects of topography on precipitation processes, especially in the Intermountain West (Rasmussen et al. 2011). Numerous studies using GCMs have attempted to quantify the effects of increasing temperatures and changes in precipitation on future runoff in the Southwest. In general these studies show declines in the southern Southwest and increases in the northern Southwest (see Chapter 6). Almost all studies show decreasing April 1 snow water equivalent (the amount of water contained in a snowpack), and declines in late summer runoff (Brekke et al. 2007; Ray et al. 2008; Reclamation 2011d).

Sensitivity studies attempt to quantify future changes in runoff without relying on GCM projections that combine changes in temperature and precipitation. Using a hydrology model driven by temperature and precipitation when temperature is varied and precipitation is held constant for every 1°F (0.6°C) increase in temperature, sensitivity studies show there is a decrease in Colorado River streamflow at Lees Ferry of 2.8% to 5.5%. Similarly, holding temperature constant, each 1% change in precipitation (either an increase or decrease) converts into a 1% to 2% change in runoff (Vano, Das, and Lettenmaier 2012).

The state of Colorado recently estimated that in the Upper Colorado River Basin, irrigated-agriculture requirements could increase by 20% and the growing season could lengthen by 18 days in 2040 (AECOM 2010). Demand studies are highly dependent on the method used to calculate actual and potential evapotranspiration[ii] (Kingston et al. 2009).

## 10.3 Human and Natural Systems Impacts, Risks and Vulnerabilities

Climate change will affect a large number of human and natural sectors that rely on water. Many of these impacts have been well documented, both in this report and elsewhere

(Kundzewicz 2007; Bates et al. 2008; Ray et al. 2008; CDWR 2009a). A short summary of these issues follows.

Water demands for agriculture and urban outdoor watering will increase with elevated temperatures. Higher temperatures will raise evapotranspiration by plants, lower soil moisture, lengthen growing seasons, and thus increase water demand.

Changes in snowpack, the timing of streamflow runoff, and other hydrologic changes may affect reservoir operations such as flood control and storage. For example, reservoirs subject to flood control regulations may need to evaluate their operations to compensate for earlier and larger floods. Reduced inflows to reservoirs may cause insufficient or unreliable water supplies (Rajagopalan et al. 2009). Changes in the timing and magnitude of runoff will affect the operation of water diversion and conveyance structures.

Although other factors such as land-use change generally have a greater impact on water quality, "water quality is sensitive both to increased water temperatures and changes in patterns of precipitation" (Backlund et al. 2008, p.8). For example, changes in the timing and rate of streamflow may affect sediment load and levels of pollutants, potentially affecting human health. Heavy downpours have been associated with beach closings in coastal areas due to the flushing of fecal material through storm drains that end at the ocean (Karl, Melillo and Peterson 2009). Water quality changes are expected to impact both urban and agricultural uses.

Stream temperatures are expected to increase as the climate warms, which could have direct and indirect effects on aquatic ecosystems, including the spread of in-stream, non-native species and aquatic diseases to higher elevations, and the potential for non-native plant species to invade riparian areas (Backlund et al. 2008). Changes in streamflow intensity and timing may also affect riparian ecosystems; see further discussion in Chapter 8.

Changes in long-term precipitation and soil moisture can affect groundwater recharge rates. This may reduce groundwater availability in some areas (Earman and Dettinger 2011). Also, higher sea levels can promote the intrusion of salt water into coastal freshwater aquifers (Sherif and Singh 1999).

Earlier runoff and changes in runoff volumes may complicate the allocation of water in prior-appropriation systems and interstate water compacts, affecting which rightholders receive water and operations plans for reservoirs (Kenney et al. 2008). In one study, the City of Boulder, Colorado, found that its upstream junior reservoir storage rights may allow more storage of water when runoff occurs earlier in the year, because downstream senior agricultural diverters will not be able to use the water during shorter daylight hours (Averyt et al. 2011). Reductions in Colorado River flows could affect the multi-state allocation of water via the Colorado River Compact (Barnett and Pierce 2008).

Water demands and their associated pumping and treatment costs may be affected by a changing climate. Warmer air temperatures may place higher demands on hydropower reservoirs for peak energy periods. Reductions in flows for hydropower or changes in timing may reduce the reliability of hydropower. Reliable, instantaneously available hydropower is currently used in some cases to backup intermittent renewable energy sources. Warmer lake and stream temperatures may mean more water must be used to cool power plants (Carter 2011).

**Box 10.1**

## *Colorado River Vulnerabilities*

The Colorado River drains approximately 15% of the area of the continental United States and most of the American Southwest. In the United States it serves over 35 million people in seven states and irrigates over 3 million acres. In Mexico it irrigates over 500,000 acres and also meets some limited municipal demand along the international border. The river is subject to a series of interstate compacts including the original 1922 compact, legal rulings, federal legislation, and an international treaty. This "Law of the River" is said to be the most complex legal arrangement over any river in the world. Changes to any of the agreements generally take years of negotiations.

Although the river has been over-allocated for many years, only in recent years have actual demands exceeded supplies. The U.S. Bureau of Reclamation, which has a prominent role in overseeing the river, projects this imbalance to widen in the coming years due to increasing growth and declining flows due to climate change (Reclamation 2011a). For allocation purposes the compact breaks the river into two parts, the Upper Basin (Wyoming, Colorado, Utah and New Mexico) and the Lower Basin (California, Arizona, and Nevada) (Meyers 1967).

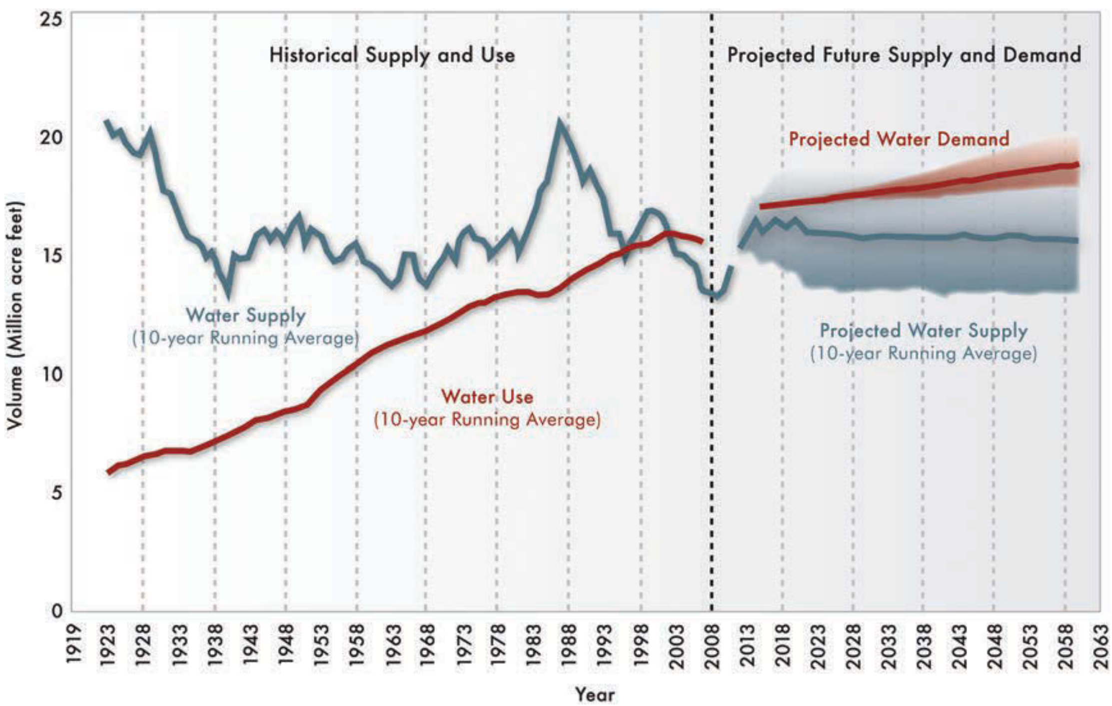


**Figure 10.1 Colorado River long-term supply-demand imbalance in the twenty-first century.** Reproduced from the U.S. Bureau of Reclamation (Reclamation 2011a).

**Box 10.1 (Continued)**

*Colorado River Vulnerabilities*

There are two major social vulnerabilities in the basin, one for the Upper Basin, and one for the Lower Basin.

For the Upper Basin, it is not known how much additional water (if any) exists to develop. This uncertainty is due to both natural climate variability as well as a wide range of projected future declines in flows. These declines are projected to range from 5% to 20% by 2050 (Hoerling et al. 2009). Overuse of water and hence violation of the 1922 Compact by the Upper Basin could lead to the curtailment of water to major Upper Basin water users (including Albuquerque, Salt Lake City, Denver, and most other Front Range municipalities in Colorado), with potentially very large economic impacts. Despite the uncertainty of future water availability and the consequences of overdevelopment, plans to develop additional supplies are being discussed in Colorado and Utah. Colorado is currently investigating how to administer such an unprecedented event (Kuhn 2009).

The Lower Basin is currently relying on unused water from the Upper Basin to which it has no long-term legal right. If this surplus of unused water were to cease to be available either because of climate change or increased Upper Basin use, the Law of the River would force water shortages almost entirely on Arizona (Udall 2009). Arizona has long been unsuccessful at its attempts to procure a larger share of Colorado flows to cover its current overuse. In addition, the current legal arrangements to protect Lake Mead contents by requiring delivery reductions at specified lake elevations fail to indicate what actions will be taken once Lake Mead falls below elevation 1025 feet, approximately 25% of capacity. Several recent studies have suggested that Lakes Mead and Powell, the two largest reservoirs in the United States, could face very large fluctuations or even empty under Upper Basin demand increases and declining flows (Barnett and Pierce 2008; Rajagopalan et al. 2009).

There are also significant environmental vulnerabilities. The Colorado River also has a number of endangered species in both the Upper Basin and Lower Basin. Although an endangered fish recovery program is in place in the Upper Basin and a multi-species conservation plan exists for the Lower Basin (Adler 2007), in recent years no water has reached the ocean in Mexico. Without new international arrangements, environmental flows in this reach are unlikely to occur on a regular basis (Luecke et al. 1999; Pitt et al. 2000; Pitt 2001). The United States and the seven basin states would like Mexico to share in any shortages that may be required to manage the system during extraordinary drought. Although such shortages were anticipated by the 1922 Compact, no agreement has been reached. Transnational negotiations are in progress with Mexico to resolve deliveries to that nation during extraordinary drought.

A study supported by Reclamation and the seven basin states is currently underway to identify and analyze long-term solutions for the supply/demand imbalance.

Changes in air, water, and soil temperatures will affect the relationships among forest ecosystems, surface and ground water, wildfires, and insect pests. Water-stressed trees, for example, are more vulnerable to pests (Williams et al. 2010).

The effects of forest fires alter the timing and amount of runoff and increase the sediment loads in rivers and reservoirs. Denver Water, for example, has expended considerable resources to dredge sediment from reservoirs after recent fires (Yates and Miller 2006).

Changes in reservoir storage will affect lake recreation, just as changes in streamflow timing and amounts affect such activities as rafting and trout fishing. Changes in the character and timing of precipitation and the ratio of snowfall to rainfall will continue to influence winter recreational activities and tourism (Ray et al. 2008).

**Box 10.2**

## *Sacramento-San Joaquin Bay Delta Vulnerabilities*

The functioning of the Sacramento–San Joaquin Bay Delta is the most critical water issue in California and arguably the most pressing water problem in the United States. This confluence of California's two major river systems—the largest estuary on the West Coast—is used as a natural conveyance facility to move water for 25 million people. Seventy percent of the state's water moves southward from the Sacramento River, through the delta, to canals that supply both Central Valley agriculture and the municipal and industrial demands in the Los Angeles metroplex.

The delta has been substantially modified by humans from its original state and is highly vulnerable to shutdown due to both physical and legal issues (CDWR 2005; NRC 2010, 2011, forthcoming). Within the delta, approximately sixty islands sit below or near sea level and are protected by 1,300 miles of aging levees. These levees are subject to failure from sea-level rise, subsidence, freshwater flooding, earthquakes, and poor levee maintenance (Mount and Twiss 2005) . Failure of the levees from any cause could cause a massive influx of sea water from the San Francisco Bay into the freshwater delta, thus curtailing the movement of freshwater through the delta. Disruption of the flow could cost upwards of $30 billion and require many years to fix (Benjamin and Assoc. 2005). Both the State Water Project and the federal Central Valley Project are at risk (CDWR 2009b; Lund et al. 2010).

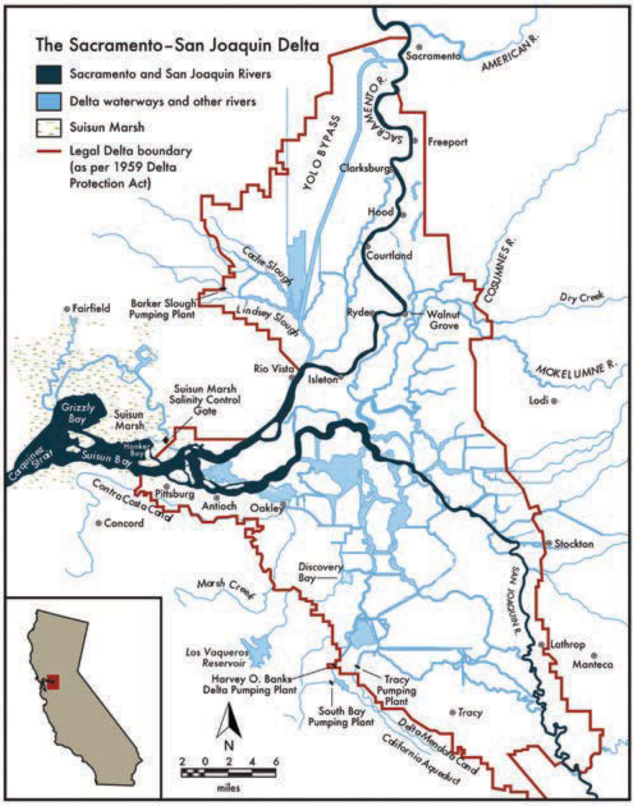


**Figure 10.2 Map of Sacramento-San Joaquin Bay Delta.** Reproduced with permission from the Public Policy Institute of California (Lund et al. 2007, Figure 1.1).

**Box 10.2 (Continued)**

*Sacramento-San Joaquin Bay Delta Vulnerabilities*

In addition to its physical vulnerabilities, the delta also is home to several threatened and endangered species and many invasive species. To protect endangered species, the cross-delta pumps have been shut down for short periods in recent years by federal court order (NRC 2010).

A $11 billion bond issue has been proposed to build a canal around the periphery of the delta but has not yet been put on the ballot in part due to California's continuing budgetary problems and disputes over the impacts of the canal. In 1982, a similar peripheral canal was heavily rejected by voters (Orlob 1982; Hundley 2001).

Besides its vulnerable water infrastructure, the delta is traversed by other key infrastructure including major north-south and east-west highways, electrical power lines, gas lines, and rail lines, all of which are threatened by flooding from the two rivers and by sea-level rise (Lund et al. 2010).

All of these factors have created a contentious situation. Over the last ten years, federal, state, municipal, agricultural, and environmental interests have engaged in a variety of complex and expensive stakeholder initiatives in an attempt to create solutions acceptable to all parties (Owen 2007; Isenberg et al. 2007; Isenberg et al. 2008).

## 10.4 Water Sector Adaptation Activities

Federal, state, regional, and municipal water management entities over the last five years or so have made substantial investments to understand the physical impacts to water supplies under a changing climate. Additional but more limited work has focused on societal vulnerabilities to these impacts. Many supply-side and demand-side adaptation strategies and solutions are now being considered. The principal challenges and barriers to climate-change adaptation include (1) uncertain, rapidly moving, and, in some cases, contentious scientific studies, and (2) physical, legal, and institutional constraints on strategies and solutions. Adaptation strategies and solutions are generally very specific to a region, limiting widespread application. Twentieth-century water planning was based in part on the idea that climatic conditions of the past would be representative of those in the future; but this model is much less useful in the twenty-first century. Reservoir size, flood control operations, and system yield calculations were all predicated on this important concept, known as stationarity. Replacing this fundamental planning model, or paradigm, is proving to be extremely difficult (Milly et al. 2008; Barsugli et al. 2009; CDWR 2009a; Brown 2010). The unreliability of regional projections has hindered planning efforts; water managers cannot simply replace historical flow sequences in their planning models with projected flows (Kerr 2011b). The rest of this section describes the various adaptation activities being pursued by water managers in the Southwest.

## 10.5 Planning Techniques and Stationarity

In the late twentieth century, water planning was aided by simulation models driven by historic flow sequences. Flow sequences derived from paleoclimatic evidence were later added to these simulations to test systems under further or more extreme climate variability. Scientists who conducted early climate-change studies used the same simulation models driven by crude GCM-derived future-flow sequences. As statistical downscaling became prevalent (see Chapter 6), hydrology models were used to construct streamflows using highly resolved spatial and temporal inputs of temperature, precipitation, and sometimes other variables. Ultimately, a number of concerns surfaced after deeper analysis of these projections occurred.

GCM-related concerns include widely varying future GHG emissions pathways, differing climate-model responses to GHGs, poorly resolved topography, varying responses to the North American monsoon, and wide ranges of projected precipitation. Concerns about statistical downscaling arose from its use of historical climate data (with the implicit acceptance of stationarity) to build statistical models and from the substantially different results obtained using equally valid statistical techniques. Collectively, these issues caused debate about the suitability of adaption actions relying on GCM projections (Kerr 2011a, 2011b). (See the section on model uncertainties in Chapter 19 for further exploration of this topic.)

Some scientists have cautioned about overreliance on climate change science that is regionally focused (Nature Editorial Board 2010). Water managers have now begun to investigate other methods for decision support, including decision analysis,[iii] scenario planning,[iv] robust decision making,[v] real options,[vi] and portfolio planning[vii] (Means et al. 2010).

In the absence of an alternative to assuming stationarity in management and planning, the National Research Council suggests that "Government agencies at all levels and other organizations, including in the scientific community, should organize their decision support efforts around six principles of effective decision support: (1) begin with users' needs; (2) give priority to process over products; (3) link information producers and users; (4) build connections across disciplines and organizations; (5) seek institutional stability; and (6) design processes for learning" (NRC 2009, p. 2).

## 10.6 Potential Supply and Demand Strategies and Solutions

Water strategies and solutions to meet the needs of Southwestern population growth range from increasing supplies to decreasing demands. Many of these could also be employed as climate-change adaptation strategies. Examples of these strategies include new dams (in California and Colorado), desalination (San Diego), basin imports via pipeline (in St. George, Utah, and the Front Range of Colorado), municipal conservation, permanent transfers from agriculture (Colorado Springs), water markets, land fallowing (Los Angeles), canal lining (San Diego), retirement of grass lawns through financial incentives (Las Vegas), groundwater banking (Arizona), water re-use (Orange County, California. and Aurora, Colorado), new water rate structures, consumer education, indoor fixture rebates (Denver), new landscape and xeriscape design, water-loss management from leaky mains, and aquifer storage and recovery (Arizona) (Western Resource Advocates 2005). Per-capita demand in recent years has been reduced in many Southwestern cities through active demand-management programs (Gleick 2010; Cohen 2011) (see also Chapter 13, Figure 13.10).

## 10.7 Barriers to Climate Change Adaptation

Effective climate-change adaptation will require advancements in climate science. As mentioned above, climate models and downscaling are not yet creating projections that can adequately and accurately inform adaptation efforts. Climate variability—both in nature and in climate model projections—can also confound analysis and adaptation planning. Among others, the Water Utility Climate Alliance suggests that climate model outputs suitable for water resource decision making may be a decade or more away (Barsugli et al. 2009). Model improvements in precipitation projections are unlikely to occur in the near-term to medium-term (Hawkins and Sutton 2011).

Adaptation is also constrained by numerous non-climate factors. Western water management in particular is limited by a variety of federal and state laws, interstate compacts, court cases, infrastructure capacities, hydropower considerations, and regulations pertaining to flood control, endangered species, and environmental needs. Infrastructure is also expensive to build and maintain. Many solutions improve one area's welfare at the expense of another and numerous stakeholder groups desire input into the process. Solutions can take years to discover and implement (Coe-Juell 2005; Jenkins 2008). All of these factors must be considered when designing responses.

## 10.8 Federal Adaptation Initiatives

The federal government has twenty or more agencies with an interest in water management (Udall and Averyt 2009). Historically, coordination of these agencies has been limited, but the last five years has seen the birth of many interagency adaptation activities related to water. A 2009 federal law, the SECURE ("Science and Engineering to Comprehensively Understand and Responsibly Enhance") Water Act (Public Law 111-11), provided the impetus for some of the coordination. New interagency coordinating groups include Climate Change and Water Working Group (CCAWWG), the Western Federal Agency Support Team (WestFAST), and the Water Resources Working Group of the Council on Environmental Quality's Interagency Climate Change Adaptation Task Force. Other federal collaborative efforts include the National Integrated Drought Information System (NIDIS), NOAA's Regional Integrated Sciences and Assessments (RISA), EPA's Climate Ready Water Utilities Working Group, and the DOI Landscape Conservation Cooperatives and Climate Science Centers. Federal climate-change adaptation efforts are in an early formative stage, but they can be expected to grow and evolve in the coming years (WestFAST 2010; Interagency Climate Change Adaptation Task Force 2011). (Relatedly, see Chapter 2, Table 2.1 for a selected list of federal-agency climate assessments that also, directly or indirectly, address issues of water resources.)

## 10.9 SECURE Water Act Overview

The SECURE Water Act directed the U.S. Bureau of Reclamation to establish a climate-change adaptation program in coordination with the U.S. Geological Survey (USGS), National Oceanic and Atmospheric Administration (NOAA), state water agencies, and NOAA's university-based RISA program. Other sections of the act authorized grants to improve water management, required assessment of hydropower risks, created an intra-governmental climate-change and water panel, promoted enhanced water data collection, and called for periodic water-availability and water-use assessments. (See Box 10.3 for specific Department of the Interior implementation actions since its passage.)

**Box 10.3**

### *Department of the Interior SECURE Implementation Actions*

Congress passed the SECURE Water Act to promote climate-change adaptation activities in the federal government, especially within the Department of the Interior. The department established the WaterSMART program to assist with the implementation of the Act in 2010. Among other activities, WaterSMART has funded twelve "basin studies" in the West, six of which are in the Southwest. Basin studies investigate basins where supply and demand imbalances exist or are projected, and define options for meeting future demands. Each basin study will provide projections of future supply and demand, analyze how existing infrastructure will perform in the face of changing water supplies, develop options to improve operations, and make recommendations for optimizing future operations and infrastructure. The Colorado River was one of the first basin studies announced and an interim report for this study was released in early 2011 (Reclamation 2011a)

**Table 10.1** Selected projections for natural flows in major southwest rivers in 2020, 2050, and 2070

| Gauge Location | 2020s Median Flow | 2050s Median Flow | 2070s Median Flow |
|---|---|---|---|
| Colorado River above Imperial Dam | -2% | -7% | -8% |
| Colorado River at Lees Ferry | -3% | -9% | -7% |
| Rio Grande at Elephant Butte Dam | -4% | -13% | -16% |
| Sacramento River at Freeport | 3% | 3% | -4% |
| Sacramento-San Joaquin Rivers at Delta | 3% | 1% | -4% |
| San Joaquin River at Friant Dam | 1% | -9% | -11% |

Note: Changes are relative to simulated 1990-1999.

Source: Reclamation (2011d).

**Box 10.3 (Continued)**

*Department of the Interior SECURE Implementation Actions*

with completion anticipated in 2012. Other Southwest basin studies underway include the Truckee River in California, the Klamath River in California and Oregon, and the Santa Fe River in New Mexico. Preliminary studies were also begun in 2011 for the Greater Los Angeles area and the Sacramento–San Joaquin Basin.

SECURE requires regular reports to Congress beginning in 2012 and every five years thereafter. In April 2011, Reclamation released its first report which quantified the risks from climate change to the quantity of water resources in seven Reclamation basins, defined the impacts of climate change on Reclamation operations, provided a mitigation and adaptation strategy to address each climate change impact, and outlined its coordination activities with respect to the USGS, NOAA, USDA and appropriate state water resource agencies (Reclamation 2011c).

Reclamation has also issued other SECURE documents. In March 2011, Reclamation released bias-corrected and spatially downscaled surface-water projections for several large Reclamation basins as part of a "West-wide Climate Risk Assessment" (Reclamation 2011d). Reclamation acknowledges that the projections suffer from a lack of model calibration and that this problem must be addressed in the next iteration of projections. Projections for 2050 showed anticipated declines of around 10% in annual runoff in the southern portion of the Southwest with a distinct north to south gradient of declining flows (see Table 10.1 and Figure 10.3).

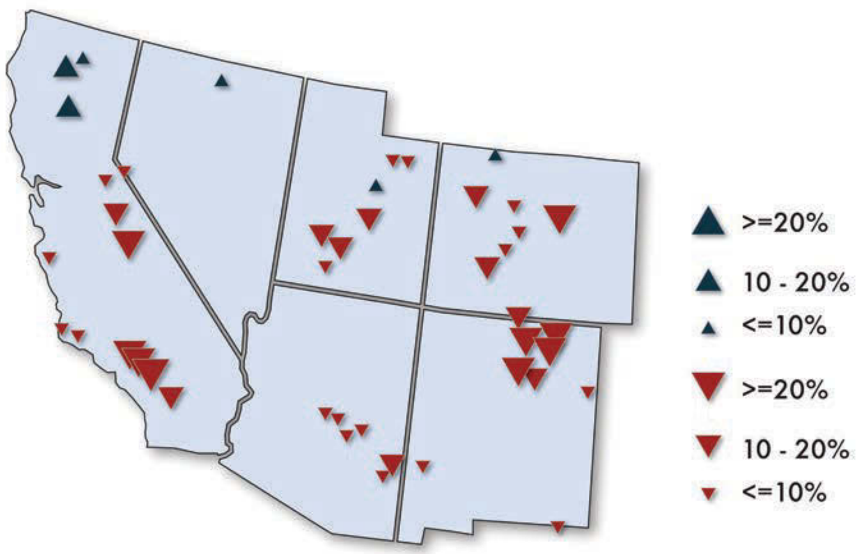


**Figure 10.3 Ensemble median percentage change in annual runoff (2050s vs. 1990s) in the Southwest region.** Reproduced from the U.S. Bureau of Reclamation (Reclamation 2011d, Figure 65).

## 10.10 Western States Federal Agency Support Team (WestFAST)

WestFAST is a collaboration among eleven federal agencies with water management responsibilities in the West (WestFAST 2011). The effort began in 2008 to coordinate federal water resource management goals with the needs of the Western States Water Council and its parent, the Western Governors' Association. WestFAST works on (1) climate change, (2) water availability, water use and re-use, and (3) water quality. In 2010, WestFAST produced an inventory of its agency efforts on water and climate change, and supported NIDIS and the newly created Landscape Conservation Cooperatives (WestFAST 2010).

## 10.11 Climate Change and Water Working Group (CCAWWG)

In 2007, NOAA, Reclamation, and USGS jointly created CCAWWG. The group was later expanded to include the Environmental Protection Agency, the U.S. Army Corps of Engineers, and the Federal Emergency Management Agency, and the name was changed slightly to reflect its now national scope. The purpose of this ongoing effort is to work with water managers to understand their needs, and to foster collaborative efforts across the federal and non-federal scientific community to address these needs in a way that capitalizes on interdisciplinary expertise, shares information, and avoids duplication.[viii]

CCAWWG produced a document in 2009 describing the challenges of adapting to climate change (Brekke et al. 2009). In addition, CCAWWG plans to produce four related documents, two on user needs and on two on science strategies, one each for short-term and long-term problems. The long-term user needs assessment was released in 2011 (Brekke et al. 2011). In 2010, CCAWWG published a literature synthesis of climate change studies for use in planning documents such as environmental impact statements and biological assessments under the Endangered Species Act. This document was updated in 2011 (Reclamation 2011b). The geographic focus of these literature syntheses is the Upper and Lower Colorado and the Sacramento-San Joaquin basins. CCAWWG, along with the RISAs, recently started an authoritative training program to facilitate the translation and application of emerging science and technical capabilities into water-resource planning and technical studies.

## 10.12 State Adaptation Efforts

Most Southwestern states have begun to categorize the impacts of climate change on water supplies. New Mexico, Utah, Colorado, and California have produced documents describing climate impacts on water resources and, in some cases, societal vulnerabilities to water resources under a changing climate (D'Antonio 2006; Steenburgh et al. 2007; Ray et al. 2008; CDWR 2009a).

The state of California has invested heavily in climate-change studies relating to water resources (Vicuna and Dracup 2007). In 2006, California released *Progress on Incorporating Climate Change into Management of Water* (CDWR 2006). Its 2009 state water plan contains substantial analysis of the impacts of climate change and the strategies necessary to adapt to it (CDWR 2009a). The California Energy Commission, with independent funding, has solicited numerous reports on the impacts of climate change on water, energy, agriculture, and many other topics and has worked closely with other state agencies.[ix]

In 2008, Colorado Front Range water utilities, in partnership with the Colorado Water Conservation Board (CWCB), the Water Research Foundation, and the Western Water Assessment RISA, investigated the impacts of climate change with the Joint Front Range Climate Variability Study (Woodbury et al. 2012). In 2010, the CWCB also funded the Colorado River Water Availability Study to assess changes in the timing and volume of runoff in the Colorado River Basin under several climate change scenarios for 2040 and 2070 (AECOM 2010). Colorado produced a directory of state adaptation activities related to climate variability and climate change in 2011 (Averyt et al. 2011).

Despite all of this adaptation-focused information-gathering activity in the Southwest, few if any water-related decisions have been made due to these actions. This is in part due to the wide range of projections for both temperature increases and precipitation changes from climate models. Decision makers everywhere are struggling to obtain *actionable science*, defined as “data, analysis, forecasts that are sufficiently predictive, accepted and understandable to support decision making” (Kerr 2011a, 1052). A related issue is modification of decision making and planning processes to incorporate non-stationarity.

## 10.13 Regional and Municipal Adaptation Efforts

The Water Utility Climate Alliance (WUCA), a consortium of ten large water utilities serving 43 million persons across the United States, was created in 2007 to (1) improve and expand climate-change research, (2) promote and collaborate in the development of adaptation strategies, and (3) identify and minimize greenhouse gas emissions. WUCA and participating scientists have published two documents, one on how to improve climate models and the other on useful techniques for decision making under uncertainty (Barsugli et al. 2009; Means et al. 2010). Six of the ten WUCA utilities are located in the Southwest. WUCA members serve on climate-related research review panels, have provided keynote addresses at major conferences, and are on the Federal Advisory Committee for the 2013 National Climate Assessment. Several RISAs recently joined with WUCA utilities to identify how climate models can be used in impact assessments in the *Piloting Utility Model Applications for Climate Change* project.[x]

Major municipal utilities in the Southwest (in San Francisco, the greater Los Angeles area, Las Vegas, Denver, and Salt Lake City) now have personnel dedicated to studying the impacts of climate change on their systems (see also Chapter 13, Section 13.1.4). Reclamation and other federal agencies in the Southwest also now have scientific staff whose primary mission is to research, understand, and communicate climate-change impacts.

The Western States Water Council, an affiliate of the Western Governors’ Association (WGA), has convened multiple meetings over the last few years on the topics of drought and climate. WGA was instrumental in the creation of NIDIS by Congress in 2006. In 2009, WGA convened a climate adaptation working group designed to determine appropriate uses of climate-adaptation modeling, and identify and fill existing gaps in climate adaptation efforts at WGA. Since 2006, WGA has released several reports that cover water and climate (WGA 2006, 2008, 2010).

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## Endnotes

i Under prior appropriation, the first person or entity to establish a water right by putting it to "beneficial" use has a right to the full amount from available supplies before a junior appropriator (one who came later) can use his.

ii Evapotranspiration is composed of evaporation from water surfaces and the soil and transpiration of water by plants. Transpiration is the process by which plants take up and use water for cooling and for the production of biomass. Evapotranspiration is frequently measured in two ways: (1) the amount that occurred and (2) the potential amount that would have occurred if enough water had been present to meet all evaporation and transpiration needs. In arid areas the actual amount is frequently less than the potential amount.

iii Decision analysis, according to the Water Utility Climate Alliance (WUCA), is where uncertainties can be well described and decision trees can be used to find optimal solutions.

iv Scenario planning in this context is a tool in which key uncertainties are identified and future scenarios are constructed around these uncertainties. The hope is that different scenarios will identify common, robust approaches for managing the range of uncertainties.

v Robust decision making is a technique that combines classic decision analysis with scenario planning to identify coping strategies that are robust over a variety of futures.

vi Real options is a type of financial based planning method for uncertainty. WUCA describes it as a type of cash flow analysis that includes flexible implementation. It uses classical decision analysis with hedging concepts from financial planning.

vii Portfolio planning is a financial tool where a portfolio is selected to minimize risk and to hedge against future uncertainty.

viii See http://www.esrl.noaa.gov/psd/ccawwg/.

ix See http://www.energy.ca.gov/.

x See http://www.wucaonline.org/html/actions_puma.html.