# *Water Consumption and Sustainability in Arizona: A Tale of Two Desert Cities*[1]

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Helen Ingram, an astute critic of inequity, inefficiency, and flawed policy instruments, inspired a generation of scholars (including the authors of this essay) to critique the status quo and engage in scholarly research designed to improve the social and environmental consequences of water management. This essay honors her contributions to socially engaged scholarship.

## Introduction

In his provocative book *Bird on Fire,* Andrew Ross predicts a bleak future for the booming desert metropolis of Phoenix, which he calls "the world's least sustainable city." Ross sees Phoenix as a paradigm of the "national appetite for unrestrained growth," which he considers a dangerous anachronism in an age of global warming and overallocated and declining water supplies in the American Southwest.[2] Environmental journalist William DeBuys, in his book *A Great Aridness,* endorses a similarly pessimistic view about the sustainability of metropolitan Phoenix in the face of increasing water demand from population growth and decreasing water supply due to climate change and shrinking groundwater supplies.[3] Perhaps most pessimistic is science fiction writer Paolo Bacigalupi who recently imagined an unrelentingly dystopian future for Phoenix and the desert Southwest in his apocalyptic novel *The Water Knife*. Anticipating reduced water supplies and increased heat and thirst by the mid-21st century, Bacigalupi portrays a collapsed oasis civilization replete with interstate water wars, abandoned infrastructure, and extreme social inequality.[4]

In stark contrast to these portrayals of impending crisis are ubiquitous reassurances from municipal and state water managers that Phoenix's

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and Tucson's water supplies are reliable and secure. Water managers and policy makers acknowledge that these urban centers may face some potentially serious challenges in future decades, but in contrast to the above authors, there is no sense of a coming crisis. Instead, official publications are full of praise for Arizona's purportedly smart and forward-thinking approach to securing water supplies for the long term, and full of assurances that there is plenty of water now and for the foreseeable future. For example, William R. Mee, former administrator for the City of Phoenix Water and Wastewater Department, stated in 1990: "Through comprehensive and thoughtful planning, the responsible application of best available water conservation technology, public education, and reuse of wastewater, our water resources can be managed to sustain projected growth."[5] Similarly, in 2014 the Arizona Department of Water Resources (ADWR) published a report, *Arizona's Next Century: A Strategic Vision for Water Supply Sustainability*, in which the agency proudly touts Arizona's accomplishments. In a foreword to the report, the director of ADWR, Sandy Fabritz-Whitney, effused that "Arizonans should be proud of our long history of confronting our water supply challenges and successfully meeting the needs of our agricultural, industrial and domestic water users. Arizona has long demonstrated the resolve to take the necessary actions to ensure that sufficient and dependable water supplies are available for its long-term economic stability."[6] In 2015, Arizona governor Doug Ducey introduced his Arizona Water Initiative with the following praise: "Thanks to more than a century of careful planning, sound decision-making and bold leadership from our predecessors, Arizona's water supply, at least in the near-term, is in a better-than-expected position."[7]

If one reads the reports of climate scientists and the publications of water resource scholars who analyze Arizona's water supply situation, a different picture emerges. While few of them are as pessimistic as Bacigalupi, DeBuys, and Ross, few of them are as sanguine as the politicians and agency heads quoted above. According to leading Southwest climate and water resource researchers at the University of Arizona and Arizona State University, a serious water supply deficit exists *now* but has been masked by the draining of underground aquifers and the emptying of Lakes Powell and Mead, the two largest storage reservoirs on the Colorado River. Since 1995, the Colorado River Basin states have been diverting more water from the Colorado River than the annual flow and by 2007 both Lakes Powell and Mead stood half empty.

According to the Colorado River Research Group, the Colorado River water budget is "broken."[8] At the time of this writing in late 2016, Lake Powell stands at 45 percent of capacity and Lake Mead at 37 percent of capacity. The Bureau of Reclamation expects both reservoirs to decline further, making an official declaration of shortage on the river highly likely in 2018.[9]

As noted above, the structural deficit in Arizona's water supply has been partially masked by unsustainable pumping of groundwater. Arizona continues to extract far more water from its ancient aquifers than is recharged, despite more than three decades of concerted effort to reduce groundwater overdraft beginning with the passage of the Arizona Groundwater Management Act in 1980. The act mandated that Arizona's major municipal and agricultural regions achieve "safe yield" of groundwater by 2025, yet hardly anyone expects this goal will be met. Water supply optimists point proudly to efforts since 1996 to recharge excess Central Arizona Project (CAP) water into depleted underground aquifers for later use, but after 20 years of effort and hundreds of millions of dollars invested, only 9 million acre-feet were stored in aquifers. Annual consumption in Arizona from all sources ranges from 7 million to 9 million acre-feet. So, 20 years of storage effort resulted in a little over a year of stored water. One could put a brighter spin on the data by pointing out that municipal water consumption in the Phoenix and Tucson Active Management Areas (AMAs) is currently a little over 1 million acre-feet a year, so if demand does not rise with population growth and if all the water banked since 1996 was allocated to cities, it would last almost a decade. But with Arizona currently in the 17th year of a sustained drought and climatologists predicting longer, more intense droughts later this century, 10 years of banked water doesn't inspire much confidence.

Importantly, much of the water recharged into underground storage in Arizona since the 1990s was temporary "excess" CAP water, not a sustainable supply that can provide continuing recharge. Once everyone with rights to CAP water calls for their full allocation, this surplus will be gone. Moreover, a great deal of this "banked" water has been stored underground in remote recharge basins along the CAP Canal without much recovery infrastructure, and is therefore not readily available to areas of the state with declining aquifers. Arizona's cities remain concerned about how that stored water will be recovered and delivered to where it is needed in the future.[10]

Currently, according to ADWR, the total amount of natural and artificial recharge of aquifers in Arizona's five "Active Management

Areas"[11] amounts to about 1 million acre-feet per year, yet Arizonans extract approximately 3 million acre-feet per year from those aquifers.[12] Thus, despite the laudable recharge efforts, Arizona's overall water supply is still being unsustainably subsidized by consuming the capital from its underground supplies. Since 2010, the City of Tucson has moved assertively to reduce its total water demand and increase the amount of that demand supplied by CAP water. By 2015 Tucson Water—the utility serving the city and some surrounding communities—claimed it was recharging as much CAP water into the aquifer as it was pumping from the aquifer, essentially ending the city's overdraft.[13] If that trend holds, it will be a good model to follow for other cities that have access to CAP water—so long as CAP water remains available and affordable, which, as noted above, is not a foregone conclusion. However, the larger Tucson AMA within which the city is situated includes agricultural and municipal users with large groundwater pumping rights, and therefore the AMA as a whole is not doing as well in its efforts to end groundwater overdraft. As ADWR acknowledged in 2016, "Big challenges to safe-yield in the Tucson area remain. The current cumulative volume of grandfathered groundwater-right allotments in the Tucson AMA, for example, far exceeds the amount of groundwater available for pumping under safe-yield conditions."[14] Greater Phoenix is not much better off in this regard. As veteran water policy analyst Sharon Megdal observed, "Despite the progress made…to reduce total GPCD [gallons per capita per day] rates and groundwater overdraft, there is still a significant groundwater mining problem within the [Phoenix] AMA. Groundwater mining is expected to continue beyond 2025."[15]

With such vividly contrasting messages, the public and policy makers can be forgiven for feeling confused or uncertain about water sustainability in Arizona's urban areas. Reflecting this ambiguous set of messages inherent in a complex water supply-demand environment, the *Arizona Republic* newspaper in 2014 published an investigative report on drought and water supply provocatively titled "5 Reasons to Panic about Arizona's Water, and 5 Reasons Not To."[16] Most people in Arizona intuitively understand that they live in an arid region with limited rainfall, yet they revel in their pools and lawns and fountains and golf courses, generally proud and protective of the oasis civilization constructed with federal, state, and private water development investments over the past century. In addition to water, both the Phoenix and Tucson metropolitan regions are dependent on relatively abundant cheap energy for pumping water and for air conditioning. Ironically, that energy is heavily reliant on cheap water for steam and for cooling in the thermal power plants that dominate the region's electric supply.[17] People's comfort, health, and economic security largely depend on maintaining that oasis condition, particularly in the summer. Without it, millions of people would undoubtedly flee the region, as Andrew Ross suggested in *Bird on Fire*. That's what makes the debate over the region's water supply and demand so important.

A century ago, the water supply sufficiency debate in Arizona revolved almost entirely around agriculture, which comprised more than 90 percent of the state's water demand. But things changed rapidly as Arizona experienced an extraordinary, extended population boom after World War II. In 1910 just over 200,000 people lived in Arizona. Today, there are 6.7 million. Four-fifths of those people live in metropolitan Phoenix and Tucson (Maricopa and Pima Counties). By 1980, municipal water demand played a much more important role in shaping water policy and informing questions of water adequacy. In 1985, agriculture in the Phoenix Active Management Area still consumed approximately 56 percent of the water budget, but by 2006 it was down to 33 percent and still declining. In contrast, municipal water consumption in the Phoenix AMA grew from 28 percent of the total in 1985 to 50 percent in 2006.[18] To the south in the Tucson AMA, the agricultural sector made up 42 percent of total water consumption in 1985, but only 26 percent in 2006. Municipal use in those years climbed from 41 percent of the total to 55 percent.[19] Since the 1980s, then, Arizona's desert cities have grown increasingly central to the question of future water sustainability and they will be even more central in the coming decades as Arizona's population continues to grow. Importantly, the water demands of cities are far less elastic than the water demands of agriculture. If a farmer of annual crops loses access to water in a drought, he or she can postpone planting for a year or two. If a city loses access to water in a drought, millions of people are affected. Moreover, crop insurance can help mitigate the effect of drought on farmers. But there is no equivalent protection for the loss of household access to water. It's important to get it right.

Whether one is an optimist or a pessimist, the evidence tells us that current rates of water consumption in central and southern Arizona—where the vast majority of the state's population resides—are unsustainable and that the gap between water demand and a sustainable supply will grow wider as the population increases. The evidence also shows that options for solving the problem are fairly limited. We have to reduce groundwater pumping by another two-thirds to reach "safe yield," so Arizona's already depleted aquifers cannot sustainably close the demand-supply gap. The largest source of "renewable" surface water is the Colorado River, but that river's water is overallocated, global warming is likely to reduce flows in the river, and the river's two main storage reservoirs are so depleted that they can no longer provide a buffer against drought. When the inevitable shortages arrive, Arizona's CAP takes the first and the biggest cuts (for more on this, see under Context below). So, depending on CAP water cannot relieve the demand-supply deficit either. The Phoenix metro area has a third water supply in the Salt and Verde Rivers managed by the Salt River Project (SRP). That water supply is more secure than the Colorado River allocation, but it comprises only about a third of the Phoenix AMA's water budget and it, too, is adversely affected by drought and climate change.[20]

On the supply side, Arizonans can always try to import more water from somewhere else. But this option is probably the least reliable and feasible. There is no significant body of un-owned, un-allocated freshwater accessible to residents of central and southern Arizona in quantities sufficient to resolve the water supply deficit. In 2015 the Water Resources Research Center at the University of Arizona acknowledged that importation of significant new freshwater supplies "is the least likely option to be developed, considering the needs of the already-established communities along the Mississippi, Missouri, Green, Snake, and Columbia Rivers from which the supplies would come. The costs would be high as well, and significant controversy is associated with these options on environmental, political, financial, and regulatory levels."[21]

Water recycling and re-use are often mentioned as additional "supply" options, but in both Phoenix and Tucson nearly all municipal wastewater is already reclaimed and re-used. Thus it is not a significant *additional* source of supply for the greater Phoenix and Tucson regions. Theoretically, wastewater could be re-allocated from golf courses, power plants, and wetland restoration and put into the drinking water supply, if necessary, but those options will involve significant and difficult trade-offs. Besides, such re-allocations do not really provide new water, but rather simply shift reclaimed water from one user to another. Water now allocated to coal-fired, gas-fired, and nuclear power plants can be re-allocated to municipal or agricultural use if solar photovoltaic energy becomes a dominant source of the state's energy supply, but this transition will take decades and impact many vested interests.[22]

Some people hold out hope that seawater desalination may be the next technological fix for the water deficit, but there are problems and limitations to that option (see under Context below). Again, as researchers at the University of Arizona remind us, "While supply augmentation is viable in some limited contexts (e.g., desalination to drought-proof an urban center), significant system-wide augmentation cannot occur quickly and is likely to never make sense from an economic, environmental, or political perspective, and focusing on this goal is counterproductive to implementing better solutions."[23]

What options are left then? Conservation, efficiency, and demand reduction—the other half of the demand-supply equation. Arizonans need to reduce consumption, significantly and soon. And the reductions cannot all come from one sector. Cities, farms, and industry all have to cut back their rates of consumption, *especially* cities, which are already the majority user in the Phoenix and Tucson AMAs and likely to be the most affected by extended drought and future supply crises. The remainder of this essay examines how far and how fast the Cities of Phoenix and Tucson—and the larger Active Management Areas surrounding them—have progressed toward closing the demand-supply deficit and achieving water sustainability since passage of the landmark Arizona Groundwater Management Act of 1980.[24]

Helen Ingram has written critically and insightfully for more than four decades about water policy and her influence on this essay runs deep. She has always sought to make her work serve social ends, particularly the goals of efficiency, equity, and environmental and intergenerational justice. There is a strong normative and multi-scalar emphasis to her work that is reflected in this essay. Dr. Ingram was one of the early policy scholars to forcefully argue that *implementation matters.* As we demonstrate in this essay, policy instruments like the Groundwater Management Act should be evaluated by their outcomes, not just their intentions. Dr. Ingram has been concerned with environmental quality since before the original Earth Day in 1970, insisting that water is more than a commodity for human consumption, that it has both cultural and ecosystem values that must be equally considered alongside economic values. Dr. Ingram has consistently argued that good policy must include broader democratic goals of public engagement, social empowerment, an embrace of diverse values, and bottom-up collaborative governance more than top-down command and control governance.[25] She is willing to take controversial positions when necessary, speaking truth to power, such as arguing that unrestrained population growth, the elephant in the room that few want to acknowledge, must be addressed when seeking solutions to water supply challenges in the Southwest. All these insights and ethical commitments are reflected in the analysis below, with gratitude to the mentor who inspired them in us.

## Context

Water supply crises are not unique to Arizona or to the larger U.S. Southwest. Water scarcity is, rather, a global problem. The United Nations recently reported that current freshwater supplies may only meet 60 percent of the world's population needs by the year 2030. The report cites climate change, population growth, and policies that prioritize economic development over conservation as the driving forces behind a global water deficit. At the national level in the United States, rising demands outstripping limited and shrinking water supplies are common across the country, which prompted the U.S. Bureau of Reclamation (USBR) to launch WaterSMART in 2010 with the goal of promoting long-term sustainable use of water resources. This challenge is especially relevant for Arizona where population growth goes largely unquestioned and where policy makers deeply distrust government regulation. Since at least the 1960s, the growth industry has dominated state politics and deference to it has stymied efforts to address sustainability issues head-on. In recruiting businesses to the Valley of the Sun in the 1960s, for example, the Phoenix Chamber of Commerce assured potential investors that they would find "an abundance of water so far as domestic and industrial uses [were] concerned."[26] This promotion of a desert oasis lifestyle in Greater Phoenix enabled by inexpensive and purportedly abundant water remained largely unchallenged for the rest of the century. Periodic real estate busts generated some hand wringing, but not much change in the region's dependence on growth politics. During the financial crisis in 2009 the state's largest newspaper, the *Arizona Republic*, opined, "The automotive industry is to Michigan what growth is to Arizona….Obviously, Arizonans still have a lot to learn because we continue to rely on growth to propel our economic fortunes and repeatedly suffer the ill effects of real-estate downturns, regardless of their causes."[27] As Michael Logan showed in his book *Fighting Sprawl and City Hall*, Tucson had a more vigorous anti-growth populism than Phoenix and therefore developed at a slower and smaller scale, but even there pro-growth politics generally prevailed.[28]

This same story is writ large on the entire Southwest. Forty million people and 4.5 million acres of irrigated land across 7 states and 22 federally recognized tribes depend upon the waters of the Colorado River and its tributaries. This includes Tucson and Phoenix, but also other major metropolitan areas such as Las Vegas and Los Angeles. Mexico has rights to the river, too. There are 16.5 million acre-feet of confirmed water rights to the Colorado River, which is shared by the seven basin states—Arizona, California, Colorado, Nevada, New Mexico, Utah, Wyoming—and Mexico, but the amount of water flowing in the river for the past half century is closer to 15 million acre-feet per year. This structural deficit was not a problem before the turn of the 21st century because not everyone with rights to the river was physically withdrawing their full allocation. By 2003, however, withdrawals regularly exceeded the actual amount of water flowing in the river. This deficit was exacerbated by an extended drought in the Southwest that began in 2002 and continues to the present.[29] Since 2003 the structural deficit in Colorado River supply was ameliorated by drawing down the vast storage capacity of Lakes Powell and Mead, which together can hold 16.2 million acre-feet.[30] But that strategy has finally reached its limit.

As population continues to grow in the Southwest, the gap between demand and supply will grow. A 2012 collaborative study between the federal government and the basin states projected a cumulative total increase in water demand from the Colorado River by 2060 that ranged from 8 to 23 percent above current levels, doubling the size of the current deficit.[31] Moreover, climate change will likely reduce the volume of water in the river even more. The U.S. Bureau of Reclamation predicts the river will lose 9 percent of its current annual flow over the next 50 years due to climate change.[32] Further adding to these uncertainties about future water availability are legal battles still under way to adjudicate water rights to Native American tribes in Arizona, which will have to be satisfied from the current water budget.[33]

Among all the Colorado River Basin states, Arizona is most adversely affected by this structural deficit. To get the votes needed to fund the CAP Canal in the U.S. Congress in 1968, Arizona had to agree to a demand by the California congressional delegation that California would get all its 4.4 million acre-feet of Colorado River water before Arizona's CAP gets any of its 1.5 million acre-feet. Arizona's CAP allocation is thus last in line for fulfillment and first in line to be cut in the event of water supply shortages.[34] In 2007, with the two big Colorado River reservoirs half empty, the basin states negotiated a shortage sharing agreement in the event that the U.S. Bureau of Reclamation could not deliver all the water due to the lower basin states of Arizona, California, and Nevada.[35] The 6 percent cuts to lower basin state allocations in the shortage sharing agreement would hit the Central Arizona Project (CAP) hardest. In 2015, Colorado River water delivered by the CAP provided about a third of the water used by municipalities in the Phoenix AMA. In the City of Tucson, CAP made up about a quarter of the water budget from 2000 through 2012,[36] but by 2015 Tucson had increased its use of recharged and recovered CAP water to satisfy more than 80 percent of municipal demand.[37] An initial Stage 1 declaration of shortage on the Colorado River would result in a 20 percent reduction of the CAP allocation to Arizona. At the time of this writing (early 2017), a Stage 1 declaration is imminent and the lower basin states are currently negotiating another drought contingency plan to accommodate even deeper cuts, which would hit CAP allocations even harder.[38] Hoping for rain to solve the problem is quixotic as climatologists now suggest that a "mega-drought" of paleohistoric proportions may hit the Southwest in the second half of the 21st century.[39]

The availability of Colorado River water via the CAP Canal has been critical to reducing unsustainable pumping of groundwater in the major metropolitan centers of Phoenix and Tucson. Most groundwater in the arid Southwest is fossil water accumulated over eons that cities and farms generally pump at rates far faster than natural recharge, resulting in troublesome declines in the water table—what is called "groundwater overdraft."[40] Groundwater overdraft is a problem throughout arid regions of the world, but in the United States it is particularly problematic in the Southern Plains, southern Arizona, and California's Central Valley.[41]

Groundwater overdraft problems have plagued Arizona farms and cities since at least the 1950s, resulting in higher drilling costs to reach deeper into the aquifer; escalating energy costs for pumping from ever greater depths; agriculture abandonment; land subsidence; structural damage to roads, buildings, and canals; the desiccation of streams and wetlands; and, of course, perennial and expensive efforts to import more water. In 1980, after several failed attempts to create a legal framework for reducing groundwater overdraft, and under the threat of losing federal financial support for building the CAP Canal, the Arizona legislature finally enacted a strong groundwater code: the Arizona Groundwater Management Act (GMA). This law created Active Management Areas (AMAs) in the parts of the state with the greatest amount of groundwater pumping and mandated that groundwater extraction be reduced to a level defined as "safe yield" by 2025. In the fine print of the law, safe yield essentially means a slower rate of depletion; it does not mean ending groundwater overdraft or achieving water "sustainability." The GMA also required that proposed new housing developments in AMAs demonstrate they have a 100-year assured water supply, although this assurance was deeply compromised by Arizona lawmakers when they later created the Central Arizona Groundwater Replenishment District in 1993.[42] Replacing mined groundwater with renewable Colorado River water was a major rationale for the CAP and the GMA's lynchpin for getting to safe yield.[43]

At first, the GMA set impressive goals and appeared to be an innovative approach to sustainable water management. However, as time passed, its reputation tarnished due to ineffective implementation and legislative amendments that weakened the act.[44] As early as 1999 and continuing to the present, analysts and auditors and even ADWR have admitted that neither the Phoenix AMA nor the Tucson AMA will reach the goal of safe yield by 2025. And reaching the more stringent goal of completely ending groundwater overdraft will be even harder. As Arizona State University (ASU) water and climate researchers bluntly concluded in a 2010 analysis, "Under currently projected growth conditions and unconstrained water usage, it is not possible to achieve groundwater sustainability in 2030 under any climate scenario."[45] A year later ASU researchers similarly concluded that "current water consumption rates cannot be supported without unsustainable groundwater use under most climate model scenarios."[46]

While the GMA has many "holes in the bucket" contributing to its failure to reach safe yield, one key factor is inadequate implementation of municipal demand reduction measures in the Greater Phoenix and Greater Tucson metropolitan regions. The ADWR has taken a conciliatory approach toward non-complying cities, rather than enforce regulatory standards for reduced water demands.[47] A second, and less discussed, loophole stems from the widespread existence of groundwater wells that are exempt from regulation, even within Active Management Areas. Low-capacity wells (i.e., capable of extracting less than 35 gallons per minute) drilled for purposes other than irrigation are exempt from the requirements of Arizona's groundwater code.[48] Between 1980 and 2005, more than 16,000 exempt-well permits were approved in the Phoenix AMA and another 8,507 in the Tucson AMA.[49] The cumulative effect of so many points of withdrawal, subject to limited monitoring, may pose significant problems in the future. Therefore, while the GMA may have been a noteworthy innovative approach to sustainable water management, until very recently it was difficult to attribute much success to ADWR's policies and management plans.[50]

To summarize, the greater Phoenix AMA has three main sources of water supply: the Salt and Verde Rivers (37 percent), Colorado River water via the CAP (31 percent), and largely nonrenewable groundwater (28 percent).[51] This seems like a robust water portfolio, but the Colorado River water delivered by the CAP is limited and subject to imminent reduction due to drought and overallocation. Groundwater is still being pumped out of the ground far faster than it is being recharged, so the amount pumped from aquifers must also decline significantly if greater Phoenix is to have a sustainable water supply. Water from the Salt and Verde Rivers provided by SRP is more secure than CAP water and cheaper to deliver since it is distributed by gravity, but it, too, is limited and will likely decline over time according to climatic projections for the Salt-Verde watershed.[52] In the coming decades, cities and farms in the Phoenix AMA will have to significantly reduce total water consumption to achieve a sustainable balance of water supply and demand. The necessary reductions will need to be *even greater* to accommodate climate change, likely future reductions in CAP allocations, and continued population growth.

While Greater Phoenix has the Salt and Verde Rivers, Tucson has no permanent flowing rivers. Until the arrival of Colorado River water via the CAP Canal in the 1990s, Tucson was entirely dependent on groundwater. As the city grew, the Tucson Basin aquifer declined, instilling early awareness of the need for wise use and conservation.[53] For decades, per capita water consumption (measured in gallons per capita per day—GPCD) in metropolitan Tucson was well below that of cities in the Phoenix metro area. For example, in 1995 average consumption rates for municipal water providers in the Tucson AMA were 172 GPCD, whereas the average in the Phoenix AMA was 230 GPCD for publicly owned water utilities and 312 GPCD for private water companies.[54] (The trends for individual municipalities vary, especially in the Greater Phoenix region, where consumption in wealthy areas such as Scottsdale is substantially higher than most.) Over the following years, however, the City of Phoenix itself achieved substantial reductions in its per capita water consumption, achieving a GPCD level roughly matching that of the City of Tucson by 2003[55] (figure 1). Despite both cities' recent progress, much deeper cuts in per capita water consumption are needed to achieve a balance between supply and demand, especially as the population continues to grow.

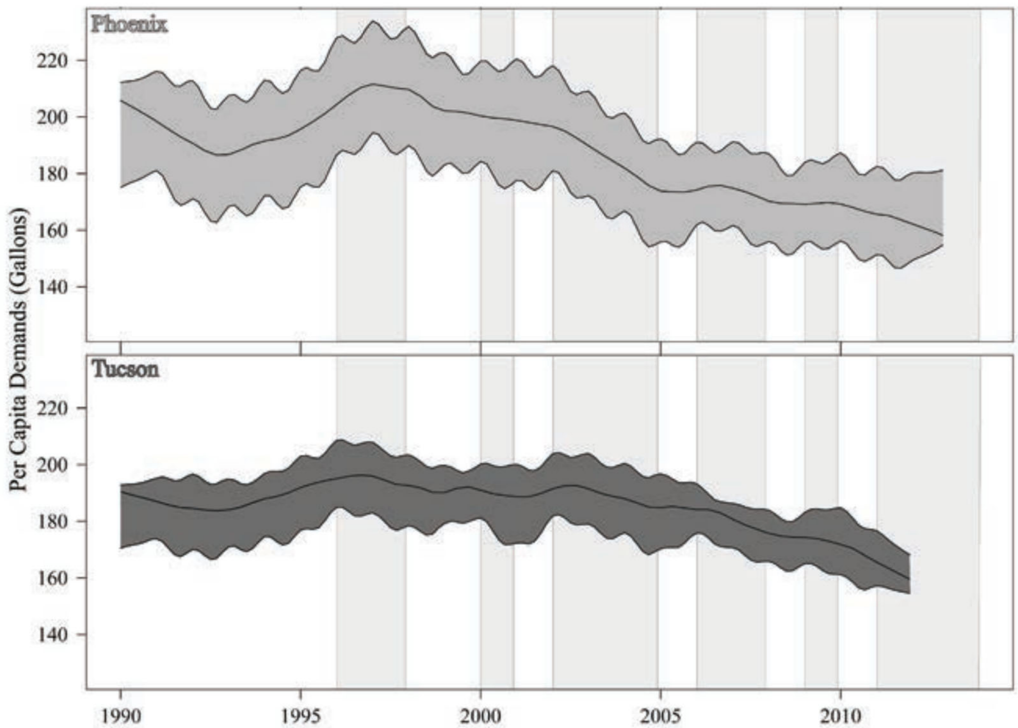


*Figure 1. Trends in per capita water demand for Phoenix and Tucson, 1990–2013, are depicted by the solid line, while smoothed seasonal and episodic variation in demand is depicted by the shaded area. Vertical bars denote years of moderate to extreme drought (a Palmer Drought Severity Index of -2 or greater). Figures were generated using billing data provided by the Phoenix and Tucson water utilities and county-level drought statistics from the Western Regional Climate Center. Credit: Cyrus Hester.*

Importantly, while both the Cities of Phoenix and Tucson have reduced their levels of *per capita* consumption since 1990, *total* municipal water consumption in the larger AMAs has increased. According to a comprehensive analysis of Active Management Area programs in 2008 by Sharon Megdal and colleagues, municipal water consumption in the Phoenix AMA increased by about 200,000 acre-feet (approximately a 30 percent rise) between 1985 and 2005. In the same years, municipal water consumption in the Tucson AMA increased by more than 80,000 acre-feet (approximately a 70 percent rise).[56] In the final analysis, it is total water consumption that must be reduced to achieve a sustainable balance between supply and demand.

Many scholars have argued that demand reduction is the most reliable, affordable, and secure option for closing water supply gaps, yet water managers still perpetually look to augment water supplies in part to avoid the social and political difficulties of reducing demand. The Salt River Project and the Central Arizona Project were central Arizona's most ambitious water augmentation schemes in the 20th century. Both were largely funded and built by the federal government, with reimbursements from the beneficiaries back to the federal government over many decades. As noted in the introduction, however, the potential for more of these kinds of water import projects in the 21st century is very limited. The collaboratively developed *Colorado River Basin Water Supply and Demand Study* produced by the U.S. Bureau of Reclamation and the basin states in 2012 dutifully included detailed sections on "water supply augmentation," including wastewater re-use, desalination, vegetation manipulation to increase water flow and decrease evapotranspiration, weather modification, and even improbable schemes to import water from the Missouri River Basin, from the Columbia River, and from icebergs towed south from Alaska. But the report did not offer much hope that any of the less ambitious proposals would make much of a difference or that any of the more ambitious dreams would ever be implemented.[57]

Likewise, in 2014 the state of Arizona produced a comprehensive assessment titled *Arizona's Next Century: A Strategic Vision for Water Supply Sustainability*, which included a discussion of eight potential ways to augment the water supply.[58] The report states that Arizonans need to find from 1 million to 3 million acre-feet of additional water per year to meet their needs over the next 20 to100 years. It explores several water transfer and re-use options, discusses the implications of mining the state's aquifers down to 1,000 feet in depth, evaluates vegetation manipulation and weather modification, and mentions large-scale rainwater harvesting. Other than continuing to mine groundwater aquifers, none of these options provides enough water to close the gap under current consumption patterns. This section of the ADWR report ends with a rather pessimistic assessment of options for importing more water from out of state, saying, "Acquiring and developing imported water supplies could be an exponentially more difficult task than it was to bring Colorado River water to Central Arizona through authorization of the CAP."[59] The financial cost, logistical and legal difficulties, and environmental impacts of larger augmentation projects make them little more than chimeric hopes. The most feasible and cost-effective options for increasing the water supply cited in this section of the report were transferring more water from agricultural use to urban use, increasing wastewater recycling, and transferring groundwater from lightly pumped basins to basins with overdraft problems, none of which actually increases the overall water supply but merely moves water from one place to another and uses it more efficiently.

Recently, some are looking to desalination as a "drought-proof" means of augmenting water supplies. Projects have been proposed along the Sea of Cortéz in Mexico, where at least some of the water produced would be intended for American consumption. Desalination's rising popularity depends principally on recent innovations in reverse osmosis (RO), which has become more affordable due to advances in RO membrane technology, falling energy costs, and increasing market competition. This has supported renewed claims that desalination could become a significant opportunity for supply augmentation. However, affordability and feasibility alone are insufficient criteria for assessing the sustainability of a proposal. Social and environmental aspects of the system also need to be factored in. For the proposed Puerto Peñasco project, expected to deliver water to Arizona, every cubic meter of freshwater produced will also generate 1.46 cubic meters of highly saline waste to be discharged back into the ocean. These discharges are also likely to contain a variety of industrial chemicals used in the operation. Many existing desalination plants simply rely on coastal currents to distribute the salt-concentrated brines, but this may not be as effective in the semi-enclosed Gulf of California. Moreover, the Sea of Cortez is an area of important marine resources, upon which local tourism and fishing economies rely. The long-term viability of such activities, when discharges are perpetually raising the salt content of the Gulf, seems doubtful.[60]

Beyond these troubling environmental externalities of desalination are the technology's high energy costs and problematic political and economic implications. Delivering desalinated water from Mexico to central Arizona will require approval at multiple levels of government, ongoing intergovernmental cooperation, and significant additional funding for pumping the water from sea level to Phoenix (about 1,000 feet above sea level) and Tucson (about 2,500 feet above). There is also a troubling bilateral inequity inherent in a project that provides clean water to one country but leaves the wastes in another country. Given the unstable history of U.S.-Mexico relations and exacerbated tensions under the Trump administration in 2017, it seems unwise to place too much reliance on desalinated seawater. In the end, we echo Wilder et al. in concluding that desalination alone "does not constitute a sustainable approach to water management."[61] It seems more rational to pursue the suite of demand management and efficiency options available, which are less prone to the costs and risks of current desalination proposals.

For more than a century, augmentation has been the preferred strategy for addressing water demand-supply challenges. Only since the 1970s has conservation, efficiency, and demand management risen to prominence as a desirable alternative. We still live with the legacy of this preference for developing new water sources. It will require significant cultural and political change to embrace the demand management strategies needed to close the water supply gap in central and southern Arizona. And that cultural and political change will have to come largely from the municipalities where most people live and most water is consumed. So, how has demand management progressed in the state's two largest urban areas over the last three decades?

## Urban Development and Water-Use Trends in Phoenix and Tucson

Arizona's population rose markedly following the advent of window-mounted air conditioning (ca. 1950) and the proliferation of retiree-focused development (ca. 1960).[62] The steady and rapid population increase since World War II saw only one brief hiatus during the economic recession of 2008–2011. This persistent growth paralleled an overall increase in water use by the Cities of Phoenix and Tucson. Yet, in recent decades both cities were able to reduce their *per capita* water consumption rates (figure 1). There are many interconnected reasons for this, some obvious and some counterintuitive. One reason for the decline in per capita consumption is that population increase *all by itself* can lower calculated per capita rates of water consumption, depending on where and how that growth occurs. For example, when farmers sell their land to developers who then build single-family homes, a larger population on the same land using the same amount (or less) of water results in a lower overall per capita rate of water consumption, even when homeowners do not do anything special to conserve water.

Landscapes have an important impact on water demand because outdoor water use accounts for half or more of residential water consumption, with lawns and pools contributing significantly to residential demands.[63] While the City of Tucson began encouraging xeric, drought-tolerant landscaping as early as the 1970s, the City of Phoenix lagged behind due to concerns with the net cost of retrofits and public sentiment favoring lawns and oasis-style landscaping.[64] The City of Tucson's embrace of xeric landscaping was accelerated by municipal water shortages in the 1970s. Severe drought in 1974 sparked conservation measures when Tucson Water was unable to meet all of its customers' demands. The city successfully incorporated conservation education through its Beat the Peak program and used pricing signals (for example, water rates increased by 22 percent in 1976[65]) to encourage conservation and discourage mesic, lawn-dominated landscaping. Vegetative cover in Tucson decreased from 37.3 percent in 1972 to 28.6 percent in 1976. From 1976 through 1979, irrigated lawns decreased by 17.5 percent.[66] This rising popularity of lower-water-use, desert-style landscaping contributed substantially to water conservation in the region. This helps explain the significant difference in GPCD between Tucson and Phoenix in the 1980s. Tucson's highest GPCD rate in the time frame of this study was 230 compared to nearly 280 in Phoenix (figure 1).

Unlike Tucson, Phoenix has long been heralded as an oasis in the desert and Phoenicians have perpetuated a preference for greener landscapes.[67] Real estate developers of the 1980s and 1990s encouraged and accommodated this. One result was the prolific construction of new golf courses as a means to raise the value of adjacent housing developments. The Greater Phoenix area added six new golf courses per year in the 1990s.[68] Three factors, however, appear to have gradually undercut this trend toward water-intensive landscapes. First, environmentally conscious landscape architects in Arizona have increasingly embraced the use of native vegetation as a means to create multifunctional, xeric landscapes that reflect the aesthetics of the Sonoran Desert. Second, water conservation mandates and incentives that developed after passage of the GMA in 1980 encouraged lower-water-use landscaping and even established penalties for water waste.[69] Third, in an effort to increase housing density and profit margins from the 1970s through the 1990s lot sizes in Phoenix declined 20 percent and landscaping area declined 28 percent.[70] Less room for landscaping naturally decreased per-unit water use in new developments compared to older housing developments. Since the turn of the 21st century, the construction of water-intensive amenities, such as private pools and public golf courses, has continued to decline.[71]

In summary, after 1980 both Phoenix and Tucson implemented a wide variety of policies over three decades aimed at reducing outdoor water use in response to drought and to meet reduced water consumption targets established by ADWR in response to the Groundwater

Management Act. In aggregate these measures seem to have contributed to a long-term decline in GPCD. Water-use trends in both Phoenix and Tucson appear to be a function of cultural preferences shifting toward water-conserving landscapes, policy initiatives aimed at conservation, and the changing structure of the urban landscape. But, such trends must also be understood in the context of a changing climate and recurring drought.

## Drought and Water-Use Trends

Drought has been, and continues to be, a significant climatic reality in the state of Arizona, but the effects of drought on water use and GPCD trends are not consistent over time. During our study period there were six times when the state of Arizona was in a severe to extreme drought, as depicted by the vertical bars in figure 1. Unusually dry conditions prevailed through the 1990s, with an extreme drought occurring from the summer of 1995 through 1996. During this time period, per capita water consumption in the City of Phoenix increased significantly. Indeed, many studies cite drought as a contributor to higher per capita consumption because people tend to water lawns and plants more often to compensate for the drier conditions.[72] The situation is reversed for the City of Tucson, however. During the mid-1990s drought, Tucson showed a declining GPCD. Several things were going on at this time, all of which may have contributed to this trend. First, CAP water arrived in Tucson, but was of such poor quality that it prompted hundreds of complaints to be filed between 1992 and 1994. Shortly thereafter, water consumption in Tucson temporarily dropped, at least until groundwater was used again to dilute the CAP water. At the same time, the City of Tucson was implementing its celebrated Xeriscaping program, offering incentives for water-conserving landscapes after 1991. Finally, in 1994 the state of Arizona launched statewide drought-planning efforts.[73]

While GPCD levels in the City of Phoenix increased during the mid-1990s drought, they declined during the more recent, longer-term drought periods of the 2000s. Upon entering the new millennium, severe to extreme drought became a climatic norm in the region. Five periods of significant drought occurred between 2000 and 2013, compared to one significant drought in the 1990s. More than half of the first decade of the 2000s exhibited extreme drought conditions. Both the City of Phoenix and the City of Tucson also saw the most significant declines in GPCD over this same time period. This is likely because more recent prolonged droughts have been coupled with drought warnings and water scarcity planning initiatives as well as a downturn in the housing market and the regional economy. Similarly, a recent study of North Carolina cities demonstrated that multi-year droughts accompanied by municipal and state water scarcity warnings and restrictions resulted in reduced per capita water consumption.[74] Thus, long, intense drought may compel more assertive water management policies and heighten citizen awareness, impacting water-use behaviors and GPCD rates.

Within the City of Phoenix, bone-dry conditions led to policy action as the city declared Stage 1 drought in January 2003. According to its Drought Management Plan, Stage 1 calls for enhanced public education and information programs stressing voluntary action, but does not include any required reductions.[75] The city remained in Stage 1 through 2005 and GPCD declined continuously through this period. In fact, the City of Phoenix claimed in 2011 that it achieved its largest annual decreases in GPCD levels during the early 2000s. Although the causal factors are uncertain, the city cited the high visibility of drought conditions—due to heightened media coverage—as contributing factors to the significant decline in GPCD.[76]

The City of Tucson likewise experienced significant drought throughout the 2000s as well as declines in GPCD levels, although the city did not take significant additional policy action until 2006 when it adopted a Drought Preparedness and Response Plan.[77] Tucson's plan was a direct result of a bill passed by the Arizona legislature in 2005 (HB 2277), which required all Arizona water providers to develop a drought preparedness plan. While state-level policy served as the impetus, each city was left to do the heavy lifting of crafting its own plan of action. Notably, the state law did not require any specific conservation measures or actual reductions in water consumption or groundwater pumping. The City of Tucson took action under its drought plan in 2007 when it declared Stage 1 drought conditions, which continued through the period of this study. It corresponds with a steady decline in GPCD levels that began in 2007. Out of a total of four designated drought stages, Stage 1 simply encourages voluntary water reductions and increased drought awareness and water conservation. In summary, it appears that severe, long-term drought coupled with drought awareness campaigns, supported by state-level policies, correlates strongly to declining GPCD levels in both the City of Tucson and the City of Phoenix. This conclusion is supported by a recent nationwide study of the influence of water supply stresses on municipal water conservation initiatives in American cities.[78]

## Arrival of CAP Water

Both the Phoenix and Tucson regions saw significant supply augmentation in the 1980s and 1990s from Colorado River water delivered by the CAP Canal. In addition, many municipalities in Greater Phoenix benefited from additional transfers of agricultural water to urban uses. With new incoming water sources for urban development, GPCD increased in both Phoenix and Tucson in the years immediately after CAP water first arrived, although these trends did not continue in the long term. CAP deliveries began in 1986 for the City of Phoenix and were followed by an increasing GPCD trend in the city and the broader AMA from 1986 through 1988.[79] The City of Tucson provides an interesting case because CAP water arrived in 1992, but proved controversial and problematic. The unusual chemistry of the CAP water caused household plumbing in many older parts of the city to dissolve and leak, resulting in lawsuits and a citizen initiative that led to a city ordinance in 1995 banning CAP water from direct municipal use.[80] CAP water was not mixed with Tucson city water for delivery again until 2001. As shown in figure 1, the arrival of CAP water in the City of Tucson in 1992 was followed by a three-year upward trend in GPCD lasting until 1996. After the ban on CAP water, GPCD declined slightly for several years, then rose again following the renewal of CAP deliveries in 2001. Therefore, it seems that the acquisition of a new, reliable water supply may have weakened public and governmental commitment to reducing water demands despite persistent drought conditions.

## Policy Incentives and Water Use Trends

While external drivers such as population growth, drought, and the arrival of CAP water impacted GPCD levels, local, state, and federal incentives and mandates for increased water conservation and efficiency also contributed to declining per capita water consumption. Both Tucson and Phoenix enacted significant plumbing codes in the 1980s. The City of Tucson, along with Pima County as a whole, revised its Universal

Plumbing Code in 1982, requiring all new construction to install reduced-flow plumbing fixtures. The city also approved a Water Waste and Theft Ordinance in 1984 imposing fines on homes and businesses that allowed water to run off their property onto the street. In 1989 Tucson revised and strengthened its plumbing code and added a rebate program that year to give homeowners incentives to upgrade to ultra-low-flush toilets.[81] Figure 1 shows a small decline in Tucson's GPCD from 1990 through 1992 following enactment of these codes.

Similarly, the City of Phoenix passed a local ordinance—called the Low-Flow Fixtures and Devices Ordinance—to be implemented in three phases from 1990 through 1992. Thereafter, at least 41,000 homes were retrofitted with low-water-use appliances.[82] During the same period, GPCD levels in Phoenix declined (figure 1). According to one study, the Phoenix ordinance saved the city 20 million gallons per year and may have been its most effective non-price-related conservation policy.[83] These ordinances resulted in measurable reductions of indoor water use and small but noticeable reductions in GPCD levels as new developments included these new technologies and customers upgraded their older plumbing fixtures. Interestingly, the federal government reinforced this trend toward more efficient indoor water use in the regulations put forth by the Energy Policy Act of 1992, which included mandates for low-flow plumbing fixtures, including 1.6-gallon flush toilets at a time when most toilets typically used 3.5 gallons or more per flush.[84]

While both cities deserve credit for stimulating water-use reductions through plumbing codes, ordinances, and rebates, some credit must also extend to state-level policies. The demand reduction goals established by the Arizona Department of Water Resources (ADWR) in the consecutive 10-year AMA management plans created incentives and support for municipal water conservation and also required drought planning at the local level. However, we could not find any significant, consistent correlation between ADWR regulations and GPCD levels in Phoenix and Tucson. Instead, during the 1980s, the City of Phoenix consistently failed to meet its target GPCD reductions established by ADWR in the first management plan for the Phoenix AMA.[85] Over the decade of the 2000s, the City of Phoenix then experienced its most significant downward trend in GPCD, despite the fact that ADWR regulations remained largely unchanged from the 1990s. Likewise, for the City of Tucson we could not identify clear correlations between ADWR regulations promulgated in the AMA management plans and GPCD trends. Nevertheless, pressure from ADWR to reduce per capita water use in the Phoenix and Tucson Active Management Areas certainly provided support and motivation for the landscaping and municipal plumbing ordinances adopted in the 1980s and 1990s as well as for the extensive information and education campaigns at the municipal levels regarding conservation and drought in the 1990s and 2000s.

In the final analysis, however, municipal, state, and even federal efforts over the past couple of decades have been inadequate to meet the long-term water supply challenges Arizona faces. The Arizona situation underscores what Denise Lach, Helen Ingram, and Steve Rayner concluded in 2005 regarding the typical response of water-managing organizations across the United States to mounting water supply stresses: They "have been timid experiments with incremental and marginal innovation" and "water managers are falling behind in the race to resolve mounting troubles."[86] It is worthwhile to note that Lach and Rayner's updated study (in this issue of *Journal of the Southwest*) reached more positive conclusions regarding water managers' climate forecast use and co-production of knowledge. Nevertheless, the conservative tendencies of water managers and state legislators inhibit the implementation of more innovative, bold, and effective strategies needed to close the demand-supply gap in Arizona and, indeed, the entire Colorado River Basin.

## Conclusion

The modest progress made in reducing per capita rates of water consumption in Phoenix and Tucson in the 35 years since passage of the Groundwater Management Act was driven by a wide array of factors including national, state, and city initiatives; huge infrastructure investments; economic incentives; historical legacies; cultural preferences; extreme drought; and even a little serendipity. It does not inspire much confidence to realize that after all this effort and expense total water consumption (from all sources) increased rather than decreased in both the Phoenix and the Tucson AMAs.[87] The decline of per capita consumption rates in the cities and the decline of agricultural use have been more than offset by continued population growth. Residents and farmers in both Active Management Areas still consume more water than is sustainable. Phoenix and Tucson will not dry up and blow away, but the boasts of progress from politicians and boosters are overstated and probably serve to inhibit more effective problem solving.

In recent years there has been much discussion of Arizona's Sun Corridor as a potential future megapolitan region spanning from Prescott in the north to Nogales in the south with Phoenix and Tucson the central nodes. The potential for an interwoven urban region spanning these two metropolitan areas has major water demand implications in an area already stressed by extreme aridity and limited, insecure supplies. Grady Gammage's study of the Sun Corridor megapolitan region identified water resources as the number-one issue that will be critical to the continued sustainable development of the region.[88]

Ironically, when the Bureau of Reclamation collaborated with the Colorado River Basin states in 2012 to estimate water demands to 2060, every state—not just Arizona—projected significant increases in their demand from the river. Population growth was the main reason cited for the increase. The bureau included a "slow growth" scenario and a "rapid growth" scenario; the former resulted in 18.1 million acre-feet of demand from the Colorado River by 2060 while the latter resulted in 20.4 million acre-feet of demand—even though there is only 15 million acre-feet of water reliably available in the river *before* any future effects of climate change are factored in. Not only do states want to avoid cuts in their allocation, but every state wants even more water in the future, despite the fact that there is already a structural deficit and all the evidence indicates that even less water will be available from the river in the future. In fact, the most recent climate research now predicts more than an 80 percent probability that a multi-decadal "mega-drought" similar to that experienced in the 12th century may hit the American Southwest in the second half of this century.[89]

Patricia Gober and colleagues at Arizona State University's Decision Center for a Desert City (DCDC) used ASU's WaterSim5 model to predict what would happen to groundwater resources and the overall water supply situation in Greater Phoenix under various assumptions. The researchers ran two scenarios extending from 2000 to 2060: a "business-as-usual" scenario in which current climate trends and GPCD reduction trends continue, and a "mega-drought" scenario matching the worst case in the climate prediction models. In both scenarios, groundwater levels continue to fall through the entire period of the simulation. In the authors' words: "Business-as-usual population growth, per capita use trends, and management strategies are not sustainable over the long term, even without mega-drought conditions."[90] Even if we dodge a mega-drought this century, the uncertainty we face regarding climate and water supply makes solving the current problems of groundwater overdraft and the structural deficit on the Colorado River even more urgent.

The past effects of drought on water consumption paint a compelling story for future water management. While no significant decreases were seen during the short episode of drought in the mid-1990s, sustained, severe drought in the 2000s correlated with noticeable decreases in per capita rates of water consumption by homeowners and businesses in the Cities of Phoenix and Tucson. During the 1990s, traditional land development practices, outdoor watering habits, and older plumbing probably helped minimize GPCD reductions despite the warning signs of extended drought in that decade. By the 2000s, however, the combined effects of stricter landscape and plumbing ordinances, state and municipal information and education programs, severe sustained drought and consequent drought management plans, and an economic recession after 2008 that slowed population growth all combined to result in a modest but significant decline in GPCD. Importantly, some of these factors leading to reduced per capita consumption are intentional while others are exogenous and serendipitous. It would be unwise for urban planners and regional water managers to rely on non-intentional, unpredictable factors to create the conditions necessary to move metropolitan Phoenix and Tucson further and faster toward water sustainability. Therefore, future strategies should aim to make this kind of progress without the aid of economic recessions and persistent drought conditions and the crisis mentality that comes with imminent declarations of water shortages.

Despite the recent progress in reducing per capita consumption rates in the last couple of decades, the Tucson and Phoenix AMAs still remain dangerously dependent on nonrenewable groundwater and an insecure supply of imported water from the CAP. Recent progress by the Cities of Tucson and Phoenix to substitute CAP water for mined groundwater will be difficult or impossible to sustain if population growth continues at current rates or if current drought conditions become the new "normal." To avoid a crisis, central and southern Arizona cities must either import more water or use significantly less water and, eventually, contain population growth. The Gober et al. article on mega-drought quoted above assessed how a variety of common drought mitigation policies would impact future groundwater levels. They looked at enhanced water conservation, water supply augmentation, growth management, water banking, and wastewater recycling. The only drought mitigation policy that resulted in an end to groundwater overdraft was when population growth in Greater Phoenix was restrained to 25 percent total increase between 2000 and 2060.[91] This is not good news. A modest growth rate of 2 percent per year will more than double the population by 2060. Moreover, no city in central or southern Arizona has shown the will or has the legal capacity to stop population growth. Moreover, the likelihood of importing additional large supplies of affordable freshwater to the region is remote. A much more significant reduction in per capita consumption *and* total water demand is needed to put Arizona's urban areas on the path to sustainability.

Many water managers and policy makers are waking up to the region's severe challenges, in the same way that many formerly in denial about climate change have recently come to accept the evidence and embrace the need for adaptation measures. Significantly, in May 2016 the Arizona Municipal Water Users Association (AMWUA), which represents virtually all the large municipal water suppliers in Maricopa County and delivers water to half the population of the state of Arizona, acknowledged the dire situation on the Colorado River and the need to act quickly. "Lake Mead has dropped to a historic low with a Colorado River shortage declaration looming as soon as the next couple of years.…Growing risk and uncertainty have caused Arizona's water managers to roll up their sleeves."[92] Despite this welcome acknowledgment of a water supply problem, what troubles the AMWUA most is the imminent declaration of a "shortage" by the U.S. Bureau of Reclamation once Lake Mead's level reaches 1,075 feet in elevation. In 2016, the reservoir was only a few feet above that level. Cutbacks to Arizona's CAP allocation begin the year after the declaration is made. Moreover, at elevation 1,025 feet a second shortage declaration will trigger additional cuts by the Bureau of Reclamation. The bureau's experts predict a 25 percent chance that Lake Mead will fall below 1,025 feet by 2023. Those shortage declarations and the possibility that the federal government will mandate specific reductions in Colorado River water allocations to the states are the "crisis" AMWUA wants to avert. So it is negotiating intensively with other parties in the basin states and Mexico to do whatever is necessary to keep the water level in Lake Mead at or above 1,025 feet.[93] While this is a welcome adaptation, it is far from a visionary or comprehensive solution to municipal water supply problems in Arizona—or elsewhere in the Southwest. Water leaders still seem stuck in a short-term crisis-response mode.

Too many water policy and water management leaders still place their hopes in water augmentation and various technological fixes like desalination, while simultaneously working to weaken regulation and mandates designed to move solutions forward. For example, in the spring of 2016 the Arizona legislature passed two laws designed to weaken both groundwater protections and a 100-year assured water supply rule adopted by several rural Arizona counties that are outside the Active Management Areas. A developer proposing a large planned community in Cochise County that would be entirely reliant on pumped groundwater was having trouble getting his development approved due to water supply adequacy problems. Frustrated pro-development legislators from Cochise County arranged a legal fix to allow the development to go forward by undercutting the assured water supply rule. Fortunately, the Arizona media was generally critical of the bills, portions of the water establishment opposed the bills, and the governor in the end vetoed them. So, at least there was a division of opinion and a mixed outcome.[94] Still, the lack of a strong commitment to assured water supply indicates a steep hill yet to climb.

While there are risks in acting prematurely to resolve long-term water supply challenges, there are greater risks from delaying adaptive action until there is an actual crisis. A crisis affords little time to carefully weigh options and adapt incrementally. It often generates stopgap solutions based on fear and stress, rather than long-term solutions based on anticipatory management, innovation, and collaboration. Decision making in a crisis usually fails to adequately incorporate broader social goals like efficiency, equity, environmental protection, fiscal prudence, and participatory governance. Finally, delaying adaptations reduces the time available for cultural change and acceptance of measures needed to secure a sustainable water supply.

The above-mentioned article on urban adaptation to drought by Gober et al. strongly underscores these points, concluding that metropolitan Phoenix *can* have a sustainable water supply for the next 60 years without draining its groundwater aquifers, even in the face of a mega-drought, but to do so it must begin immediately to adopt "a combination of modest growth management, new expanded conservation efforts, and expensive infrastructure [investment]." Accomplishing that will require decades of cooperative effort among the municipalities and the state to "share the cost of infrastructure and the responsibility of conservation, and manage growth in a way that does not undermine the sustainability position of neighboring communities in terms of groundwater assets." Finally, the authors underscore the importance of allowing sufficient time for cultural change, observing that "there are psychological, behavioral, cultural, and gender-based reasons that people use water the way they do, and these behaviors and cultural patterns (especially with respect to outdoor use) take time to change."[95]

Many people continue to believe in technocratic rather than social and behavioral solutions: that the CAP will solve the groundwater overdraft problem and more water imports will solve the larger demand-supply deficit. But relying on the supply side of the equation today seems quixotic. The challenges are more complex and contested than in 1922 or 1978, the opportunities for augmentation are more limited, and the consequences of failure are more momentous. In his book *Bird on Fire,* Andrew Ross worries that a technocratic approach to problem solving in Arizona's prevailing laissez-faire political culture will not lead to sustainability but rather to inequality and social conflict as competition for resources intensifies.[96] That's the same dystopian future that Paolo Bacigalupi imagines in *The Water Knife*. The future Arizonans get will be the future they largely choose, and serious questions remain as to whether Arizonans will choose crisis or successful adaptation.

Faith in a supply-side solution carries with it a moral hazard: It protects the status quo, permits continued delays in adopting more effective conservation and efficiency standards, reinforces laissez-faire attitudes toward water consumption, and discourages the kinds of social, political, legal, economic, and technological adaptations needed to live within our limits. For over a hundred years, with substantial assistance from the federal government, Arizonans have assiduously developed an extraordinary infrastructure for capturing, pumping, storing, delivering, and consuming water resources. But the era of big federally funded water importation projects is behind us.[97] The task facing Arizona over the next century is to work just as concertedly and collaboratively and successfully on managing water demand—managing ourselves—to close the water demand-supply gap steadily and intentionally in a way that averts crises, protects environmental resources, and advances justice, equity, and sustainability. ✣

## Notes

1. This article is based upon work supported by the National Science Foundation under Grant Numbers CBET-1204478 (Water Sustainability and Climate) and SES-1462086 (Decision Making Under Uncertainty: Decision Center for a Desert City III). Any opinions, findings, conclusions, and recommendations expressed in this article are those of the author(s) and do not necessarily reflect the views of the National Science Foundation (NSF).

2. Andrew Ross, *Bird on Fire: Lessons from the World's Least Sustainable City* (Oxford University Press, 2011).

3. William DeBuys, *A Great Aridness: Climate Change and the Future of the American Southwest* (Oxford University Press, 2011), chs. 6 & 7.

4. Paolo Bacigalupi, *The Water Knife* (Vintage Books, 2016).

5. William R. Mee, "Highlights of the City of Phoenix Water Conservation Program," *Journal of Contemporary Water Research and Education,* 83 (1990): 25–30. Quote is on p. 30.

6. Arizona Department of Water Resources, *Arizona's Next Century: A Strategic Vision for Water Supply Sustainability* (Jan. 2014). Available at: http://www.azwater.gov/AzDWR/Arizonas_Strategic_Vision/. Quote is on p. 7.

7. "Governor Doug Ducey Announces Arizona Water Initiative, http://azgovernor.gov/governor/news/2015/10/governor-doug-ducey-announces-arizona-water-initiative Accessed May 14, 2016.

8 Jonathan Overpeck and Bonnie Colby, *The First Step in Repairing the Colorado River's Broken Water Budget: A Summary Report* (Colorado River Research Group, Dec 2014): 2. Susanna Eden, Madeline Ryder, and Mary Ann Capehart, "Closing the Water Demand-Supply Gap in Arizona," *Arroyo,* a publication of the Water Resources Research Center at the University of Arizona (2015): 1–16. On pp. 1–2 the authors acknowledge that a water demand-supply gap already exists in some parts of Arizona that are dependent on groundwater and that by as early as 2035 water demand will exceed known reliable supplies by 20 percent. Patricia Gober and Craig Kirkwood, "Vulnerability Assessment of Climate-Induced Water Shortage in Phoenix," *Proceedings of the National Academy of Sciences* **107.50** (2010): 21295-21299.

9. Climate Assessment for the Southwest (CLIMAS), "May Southwest Climate Outlook" (May 19, 2016), Reservoir Volumes illustration, p. 6. Data derived from National Water and Climate Center, Natural Resources Conservation Service. Accessed at http://www.climas.arizona.edu/sites/default/files/SWClimateOutlook_MAY2016.pdf.

10 Warren Tenney, Arizona Municipal Water Users Association, "Water Bank Recovery: Preparing for Shortages on the Colorado River," https://amwua.wordpress.com/2016/08/01/3265/ accessed Dec 21, 2016.

11. The Active Management Areas (AMAs) encompass the Cities of Phoenix and Tucson as well as surrounding areas of relatively high water demands in

these metropolitan regions. For maps of the areas covered by each AMA, see http://www.azwater.gov/AzDWR/WaterManagement/AMAs/.

12. Susanna Eden, Madeline Ryder, and Mary Ann Capehart, "Closing the Water Demand-Supply Gap in Arizona," *Arroyo,* a publication of the Water Resources Research Center at the University of Arizona (2015): 1–16. See pp. 3–5.

13. See slide #3 in the presentation by Jeff Biggs of Tucson Water at a Water Reuse Symposium in July 2015 at the following URL, accessed Feb 18, 2017: https://watereuse.org/wp-content/uploads/2015/10/S4B2_Biggs_Arizona-Reuse-2015-Symposium-07-28-2015.pdf.

14. Arizona Department of Water Resources, "Water Resources Puts Finishing Touches on Latest Management Plan for the Tucson Active Management Area" (April 2016), published at http://www.azwater.gov/AzDWR/ADWR_News/tucsonAMA_4mp.html Accessed May 14, 2016.

15. Sharon Megdal, Zachary Smith, and Aaron Lien, "Evolution and Evaluation of the Active Management Area Management Plans," report prepared for the Arizona Water Institute and the Arizona Department of Water Resources (Jan. 2008). The quote is from p. 61. It is important to note that some of our analysis focuses on the municipal jurisdictions of the Cities of Tucson and Phoenix. At other times, we reference the broader metropolitan regions encompassing the central cities as well as surrounding suburbs and municipalities. In still other places, we reference the Active Management Areas, which are larger state-designated areas of water management in each region (http://www.azwater.gov/AzDWR/WaterManagement/AMAs/). Most of our water data derive from the central municipalities or the regional AMA. We specify "City of" when referring to the central cities, "AMA" where appropriate, and, otherwise, the broader "regions" or "metro areas," or the state of Arizona. This multi-scalar approach is essential given that the central cities are integrated with surrounding areas and broader regional and state-wide trends and challenges.

16. Shaun Mckinnon, *Arizona Republic*, August 2014: http://www.azcentral.com/story/news/local/arizona/2014/08/11/arizona-water-supply-drought/13883605/.

17. Arizona Town Hall, *Ninety-Ninth Arizona Town Hall: Arizona's Energy Future* (2011), edited by Clark Miller and Sharlissa Moore, ch. 6, "Arizona's Energy/Water Nexus," pp. 79–90.

18. Arizona Department of Water Resources, "Phoenix Active Management Area Water Demand and Supply Assessment 1985–2025," Summary Sheet (Dec. 2011): 1. http://www.azwater.gov/AzDWR/WaterManagement/Assessments/documents/PhxAMA_AssessmentSummarySheet.pdf.

19. Arizona Department of Water Resources, "Tucson Active Management Area Water Demand and Supply Assessment 1985–2025," Summary Sheet (Jan. 2012): 1. http://www.azwater.gov/AzDWR/WaterManagement/Assessments/documents/TAMA_AssessmentSummarySheet_.pdf.

20. The Phoenix AMA consumes more than 2 million acre-feet of water annually, and SRP contributes about 800,000 acre-feet of that: http://www.srpnet.com/about/facts.aspx. To check reservoir levels on the Salt and Verde Rivers, see SRP's hydrological data site: http://data.hydrometdataservice.info/dwr/.

21. Susanna Eden, Madeline Ryder, and Mary Ann Capehart, "Closing the Water Demand-Supply Gap in Arizona," *Arroyo,* a publication of the Water Resources Research Center at the University of Arizona (2015): 1–16. See p. 13.

22. See Douglas Kenney and Robert Wilkinson, editors, *The Water-Energy Nexus in the American West* (Edward Elgar, 2012). Four of the contributions to this volume are about water and energy in Arizona.

23. Jonathan Overpeck and Bonnie Colby, *The First Step in Repairing the Colorado River's Broken Water Budget: A Summary Report* (Colorado River Research Group, Dec 2014): 3.

24. Our analysis focuses on the central cities of each region for this time period due to the availability of data, which were obtained from the cities at the monthly time scale. However, we also reference metro-wide trends, where relevant, for understanding regional patterns in water consumption and sustainability.

25. Helen Ingram and Anne Schneider, "Science, Democracy, and Water Policy," *Water Resources Update*, Issue # 113, Universities Council on Water Resources, 1998.

26. World Water Assessment Programme, *The United Nations World Water Development Report 2015: Water for a Sustainable World* (Paris: UNESCO), p. 24. USBR, *WaterSMART Progress Report 2010–2016.* Phoenix Chamber of Commerce, *What Phoenix and Arizona Have to Offer the Textile Industry* (1960), quoted in E. T. Shermer, *Sunbelt Capitalism: Phoenix and the Transformation of American Politics* (University of Pennsylvania Press, 2013), p. 236.

27. Ioanna T. Morfessis, "Arizona Needs to Develop, Stick to Vision for Growth," *Arizona Republic* (Jan. 4, 2009), accessed Dec 14, 2016 at http://archive.azcentral.com/arizonarepublic/viewpoints/articles/2009/01/03/20090103morfessis04-VIP.html.

28. Michael Logan, *Fighting Sprawl and City Hall: Resistance to Urban Growth in the Southwest* (University of Arizona Press, 1995).

29. U.S. Environmental Protection Agency, "A Closer Look: Temperature and Drought in the Southwest": https://www.epa.gov/climate-indicators/southwest. Accessed Dec. 21, 2016.

30. U.S. Bureau of Reclamation, SECURE Water Act, Section 9503(c)—Reclamation Climate Change and Water. Prepared for United States Congress. Denver, CO, 2016. For an illustrative graphic of historical and projected supply and demand trends on the Colorado River, see the Bureau of Reclamation's brief fact sheet: http://www.usbr.gov/climate/secure/docs/2016secure/factsheet/ColoradoRiverBasinFactSheet.pdf.

31. U.S. Bureau of Reclamation, *Colorado River Basin Water Supply and Demand Study—Executive Summary* (Dec. 2012), pp. 6–10. The full study is available online at http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/.

32. According to the Bureau of Reclamation, "The median of the mean natural flow at Lees Ferry over the next 50 years is projected to decrease by approximately nine percent, along with a projected increase in both drought frequency and duration as compared to the observed historical and paleo-based scenarios"; ibid., p. 7.

33. A contemporary view of Indian Water Rights that struggles from the perspective of multiple stakeholders is found in U.S. Senate, Committee on Indian Affairs, Hearing "Addressing the Needs of Native Communities Through Indian Water Rights Settlements," 114th Cong., 1st Session (May 2015). On p. 39 the Department of the Interior cites a number of ongoing negotiations and tribal needs. See also the Sept. 2015 report by Charles Stern of the Congressional Research Service, *Indian Water Rights Settlements,* Report R44148; Figure 1 and Table 2 show ongoing negotiations with several Arizona tribes.

34. Colorado River Basin Project Act of 1968, *Public Law 90-537*. 90th Congress, S. 1004, September 30, 1968, Sec. 304 (f) (2).

35. U.S. Secretary of the Interior, Record of Decision, "Colorado River Interim Guidelines for Lower Basin Shortages…" (Dec. 2007): http://www.usbr.gov/lc/region/programs/strategies/RecordofDecision.pdf.

36. City of Tucson Water Department, *2012 Update—Water Plan: 2000–2050*, Figure 3-1), https://www.tucsonaz.gov/files/water/docs/2012_Update_Water_Plan_2000-2050.pdf. See also Arizona Department of Water Resources, *Securing Arizona's Water Future*, section 8.0.5, "AMA Cultural Water Demand—Municipal Water Demand," Table 8.0-12. (The municipal demand data are from 2001–2005.)

37. Data regarding the City of Tucson's reliance on CAP water since 2015 come from unpublished graphs prepared by the City of Tucson Water Department for public presentations in 2016.

38. http://www.cap-az.com/documents/shortage/Shortage-Fact-Sheet.pdf. http://www.azwater.gov/azdwr/ColoradoRiverShortagePreparedness.htm. http://www.slate.com/articles/health_and_science/science/2015/05/arizona_water_shortages_loom_the_state_prepares_for_rationing_as_lake_mead.html All three websites accessed May 14, 2016.

39. National Geographic, "Worst Drought in a Thousand Years Predicted for American West" (Feb. 12, 2015): http://news.nationalgeographic.com/news/2015/02/150212-megadrought-southwest-water-climate-environment/. Accessed May 14, 2016. See also Toby Ault, Julia Cole, Jonathan Overpeck, Gregory Pederson, and David Meko, "Assessing the Risk of Persistent Drought Using Climate Model Simulations and Paleoclimate Data," *Journal of Climate*, 27 (Oct 2014): 7529–7549.

40. An excellent book-length study of the groundwater overdraft problem in the U.S., with four case studies focused on Arizona, is Robert Glennon, *Water Follies: Groundwater Pumping and the Fate of America's Fresh Waters* (Island Press, 2004).

41. L. F. Konikow, *Groundwater Depletion in the United States (1900–2008): U.S. Geological Survey Scientific Investigations Report 2013–5079* (2013): http://pubs.usgs.gov/sir/2013/5079. (Available only online.)

42. Chris Avery, Carla Consoli, Robert Glennon, and Sharon Megdal, "Good Intentions, Unintended Consequences: The Central Arizona Groundwater Replenishment District," *Arizona Law Review*, 49 (2007): 339–359.

43. ADWR's summary of the essential components of the state's Groundwater Management Code can be accessed here: http://www.azwater.gov/AzDWR/WaterManagement/documents/Groundwater_Code.pdf.

44. For a critical appraisal of the implementation of the GMA see Paul Hirt, Annie Gustafson, and Kelli Larson, "Mirage in the Valley of the Sun," *Environmental History* 13(3): 492–501; accessible at http://www.jstor.org/stable/25473264.

45. The quote in the text is from Patricia Gober and Craig Kirkwood, "Vulnerability Assessment of Climate-Induced Water Shortage in Phoenix," *Proceedings of the National Academy of Sciences* 107.50 (2010): 21295–21299. Quote is on 21298. The state auditor in 1999 confirmed that none of the AMAs was likely to reach safe yield by 2025. Arizona Office of the Auditor General, Report # 99-8 (April 1999): i–ii, 9–17. Legal scholar Rita McGuire came to a similar conclusion in 2007, saying, "Although much progress has been made toward achieving safe yield since the GMA's passage, the Phoenix and Tucson AMAs still appear to be a long way from reaching this goal." Rita McGuire, "Patching the Holes in the Bucket: Safe Yield and the Future of Water Management in Arizona," *Arizona Law Review*, 49 (2) (2007): 1–23. Quote is on p. 3.

46. Patricia Gober, C. Kirkwood, R. Balling Jr., A. Ellis, and S. Deitrick, "Water Planning Under Climatic Uncertainty in Phoenix: Why We Need a New Paradigm," *Annals of the Association of American Geographers*, 100 (April 2010): 356–372. Quote is from the abstract on p. 356. See also P. Gober, E. A. Wentz, T. Lant, M. K. Tschudi, and C. W. Kirkwood, "WaterSim: A Simulation Model for Urban Water Planning in Phoenix, Arizona, USA," *Environment and Planning B: Planning and Design*, 38 (2011): 197–215.

47. Paul Hirt, Annie Gustafson, and Kelli Larson, "Mirage in the Valley of the Sun," *Environmental History* 13(3): 492–501; accessible at http://www.jstor.org/stable/25473264.

48. See http://www.azleg.gov/viewdocument/?docName=http://www.azleg.gov/ars/45/00454.htm.

49. See http://www.azwater.gov/azdwr/WaterManagement/Wells/ and https://gisweb.azwater.gov/WellRegistry/.

50. Additional critical assessments of ADWR's regulatory approach include Rita McGuire, "Patching the Holes in the Bucket: Safe Yield and the Future of Water Management in Arizona," *Arizona Law Review*, 49 (2) (2007): 1–23; Kelli L. Larson, Annie Gustafson, and Paul Hirt, "Insatiable Thirst and a Finite Supply: An Assessment of Municipal Water-Conservation Policy in Greater Phoenix, Arizona, 1980–2007," *Journal of Policy History,* 21 (2009): 107-137; and Sharon Megdal, Zachary Smith, and Aaron Lien, "Evolution and Evaluation of the Active Management Area Management Plans," report prepared for the Arizona Water Institute and the Arizona Department of Water Resources (Jan. 2008).

51. Arizona Department of Water Resources, *Securing Arizona's Water Future*, section 8.0.5, "AMA Cultural Water Demand—Municipal Water Demand," Table 8.0-12.

52. A. W. Ellis, T. W. Hawkins Jr., and P. Gober, "Estimating Future Runoff Levels for a Semi-Arid Fluvial System in Central Arizona, USA," *Climate Research,* 35 (2008): 227–239.

53. Michael P. Logan, *The Lessening Stream: An Environmental History of the Santa Cruz River* (University of Arizona Press, 2006), chs. 9–11.

54. Rebecca H. Carter and Barbara J. Morehouse, *Climate and Urban Water Providers in Arizona: An Analysis of Vulnerability Perceptions and Climate Information,* Climate Assessment for the Southwest (CLIMAS) Report #CL1-03 (Tucson, July 2003). http://www.climas.arizona.edu/sites/default/files/pdfcl1-03.pdf

55. The data we collected for this analysis are from billing data provided by the Phoenix and Tucson water utilities and county-level drought statistics from the Western Regional Climate Center. It is important to note that per capita demands can be measured in different ways, in part depending on which population estimates are used. To ensure comparability of the city trends, we used water delivery data from each municipality as well as census population estimates.

56. Sharon Megdal, Zachary Smith, and Aaron Lien, "Evolution and Evaluation of the Active Management Area Management Plans," report prepared for the Arizona Water Institute and the Arizona Department of Water Resources (Jan. 2008), pp. 60–61.

57. U.S. Bureau of Reclamation, *Colorado River Basin Water Supply and Demand Study—Executive Summary* (Dec. 2012): 11–23.

58. Arizona Department of Water Resources, *Arizona's Next Century: A Strategic Vision for Water Supply Sustainability*, section titled "Opportunities and Challenges for Arizona," pp. 51–62. Accessible at http://www.azwater.gov/AzDWR/Arizonas_Strategic_Vision/documents/OpportunitiesandChallengesforArizona.pdf.

59. Ibid. Quote is from p. 60. Thomas McCann and Susan Bitter Smith (formerly president of the board of CAP) have been among the most vocal and influential advocates in Arizona for water augmentation and especially desalination schemes. For a video podcast on one of CAP's specific augmentation strategies, see https://www.youtube.com/watch?v=OB9-I4Hi7v4.

60. M. O. Wilder, I. Aguilar-Barajas, N. Pineda-Pablos, R. G. Varady, S. B. Megdal, J. McEvoy R. Merideth, A. Zúñiga-Terán, and C. A. Scott, "Desalination and Water Security in the US—Mexico Border Region: Assessing the Social, Environmental and Political Impacts," *Water International*, DOI, 2016: 10.1080/02508060.2016.1166416: 1–20. Alon Tal, "The Desalination Debate—Lessons Learned Thus Far," *Environment: Science and Policy for Sustainable Development*, 53(5): 34–48. For a critical review of the economic and environmental costs of desalination, see T. Mezher, H. Fath, Z. Abbas, and A. Khaled, "Techno-Economic Assessment and Environmental Impacts of Desalination Technologies," *Desalination*, 266 (1–3) (2011): 263–273.

61. M. O. Wilder, I. Aguilar-Barajas, N. Pineda-Pablos, R. G. Varady, S. B. Megdal, J. McEvoy R. Merideth, A. Zúñiga-Terán, and C. A. Scott, "Desalination and Water Security in the US—Mexico Border Region: Assessing the Social, Environmental and Political Impacts," *Water International*, DOI, 2016: 10.1080/02508060.2016.1166416, p. 15.

62. Valerie Strassberg and Brad Lancaster, "Fighting Water with Water: Behavioral Changes versus Climate Change," *Journal of the American Water Works Association*, 103 (6) (2011): 54–60.

63. ADWR estimates that the average household uses 58 percent of its water budget on outdoor landscaping. It can require even more than that to support mesic landscapes in desert cities. http://www.azwater.gov/azdwr/StatewidePlanning/Conservation2/Residential/Outdoor_Residential_Conservation.htm. See also Elizabeth Wentz and Pat Gober, "Determinants of Small-Area Water Consumption for the City of Phoenix, Arizona," *Water Resources Management*, 21 (2007): 1849–1863.

64. William R. Mee, "Highlights of the City of Phoenix Water Conservation Program," *Journal of Contemporary Water Research and Education,* 83 (1990): 25–30.

65. The abrupt water rate increase in the summer of 1976 led to a recall of three city council members and the resignation of a fourth, which had a chilling effect on the use of price signals to encourage conservation. For a summary of the controversial episode in Tucson's history, see http://arizona.openrepository.com/arizona/bitstream/10150/301191/1/hwr_10-035-039.pdf.

66. E. McPherson and R. Haip, "Emerging Desert Landscape in Tucson," *Geographical Review,* 79 (4) (1989): 435–449. Elizabeth Wentz and Pat Gober, "Determinants of Small-Area Water Consumption for the City of Phoenix, Arizona," *Water Resources Management*, 21 (2007): 1849–1863.

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97. No new large dams have been built in the U.S. since the 1980s. In 1993 Bureau of Reclamation commissioner Dan Beard announced that the era of big dams was over. Since then, the U.S. has started authorizing the removal of obsolete and unnecessary dams, such as the Kennebec Dam in Maine, the Elwha and Glines Canyon Dams in Washington, and most recently several dams on the Klamath River in Oregon and California. Former commissioner Beard even called for the abolishment of the Bureau of Reclamation and the removal of Glen Canyon Dam in his 2015 book *Deadbeat Dams* (Johnson Books). According to a 2003 U.S. Government Accountability Office (GAO) report, the majority of the nation's dams were constructed before the development of contemporary engineering standards (i.e., before 1950) and over 1,800 dams have received a "high hazard potential" ranking from the American Society for Civil Engineers. See B. T. Hill, *Freshwater Supply: States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Shortages,* U.S. GAO report to Congress (2003).