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Key Points:
- Both socioeconomic and hydroclimatological factors affect water conservation
- High-income and low precipitation states tend to strong conservation policies
- High-income and low water availability cities tend somewhat to strong policies

Correspondence to:
G. M. Hornberger,
g.hornberger@vanderbilt.edu

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Water conservation and hydrological transitions in cities in the United States

George M. Hornberger[1], David J. Hess[2], and Jonathan Gilligan[3]

[1]Department of Civil and Environmental Engineering and Department of Earth and Environmental Sciences, Vanderbilt Institute for Energy and Environment, Vanderbilt University, Nashville, Tennessee, USA, [2]Department of Sociology, Vanderbilt Institute for Energy and Environment, Vanderbilt University, Nashville, Tennessee, USA, [3]Department of Earth and Environmental Sciences, Vanderbilt University, Nashville, Tennessee, USA

Abstract Cities across the world have had to diversify and expand their water supply systems in response to demand growth, groundwater depletion and pollution, and instability and inadequacy of regional surface freshwater sources. In the U.S., these problems plague not only the arid Western cities but increasingly also cities in the Eastern portions of the country. Although cities continue to seek out new sources of water via Promethean projects of long-distance supply systems, desalinization plants, and the recharge of aquifers with surface water, they also pursue water conservation because of its low cost and other benefits. We examine water conservation as a complex sociotechnical system comprising interactions of political, sociodemographic, economic, and hydroclimatological factors. We provide quantitative data on the factors that affect more and less advanced transitions in water conservation regimes, and we show that water stress and other hydrological data can only partially predict the transition. We also provide qualitative case studies to identify institutional and political barriers to more advanced water conservation regimes. This interdisciplinary, mixed methods approach typifies the need for knowledge that informs hydrologists about how their research may or may not be adopted by decision-makers.

1. Introduction

Why do some cities but not others adopt stringent water conservation measures? A casual answer might be that those cities that face pervasive water shortages or the threat of the same are the conservation-minded ones. But this turns out not to be the answer, or at least not the complete answer. Even in relatively compact regions with hydroclimatological features that should result in similar conservation measures, such as cities in Southern California, there is tremendous variation in water conservation policies [*Sierra Club*, 2013]. Additional considerations, both physical and social, affect adoption of water conservation measures. Furthermore, hydrological-modeling work shows that feedbacks among factors can make a given trajectory toward a type of water supply system depending on initial conditions as well as on management decisions made along the way [*Srinivasan*, 2015]. For municipal water utilities to deliver water to households, they must develop and maintain an extensive infrastructure and consume resources, including significant energy resources, to treat and pump water. Thus, there should be a strong economic incentive to conserve water almost everywhere. Furthermore, there may be a political dimension as well. For example, support for conserving energy has been related to political leaning at both the individual level [*Dietz et al*., 2013] and for state governments [*Chandler*, 2009], and it is possible the same is true for municipal water conservation. Furthermore, individual behavior is affected by perceptions of water use, which consumers tend to underestimate [*Attari*, 2014]. After even a cursory examination, it is clear that the answer to the question posed above is not obvious.

Our central premise is that urban water supply systems represent a complex large technological system (LTS) that includes water, ecological and climatological interfaces, infrastructure, laws, consumer practices, and public and private-sector organizations. We consider a LTS to be fundamentally a sociotechnical system because interactions among social, technological, and natural factors play important roles. Thus, the study of how these systems change, or undergo a *transition*, involves a complex articulation of social, technical, and natural systems and requires integrating the contributions of different disciplines. Transitions in LTSs are long-term processes, often on a time scale of several decades, and generally they are guided by policies in interaction with markets, infrastructures, and natural systems [*Geels and Schot*, 2007]. Examples include the transition of building energy systems from coal to natural gas and the transition of electricity generation from fossil fuels to low-carbon sources.

Traditional approaches to urban water planning focus on increasing water supply rather than on decreasing demand. These approaches can include building new pipelines and reservoirs, using surface water for aquifer recharge projects, purchasing water rights from rural constituencies, and treating brackish water and salt water. The prospects of expanding population and adverse changes in climate will require cities to find new ways to increase water availability [*Hering et al*., 2013], but it also is clear that water conservation measures are becoming important not only as a "source" of water but also as part of broader urban and regional sustainability efforts [*Saurí*, 2013]. In fact, integrated planning for management and planning for water resources for cities has reemerged using modern tools and based on previous theoretical work [*Baumann et al*., 1998] and water conservation is an element in such planning. We define *water conservation* for cities as a regime of water supply that requires or encourages the reduction of the demand for water from surface and groundwater sources (including saltwater sources). The four main elements of the metropolitan water conservation regime generally are use restrictions on urban consumers (such as limitations on the irrigation or watering of lawns, washing of vehicles, and replenishment of swimming pools), water efficiency measures (such as mandates or rebates for low-flow toilets, rainwater harvesting, and water-efficient appliances and machinery), water supply pricing policies, and water recycling (gray water systems, on-site reuse for cooling, and reclaimed wastewater for the potable water supply). Our definition is consistent with that of *Baumann et al*. [1998] who argue that a reduction in water use can lead to a net social benefit.

There is tremendous variation in the extent to which urban water conservation policies have been developed and implemented, with a growing niche of water conservation policies and different methods for integrating these new policy approaches to varying degrees into their existing water supply regime. We propose that the current state of affairs can be seen as a time of transition toward extensive integration of supply and demand management. Such a transition would reconceive water infrastructure in terms of the water-related services provided rather than the quantity of water delivered [*Fuenfschilling and Truffer*, 2013; *Wolff and Gleick*, 2002]. Previous research on water-stressed cities has found that after exhausting local sources of ground and surface water, cities generally turn to water importation (usually from more distant surface water sources via aqueducts) and then to groundwater storage, desalinization (if the city is near a saltwater source or has access to brackish groundwater), and water conservation [*Richter et al*., 2013]. Thus, water conservation is often part of a general transition of water regimes in response to water stress, but it is of particular interest because it is a low-cost option that has diverse environmental benefits, including energy conservation.

Our focus on the problem of the transition of water supply systems is therefore distinct from the literature on water conservation that analyzes the economic and psychological mechanisms by which conservation programs can be implemented successfully. This literature has shown the importance of personal beliefs [*Fielding et al*., 2012], which in turn can be influenced informally through social networks [*Athanasiadis*, 2005; *Kanta and Zechman*, 2014], as well as the role of economic incentives such as water pricing [*Olmstead and Stavins*, 2009]. In contrast to this approach, we are more interested in the general factors that affect the change in the overall water supply regime to favor inclusion of water conservation policies.

To accomplish this goal of analyzing the factors that affect a transition in the water supply regime, our project seeks to assemble and analyze a large database for U.S. cities. In this paper we analyze available data at the state level to explore characteristics associated with high "scores" for water conservation, we present a preliminary analysis for cities using an existing database, and we summarize several cases for selected cities where we have developed in-depth information of conservation policies.

2. Background

Prior to 1963, the *Journal of Geophysical Research* (*JGR*) was published as one unit. In 1964, the first split of JGR occurred when *JGR: Space Physics* was established. In 1965, *Water Resources Research* was established, and the founders decided that the journal would not be *JGR: Hydrology* because they recognized that water resources transcended hydrology as a geophysical science per se. Thus, from its very beginning *Water Resources Research* published papers that incorporated work from the physical, biochemical, and social sciences.

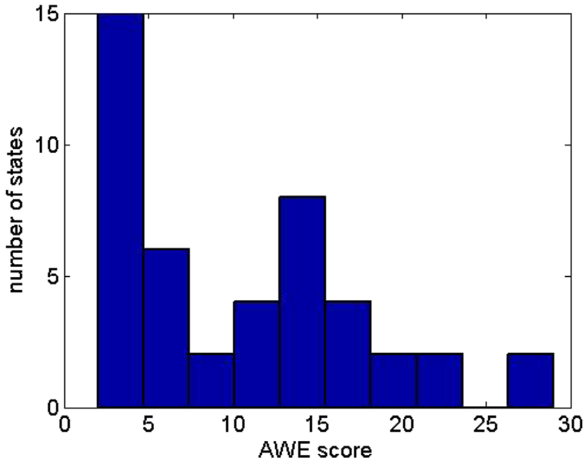

Figure 1. Histogram of Alliance for Water Efficiency (AWE) conservation scores.

A precise definition of water conservation included two criteria, reducing water use or loss and doing so in an economically favorable manner [*Baumann et al*., 1984]. Water prices have been shown to affect demand and are thus a lever for conservation policy [*Martin and Kulakowski*, 1991; *Mercer and Morgan*, 1985; *Nieswiadomy*, 1992; *Piper*, 2003]. Comparisons between command and control policies versus pricing or incentives have also been explored [*Burness et al*., 2005]. Mandates, such as water budgets or water use restrictions, can be difficult to enforce. Water pricing does have an effect on demand [*Grafton et al*., 2011]; however, researchers also have pointed to problems with pricing policies such as the relative inelasticity of demand for water [*Olmstead and Stavins*, 2009] and the need to overcome negative effects of pricing increases on low-income households [*Rogers et al*., 2002].

In general, this literature is often developed in a normative mode that examines what water conservation policies are ideal and how policies can be improved to be in line with the ideal. Rather than focus on what type of water conservation policy is better than another, our approach begins with a broad descriptive and explanatory question about the range of water conservation policies: what are the conditions—social, political, economic, hydrological, and technological—that facilitate or impede transitions to an integrated water management regime with highly developed conservation measures? Previous studies have begun to address this question at the state-government level [e.g., *Rashid et al*., 2010] and at the city-government level [e.g., *Gerrity and Snyder*, 2011; *Teodoro*, 2010]. We build on this approach by providing both quantitative and qualitative analyses that draw on both hydrological and social science perpsectives.

3. Methods

Our general approach is to use indices of water conservation measures and explore their relationship to a set of independent variables. The approach is exploratory; that is, we use conservation indices for 2011 for states and for 2010 for cities as a snapshot of present circumstances and consider a variety of other available data to explore correlations. We do not aim to model the time course of transitions in a causal way. Data were assembled from a number of sources as described below. Both state level and city level data were stratified into two classes, "C" representing those entities that have achieved a reasonable level of water conservation measures and "NC" for those that have not. Binary classification trees [*Hastie et al*., 2009] were used to explore how various measures associated with the states or cities related to the conservation classification. Four cities in regions where restricted water supply has been a problem were selected for an in-depth examination to determine what barriers exist with respect to implementing water conservation measures.

3.1. State Level Analysis

The Alliance for Water Efficiency (AWE) considered laws and policies in states in the U.S. and created a conservation scorecard [*Christiansen et al*., 2012]. Scoring was based on a survey consisting of 20 questions related to regulations, policies, and laws related to water conservation. Scores were assigned to each question based on how strongly the state regulated conservation measures. We selected the 48 contiguous states; that is, we excluded Alaska and Hawaii from our analysis. The scores are broadly distributed, ranging from 2 to 29. The distribution of scores suggests the possibility of two categories (Figure 1). We divide the states in to two classes, C and NC, taking scores greater than or equal to 10 to indicate states that have adopted modest or aggressive conservation measures or are in some stage of positive transition to

Table 1. Variables Used in State Analysis

Variable	Name	Source of Information
Average annual temperature	T	http://www.currentresults.com/Weather/US/average-annual-state-temperatures.php
Average annual precipitation	ppt	http://www.currentresults.com/Weather/US/average-annual-state-precipitation.php
Municipal groundwater withdrawal	GW	http://water.usgs.gov/edu/wugw.html
Municipal surface water withdrawal	SW	http://water.usgs.gov/edu/wusw.html
Population in 2010	Pop	http://www.census.gov/popest/data/state/totals/2013/
Population per area	PpA	http://www.census.gov/popest/data/state/totals/2013/
Population growth rate, 2000–2010	PctCh	http://www.census.gov/popest/data/state/totals/2013/
Per capita income	Inc	https://bber.unm.edu/econ/us-pci.htm
Annual electricity use per capita	E	http://energyalmanac.ca.gov/electricity/us_per_capita_electricity-2010.html
Gross domestic product	GSP	http://lwd.dol.state.nj.us/labor/lpa/industry/gsp/gsp_index.html
Average margin of victory in presidential elections from 1992 to 2004; positive for republican margins, negative for democratic margins	RB_score	http://commons.wikimedia.org/wiki/File:Red_and_Blue_States_Map_%28Average_Margins_of_Presidential_Victory%29.svg

adopting conservation (C) and scores below 10 to indicate states that have not assimilated the need for conservation (NC).

We compiled readily available data for these states to examine whether there were variables that might help explain why the states varied in the grades assigned based on survey data collected by AWE. We included variables to describe climate, water withdrawal, economics, demography, and political views (Table 1). For the analysis, we used the following variables: average annual temperature (T), average annual precipitation (ppt), per capita withdrawal of surface water (pcSW), fraction of water withdrawals from groundwater (fGW), population density (Pdens), population growth rate (GR), per capita income (INC), annual electricity use per capita (E), gross state product per capita (pcGSP), and a measure of voting trends in presidential elections (RBscore).

3.2. City Level Analysis

The American Water Works Association (AWWA) periodically produces a survey of water utilities. We used the latest data [*AWWA*, 2010] to investigate conservation measures reported by cities and their relation to other variables. The AWWA survey included information about five conservation measures—demand management, xeriscaping, low-flow plumbing retrofits, landscape audits, and customer discounts for low-flow measures. We assigned cities to class C if they reported using at least one of the conservation measures and NC if they reported using none.

In addition to the AWWA data, we used a water availability index for cities [*Padowski and Jawitz*, 2012] as a physical measure of water stress and a water quality index [*Purdex*, 2013]. The water availability index is a measure of freshwater availability in liters per capita per day scaled to the maximum values estimated. Renewable water supplies, stored water, imported water, and environmental constraints are included in the measure. The water quality index is based on data reported by the U.S. EPA and calculated using Purdex's proprietary algorithm. For our analysis we included cities from the AWWA survey that also had availability and water quality indices, giving a total of 105 cities with twelve variables considered (Table 2).

3.3. Case Studies

The various causes and consequences of cities adopting water conservation measures are complex and not captured easily with readily available data sets. We augment the quantitative analyses using a comparative case study methodology. Here we select four cities from traditionally water stressed regions of the U.S., Dallas-Ft. Worth, TX; Phoenix, AZ; San Diego, CA, and Wichita, KS. These cities are selected because they have a variation in the AWWA score from the highest to lowest group (described below). We compiled information from local media and city government sources (Table 3) to show in more detail some of the issues that cities have faced with water conservation programs and why the simplistic assumption that "water stress = water conservation" needs to be replaced by a more complex analysis of the interplay of drought, water supply, and politics.

Table 2. Variables Used in City Analysis

Variable	Name	Source of Information
Water availability index	VI	http://soils.ifas.ufl.edu/hydrology/cities/
Water quality index	WQI	http://blog.purdex.com/annual-purdex-awards/state-ranking-reports/
Service population	Pop	http://www.awwa.org/store/productdetail.aspx?productid=25831
Gallons sold	GalSld	http://www.awwa.org/store/productdetail.aspx?productid=25831
Median household income	MedInc	http://www.awwa.org/store/productdetail.aspx?productid=25831
Charges as a percent of household income for residential connection of 500 cubic feet	cf-fee-500	http://www.awwa.org/store/productdetail.aspx?productid=25831
Charges as a percent of household income for residential connection of 1000 cubic feet	cf-fee-1000	http://www.awwa.org/store/productdetail.aspx?productid=25831
Charges as a percent of household income for residential connection of 3000 cubic feet	cf-fee-3000	http://www.awwa.org/store/productdetail.aspx?productid=25831
Monthly service minimum charge	Minch	http://www.awwa.org/store/productdetail.aspx?productid=25831
Residential connection charge	TapFee	http://www.awwa.org/store/productdetail.aspx?productid=25831
Residential system development charge	DevChg	http://www.awwa.org/store/productdetail.aspx?productid=25831
Total revenues	Rev	http://www.awwa.org/store/productdetail.aspx?productid=25831
Operating expenses	Exp	http://www.awwa.org/store/productdetail.aspx?productid=25831

4. Results

4.1. State Level Analysis

The spatial distribution of states in the C and NC classes is not random, with many of the states in "dry areas" having adopted at least some conservation policies (Figure 2). Nevertheless, no clear separation of the two classes strictly on the basis of average temperature and precipitation is apparent (Figure 3). A classification tree using information for all 48 states with one level pruned results in 94% correct classification of either C or NC (Figure 4). The top level classifier variables are electricity use per capita and per capita gross state product. States with high electricity use are not conservation adopters, and several states with relatively low per capita gross state products likewise are not conservation adopters.

Table 3. Sources for Information for Case Studies

http://www.circleofblue.org/waternews/2010/world/u-s-urban-residents-cut-water-usage-utilities-are-forced-to-raise-prices/
Dallas-Fort Worth
http://online.wsj.com/articles/SB124762034777142623
http://www.star-telegram.com/2014/02/17/5576577/fort-worth-watering-restrictions.html?rh=1
http://www.star-telegram.com/2014/04/08/5722230/fort-worth-city-council-approves.html
http://www.texastribune.org/2014/05/19/now-water-board-backs-marvin-nichols-reservoir/
http://www.texastribune.org/2014/09/24/regulators-consider-northeast-texas-reservoir/
http://blogs.dallasobserver.com/unfairpark/2014/02/not_ready_water_conservation_i.php
Phoenix
https://www.phoenix.gov/waterservicessite/Documents/wsd2011wrp.pdf
https://www.phoenix.gov/waterservicessite/Documents/wsdfaqsupply072514.pdf
http://kjzz.org/content/49958/tempe-city-council-adopts-new-water-conservation-goals
http://cronkitenewsonline.com/2014/04/could-price-be-a-tool-for-encouraging-water-conservation-in-arizona/
http://www.azcentral.com/story/news/local/phoenix/2014/10/01/phoenix-start-saving-excess-water-tucson/16540877/
http://www.azcentral.com/arizonarepublic/news/articles/2008/08/31/20080831river-desalter0831.html
http://opensiuc.lib.siu.edu/jcwre/vol83/iss1/3/
http://archive.wired.com/science/planetearth/magazine/16-05/ff_peakwater?currentPage=all
http://www.nytimes.com/2013/06/17/us/an-arid-arizona-city-manages-its-thirst.html?_r=0
San Diego
http://www.utsandiego.com/news/2014/oct/07/environment-san-diego-water-restrictions-drought/2/?#article-copy
http://www.utsandiego.com/news/2009/nov/17/sd-council-hikes-water-rates-775/
http://www.sandiego.gov/publicutilities/infrastructure/index.shtml
http://www.sandiego.gov/water/pdf/brochure.pdf
http://www.utsandiego.com/news/2014/nov/18/water-recycling-sewer-tap-council-approves/
http://www.utsandiego.com/uniontrib/20070108/news_1m8water.html
http://sandiegofreepress.org/2014/11/water-conservation-san-diego-style-dont-ask-dont-tell/
http://timesofsandiego.com/politics/2014/11/11/mayor-reminds-residents-mandatory-water-saving/
http://timesofsandiego.com/opinion/2014/10/17/dry-years-highlight-need-for-conservation-desalination/
Wichita
http://www.kansas.com/news/article1118095.html
http://www.kansas.com/news/article1128652.html
http://www.kansas.com/news/local/article1109506.html

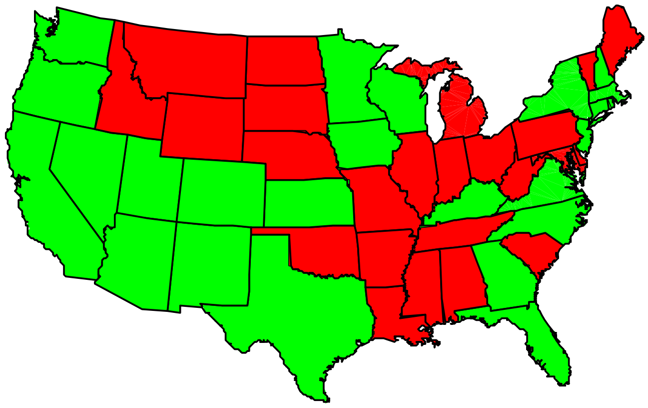

Figure 2. States ranked having adopted strong conservation policies (C) in green and those that have not (NC) in red.

Conservation-minded states have relatively low per-capita electricity use, relatively high per-capita gross state products, relatively high per-capita surface water use, or relatively large fraction of withdrawals from groundwater. These variables show some separation between the two classes, but there is much overlap (Figure 5).

Our classification into two groups, C and NC, masks finer gradations in the AWE scores. In particular, there are degrees of "conservation" across states with some clear spatial patterns (Figure 6). Three states with the highest scores are AZ, CA, and TX. Three others, NM, NV, and UT, have more modest conservation scores. Among states with the lowest conservation scores, several groups of contiguous states suggest themselves—MT, ND, and WY; AL, MS, and TN; and OH, PA, and WV. These groups do have some characteristics that distinguish them from one another (Figure 7).

4.2. City Level Analysis

As with the state level analysis, physical variables such as the water availability index and water quality index do not clearly distinguish between the conservation and no conservation classes (Figure 8) even though cities with low values of supply index (more vulnerable) and low water quality index (lower quality) tend to be conservation adopters. A classification tree based on three variables (median household income, system development charge, and residential connection fee for 3000 cubic feet) correctly classifies 70% of the cities (Figure 9). Cities with a high median household income, a high system development charge, and high fee for residential customers at 3000 cubic feet per month tend to be conservation adopters, although once again there are not clean distinctions on any one of these variables (Figure 10). Because fees for high water use might be classified either as factors that influence adoption of conservation measures, or as conservation measures themselves, endogeneity is a concern in trying to understand causation. Six of the 105 cities were classified as conservation adopters strictly on the basis of answering affirmatively to the demand management question. Four of these six cities were actually misclassified in the tree, so we conclude that endogeneity is not a problem in our analysis.

Once again our classification into two groups with regard to conservation ignores some variability in the AWWA reports. Each water utility was asked to report whether they implemented five items, demand management, xeriscaping, low-flow plumbing retrofits, landscape audits, and customer discounts for low flow measures. We compared four selected groups of three cities in the traditionally drier parts of the U.S. on the basis of whether they reported implementing either four or all five of the items (Los Angeles, San Antonio, San Diego), three of the items (Lubbock, Phoenix, Riverside), one of the items (Dallas, Tulsa, Salt Lake City), and zero of the items (Amarillo, Las Cruces, Wichita). Although there is some tendency for high-income cities with low water availability indices to engage in more conservation items, there is much variability (Figure 11).

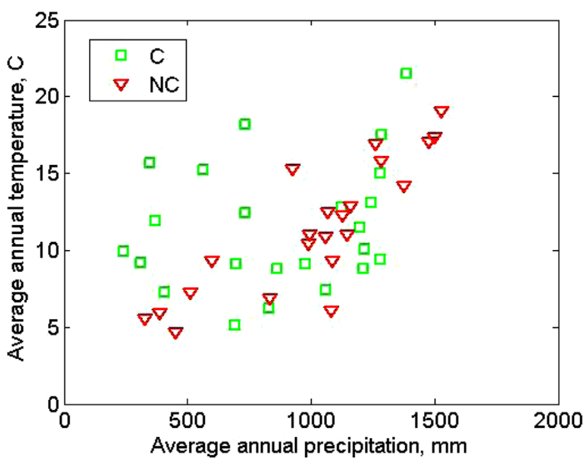

Figure 3. Distribution of states adopting conservation measures (C) and states not adopting measures (NC) with average temperature and precipitation.

4.3. Case Studies of Four Cities

Four cities are discussed in more detail as examples of the range of the integration of

		E<15300								E>=15300
pcGSP<38500				pcGSP>=38500						NC
		pcSW>=0.103					pcSW<0.103			AL
NC		C			fGW<0.356			fGW>=0.356		AR
ID		CA		ppt<1171		ppt>=1171		C		IN
ME		CO		NC		C		AZ		KY
MT		CT		IL		GA		DE		LA
		NV		MD		MA		FL		MS
		NY		MI		NC		IA		NE
		OR		MO		RI		KS		ND
		TX		OH				MN		OK
		VA		PA				NH		SC
				VT				NJ		TN
								NM		WV
								SD		WY
								UT		
								WA		
								WI		

Figure 4. Classification tree for AWE state data. Purple shading indicates incorrect classification.

water conservation policies into the water supply regime. From Figure 11, San Diego can be considered an example of a "high transition" city because it has four of the five measures of conservation in the AWWA survey, whereas Phoenix has three measures, Dallas-Fort Worth two measures, and Wichita one measure. In Figure 11, San Diego has a relatively high income and low water supply, whereas water supply availability and median income are fairly close for Phoenix, Wichita, and Dallas. Thus, although the broad aggregate measures that we used for the cities have some value in providing insight into the factors that affect the degree of transition, case study analysis serves as a complementary method that can generate additional hypotheses. We discuss the cities in descending order, from high to low integration of water conservation into the water supply regime.

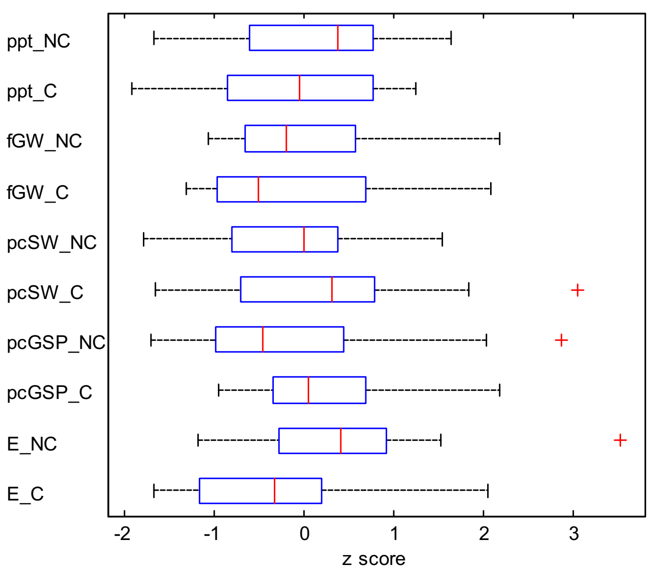

Figure 5. Distribution of z scores for gross state product (GSP), precipitation (ppt), per capita income (INC), and growth rate (GR) for states that have adopted strong conservation policies (C) and those that have not (NC).

4.3.1. San Diego, California

Since the early 1990s the region has pursued a water diversification strategy to reduce its reliance on surface water. As of 2015, San Diego's water comes from the State Water Project (Sacramento-San Joaquim Delta), the Colorado River Project, and local rainwater, which is collected at nine reservoirs. Because of continued drought conditions and high risk of reductions in freshwater sources, the most available option for increasing water supply sources is through desalinization, a relatively costly and energy-intensive form of water acquisition. The Carlsbad desalinization plant, scheduled to go online in the fall of 2015, will provide water for the equivalent of 112,000 homes [*Weston*, 2014].

Because of the limitations to increasing water supply, the city has been a leader in water conservation and recycling. The

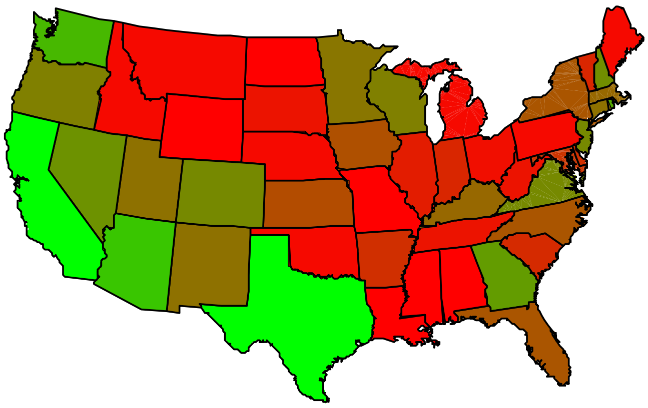

Figure 6. State AWE scores from highest (bright green) to lowest (bright red).

city has two recycled water plants that produce water for landscape irrigation on golf courses and for large institutional customers [*City of San Diego*, 2014a]. In 2014, the city also approved the Pure Water Recycling Program, which was portrayed as a strategy to keep water prices down in the long term and to reduce dependence on imported water. The program has the goal of producing 35% of San Diego's water from recycled water by 2035. It was supported by growth coalition organizations such as the Chamber of Commerce and Builders Association, but environmentalists also supported the program partly because it would improve the city's waste treatment technology, which historically has resulted in the dumping of under-treated wastewater into the ocean [*Garrick*, 2014].

The city has extensive water conservation programs, but public opposition has emerged in some cases. In 2007, the city enacted a 3 year, 6.5% rate increase per year to pay for infrastructure improvements to prevent water main breaks and to improve wastewater treatment [*City of San Diego*, 2014b]. The mayor and city attorney argued that the improvements were obligatory due to lawsuits from environmental groups and a compliance order from the California Department of Health Services [*Rodgers*, 2007]. However, when in 2009 the city enacted a 7.75% rate increase, its sixth increase since 2007, over 14,000 ratepayers sent in protests [*City News Service*, 2009]. In 2011, the city also enacted several water conservation restrictions, including no washing of driveways and sidewalks and a requirement to repair all leaks within 72 h [*Brennan*, 2014]. Because of the city's 2011 rules, statewide conservation measures that were implemented in 2014 did not apply [*Brennan*, 2014]. In 2014, a drought alert led the city to implement additional restrictions that limited lawn watering to a three-day-per-week, odd-even schedule. The city's water conservation efforts resulted in a 20% decrease in per capita water consumption between 2007 and 2014 [*Weston*, 2014].

In summary, the San Diego case suggests several conditions that enable a level of integration of water conservation in the water supply regime: severe pressure on existing water supply with only expensive alternatives for increased supply (e.g., desalinization), and an agreement between the growth coalition and environmentalists in favor of water conservation. However, the public reaction to price increases also shows the limitations of that policy instrument for achieving a rapid transition to water conservation. Outdoor watering restrictions in response to drought conditions provoked less opposition.

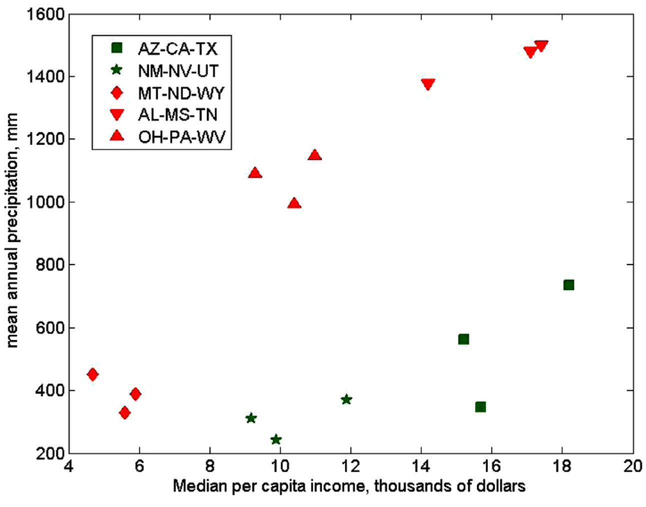

Figure 7. Selected groups of states with highest AWE scores (green squares), with modest AWE scores (green stars) and with the lowest AWE scores (red diamonds and triangles).

4.3.2. Phoenix, Arizona

The main sources of water for Phoenix are the Salt River, Verde River, and Colorado River. To increase supplies, the city has invested in the enlargement of reservoirs on the Salt and Verde Rivers and in an aggressive water repair system. Furthermore, approximately 90% of the city's wastewater is reclaimed and used for energy, crops, wetlands, and groundwater recharge [*City of Phoenix*, 2011]. The city exchanges reclaimed water with the Roosevelt Irrigation District for groundwater that is fed into the Salt River canal system

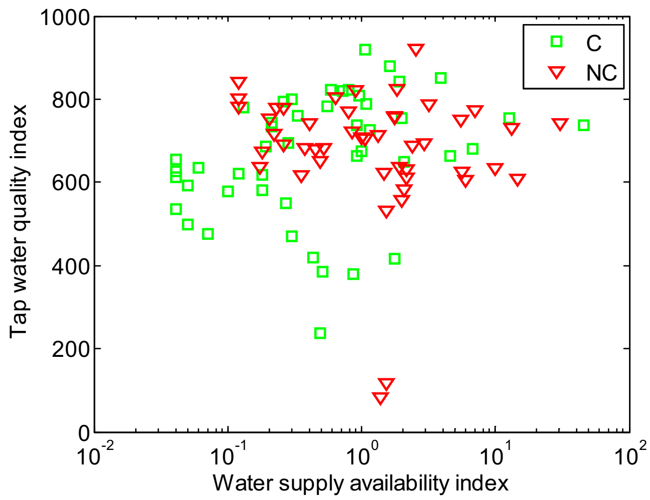

Figure 8. Distribution of C and NC with respect to Padowski's water vulnerability and Purdex water quality index.

[*City of Phoenix*, 2011]. The city is a leader in water banking, and it claims to have banked enough water in aquifers to supply its needs for 100 years [*City of Phoenix*, 2014]. The goal is necessary because under state law the city must demonstrate the long-tern water supply in order to gain approval for new real estate developments.

The Phoenix area has had a water conservation program since 1982 [*Mee*, 1990], and it has managed to keep the demand for water stable despite population growth. However, the city's water policy is controversial due to the focus on voluntary measures and passive conservation (e.g., low-flow toilets) rather than on mandatory outdoor water restrictions, rebates, and tiered pricing. As the deputy water services director, Brandy Kelso, commented, "I don't mean to say that we don't do conservation. We just do it differently" [*Santos*, 2013]. Likewise, as the city's Water Services Department notes, "Water use restrictions simply have not been necessary due to wise planning and use" [*City of Phoenix*, 2014]. Comparisons are sometimes drawn between the relatively high use of residential water in Phoenix in comparison with Tucson [*Santos*, 2013]. Whereas Tucson has a four-tiered block pricing scheme, Phoenix has uniform pricing with seasonal variation, and residents pay much less overall for water than in Tucson. One study indicated that between 60 and 75% of residential water is used outdoors to maintain nonnative, water-intensive landscapes and swimming pools [*Balling et al.*, 2008]. Despite the concentration on voluntary conservation in Phoenix, the city anticipates having to implement mandatory water use restrictions when faced with even moderate drought [*Dorfman and Mehta*, 2011].

In summary, state law that links economic development to assured water supply has led the city to support water banking in order to preserve economic growth. However, its transition to conservation has focused on the exchange of reclaimed wastewater for agricultural water and on the repair of leaks in the infrastructure. This strategy has avoided the political repercussions of mandatory conservation instruments.

4.3.3. Dallas-Forth Worth, Texas

Dallas and Fort Worth derive their drinking water from a network of regional reservoirs. To support the growing metropolitan economy, Dallas has continued to seek water sources from eastern Texas, and the expansion of water sources has created conflicts. For example, the proposed Marvin Nichols Reservoir and other proposed reservoirs have provoked opposition from area residents and state environmental organizations [*Satija*, 2014a, 2014b]. Opponents argue that the Dallas-Fort Worth area should first focus on more developed conservation measures, and they suggest that Dallas is a "water hog" [*Campoy*, 2009].

In this context, water conservation programs are necessary to legitimate the goal of building more reservoirs against opposition from community and environmental groups, and since 2000 the region has instituted some water conservation measures. Dallas made twice-weekly watering restrictions permanent in 2012, and Fort Worth did the same in 2014 [*Hirst and Schrock*, 2014]. Due to various water conservation initiatives, in Fort Worth water consumption has been reduced by 26% per capita during the 15 year period following 1999. However, in an example of the dilemma that water departments and utilities face when conservation programs are successful, the lawn-watering restrictions put into effect in 2013 (prior to the decision to make the restrictions permanent in 2014) led to an estimated $11 million shortfall in the city's budget and contributed to a downgrading of the city's bond rating [*Silverstein*, 2014]. To address the problem, the city is shifting more of the revenue to the fixed-based fee that is charged to customers [*Hirst*, 2014].

Median income<$46,242			Median income>=$46,242			
cf-fee-3000<0.0317	cf-fee-3000>=0.0317		DevChg<1259			DevChg>=1259
NC	C		Median income<$52,850	Median income>=$52,850		C
Abilene, TX	Asheville, NC		NC	C		Albany, OR
Akron, OH	Atlanta, GA		Augusta, GA	Austin, TX		Albuquerque, NM
Allentown, PA	Pittsburgh, PA		Des Moines, IA	Charlotte, NC		Ann Arbor, MI
Amarillo, TX	Tucson, AZ		Fayetteville, NC	Kennewick, WA		Boulder, CO
Athens, GA			Greensboro, NC	Port St. Lucie, FL		Columbus, OH
Baltimore, MD			Houston, TX	Raleigh, NC		Concord, CA
Billings, MT			Jacksonville, FL	Seattle, WA		Denton, TX
Bridgeport, CT			Little Rock, AR	Virginia Beach, VA		Denver, CO
Brownsville, TX			Murfreesboro, TN			Eugene, OR
Buffalo, NY			Nashville, TN			Kissimmee, FL
Canton, OH			Omaha, NE			Las Vegas, NV
Charleston, SC			Rockford, IL			Lincoln, NE
Cincinnati, OH						Medford, OR
Cleveland, OH						Orlando, FL
College Station, TX						Portland, OR
Columbus, GA						Riverside, CA
El Paso, TX						Sacramento, CA
Erie, PA						Salt Lake City, UT
Gainesville, FL						San Antonio, TX
Knoxville, TN						San Diego, CA
Lakeland, FL						San Jose, CA
Lancaster, PA						Santa Barbara, CA
Lansing, MI						
Las Cruces, NM						
Louisville, KY						
Lubbock, TX						
Miami, FL						
Milwaukee, WI						
Mobile, AL						
New Orleans, LA						
Ocala, FL						
Oklahoma City, OK						
Panama City, FL						
Pensacola, FL						
Philadelphia, PA						
Providence, RI						
Pueblo, CO						
Richmond, VA						
Savannah, GA						
Spartanburg, SC						
Springfield, MA						
St. Louis, MO						
Toledo, OH						
Tulsa, OK						
Yakima, WA						

Figure 9. Classification tree for AWWA conservation index. Purple shading indicates misclassification.

The Dallas-Fort Worth case shows how a growth-oriented water supply regime can remain dominant if there are still potential, affordable freshwater supply options. However, gaining access to the new supply sources can trigger public opposition from host communities. In this case the transition to water conservation is more limited and to some degree developed as a legitimation measure for water acquisition strategies.

4.3.4. Wichita, Kansas

Although the city lies on the Arkansas River, its main water supply (60%) is from the Cheney Reservoir, located on the North Fork Ninnescah River. A drought in 2013 led to low levels in Cheney Reservoir, and in response the city considered a plan to increase water intake from the Equus Beds well-field, the primary source of the remaining water supply, and to increase prices for summer watering [*Wilson*, 2013a]. Negative incentives, such as fines of up to $1,000 for chronic users, led to a public outcry, to divisions between the city council and city administration, and eventually to much smaller penalties. The city manager commented, "Candidly, the community push-back to doing anything meaningful on conservation after a 3 year drought makes you wonder how much will this community be willing to do to get meaningful conservation" [*Wilson*, 2013a]. One city councilmember worried that continued discussions of the low level of the

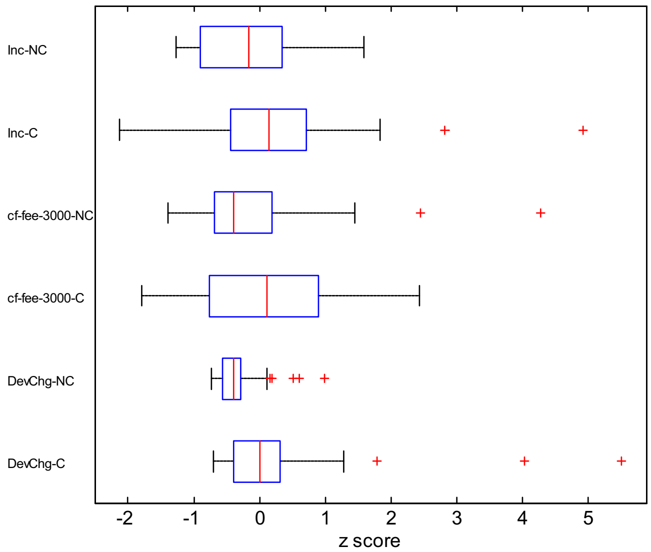

Figure 10. Distribution of z scores (value minus the mean divided by the standard deviation) for system development charge (DevChg), residential connection fee for 3000 cubic feet (cf-fee-3000), and median household income (INC) for cities that have adopted conservation policies (C) and those that have not (NC). On each box, the central mark is the median, the edges of the box are the 25th and 75th percentiles, the whiskers extend to the most extreme data points not considered outliers, and outliers are plotted individually.

Cheney Reservoir would send a negative message to businesses that were considering Wichita as a new home [*Wilson*, 2013a]. Faced with the lack of popularity for mandatory consumer-oriented measures, in 2013 the city approved a range of water conservation measures for government facilities [*City of Wichita*, 2013]. The programs included reduction of outdoor water use, faster repair of leaks, and a gray-water recycling program for trees. In June 2013, the city also launched a $1 million rebate program for water-efficient washers, dishwashers, low-flow toilets, irrigation controllers and rain barrels, but after 1 year $600,000 remained in unspent funds, and in 2014 the program was relaunched with a more extensive set of options [*City of Wichita*, 2014; *Wilson*, 2013b].

By the end of 2014, the reservoir was full again, and public concern with water conservation receded. The city continued to develop its long-term plan and proposed an expansion of the Equus Beds Aquifer Storage and Recovery (ASR) project, which was originally implemented in 2007 with water and drew on water from the Little Arkansas River. The proposed expansion of the ASR would have cost $250 million and would have increased water storage by over 100%. However, in November 2014, voters rejected the 1% sales tax that would have provided $400 million in revenue to fund the plan and to support other projects, such as transportation and economic development. Although the existing ASR project may be adequate to fulfill the city's water supply needs "for the foreseeable future" [*Chowdhury et al.*, 2013], voters were not willing to support expansion of the ASR to provide resilience during severe droughts. In this city one finds substantial resistance to a more complete transition in the water conservation policies: consumers did not rush to embrace rebates, and voters also rejected a long-term water resiliency project.

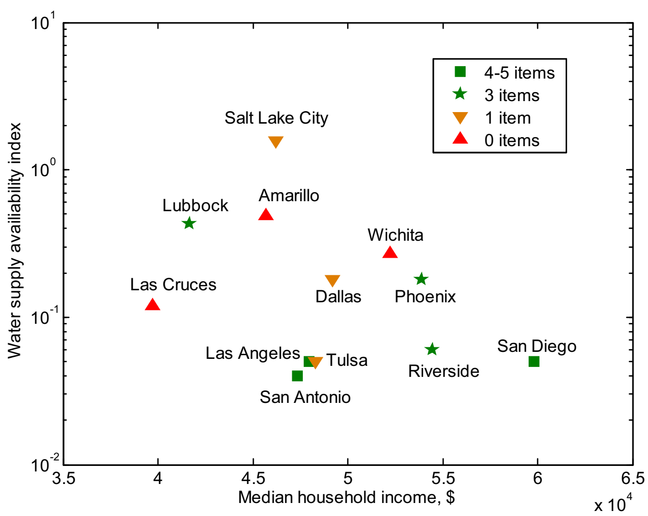

Figure 11. Comparison of cities that report engaging in four to five items related to encouraging conservation, three items, one item, and zero items.

In summary, in Wichita there is substantial resistance to a more complete transition in the water supply regime: consumers did not rush to embrace rebates, and voters also rejected a long-term water resiliency project. The threat to water supplies was not lengthy enough to force greater acceptance of water conservation measures, and the use of a tax increase as the policy instrument was also unpopular. The fact that a major river runs through the city may also contribute to the general sense that a transition is not a priority.

5. Summary

The case studies suggest factors that affect a transition to a strong water conservation regime that go beyond variables identified with quantitative methods. First, the cases suggest that water pricing strategies may encounter strong political resistance. The city or water utility may find it easier to engage in more invisible forms of conservation such as repairing water line leaks or voluntary measures. Second, if a city has access to potential new freshwater sources (as do Dallas and Wichita), then water conservation may not grow beyond a niche position in the water supply regime, but it may be used to legitimate water acquisition strategies.

6. Discussion

Issues of water governance involve a combination of policy instruments, including regulation, pricing, fines, rebates, audits, and education campaigns [*Saurí*, 2013]. Our approach here is an exploratory analysis to discern whether and how variables that reflect economics, politics, water resources, and demographics are correlated with water conservation policies.

At the state level, we find that electricity use per capita, gross state product per capita, surface water withdrawal per capita, and the ratio of groundwater to surface water withdrawals are the best classifiers for states with respect to a conservation score assigned by the Alliance for Water Efficiency [*Christiansen et al*., 2012]. States with low electricity use, high gross state product and either high surface water use or high fractional groundwater use tend to have the higher AWE scores (Figures 4 and 5). *Rashid et al*. [2010] reviewed progress of states in the U.S. with respect to water conservation; they classified 23 states into "category 1," which was defined as those that currently have a legislative, regulatory, or administrative mandate requiring conservation planning or programs. The authors indicated that there was some evidence that states they classified into category 1 tended to expect water shortages in the future and to anticipate continued high population growth. Nineteen of the Category 1 states are included in the twenty four that we classified as adopting conservation measures using the AWE score. Our finding that conservation states tend to have lower precipitation and higher per capita gross state product (Figure 5) offers some support for water stress and economic growth as explanatory variables.

Partial correspondence between the states we identified as conservation minded states using the AWE scores and the category 1 states defined by *Rashid et al*. [2010] allow further exploration. Although we do not have longitudinal data to explore the idea of whether there are 'triggers" for changes to becoming a "conservation state," we can compare our data based on current (2009 or 2010) data with suggestions about timing by *Rashid et al*. who show eight states having passed laws that led to inclusion into category 1 in the 1990s (CO, GA, MN, NV, NJ, TX, UT, and VA) and six states entering category 1 in the decade 2000–2009 (AR, DE, FL, MD, NH, NC). Of these states, CO, NV, TX, and UT had very high population growth rates and also have low precipitation. The southeastern states FL, GA, an NC have high growth rates and also experienced significant drought in the early to mid-2000s. Although AR and DE made it to category 1 on the basis of legislation, they have very low AWE scores so we do not consider them conservation states. [Delaware passed legislation creating a Water Supply Coordinating Council following a 2002 drought but the Commission concluded "The expectation is that Delaware should not have to impose any mandatory water use restrictions even with a recurrence of a 2002 drought." (http://www.dnrec.delaware.gov/wr/Services/Pages/WaterSupplyCoordinatingCouncil.aspx; accessed 24 April 2015)] This leaves MD, MN, NJ, NH, and VA as "outliers with modest population growth and, except for MN, abundant rainfall. The notable thing about these states in our data is that they all have high median incomes.

At the city level, we find that there is some tendency for cities with a low water availability index [*Padowski and Jawitz*, 2012] and a low water quality index [*Purdex*, 2013] to have reported implementing at least one water conservation measure, but the relationship is clouded at best (Figure 8). A previous analysis indicated that urban water demand was influenced by water quality (hardness) but that only large differences in water quality made an operationally significant difference [*Piper*, 2003]. Results from the classification tree indicate that cities with high median household income and with utilities that have a significant residential system development charge are ones that have adopted conservation measures (Figure 9). These results are broadly consistent with previous studies that have explored economic factors. *Teodoro* [2010] analyzed two policies, landscape audits and rate structure, and found that higher moisture index and groundwater use were positively associated with both policies and that higher median income was positively associated with rate structure policy. In a study of utility rates, *Rahill-Marier and Lall* [2013] found that groundwater was the least costly source and that use of diverse sources is very costly, although they also found indications that this is changing and that in some markets groundwater may soon become even more expensive than nontraditional sources, such as desalination. Groundwater use tends to be highest in the West and the Midwest, so this may also influence the spatial distribution of cities where conservation measures have been adopted.

Our four case studies illustrate the complexity of water use, development, and conservation measures that abounds across municipalities in the U.S. The review of these cities has led to the identification of three main institutional barriers to a transition to a high level of water conservation. First, although economists frequently recommend pricing policies as the most efficient way of instituting water conservation policies, they do not examine the broader political context of price increases. Such policies must be implemented with care in order to be technically effective (that is, to have the proper structure of block pricing to encourage demand reduction) and politically acceptable. In extreme cases, such as the first implementation of block pricing in Tucson, ratepayers were so upset that they supported a recall election that unseated the entire city council. Second, it is increasingly common to find the use of water police who issue fines for the violation of watering restrictions and even the emergence of household water quotas, but some cities have rejected this more heavy-handed approach to water conservation in favor of education and voluntary measures. Phoenix is a good example of a city that has avoided mandates, tiered pricing, and even the more extensive rebates that are found in other cities. Third, the implementation of successful water conservation measures can lead to significant reductions in demand and therefore revenue. To compensate for water conservation, water departments or utilities must raise prices, but this in turn leads to a decrease in demand, a problem known as the water conservation conundrum [*Beecher*, 2010]. Utilities that have tiered pricing can raise rates in the upper tier, an option that is politically palatable. However, the strategy will accelerate conservation and economic pressures on the water supply system. In contrast, raising the rates in the lower tiers may have a less deleterious effect on the economics of the system, but it can lead to stronger consumer backlash. One solution is to separate fees for fixed costs from usage, as we saw occurring in Dallas. Another example is to use property taxes to pay for capital costs, and to separate those costs from water use, a strategy that has been implemented with success in Irvine, California [*Walton*, 2010].

Finally, we note that adoption of conservation policies is not equivalent to reducing water use. Per capita water use in U.S. cities has been declining steadily over the past few decades [*Rockaway et al.*, 2011] and not only in areas that experience water stress. *Nieswiadomy* [1992] examined water prices across U.S. cities and found that price elasticity tended to be higher in the South and West, suggesting that climate has some impact on how water is valued. Nevertheless, he found that a water conservation metric did not appear to be related to water use. Given that the drivers of recent declining trends in per capita water use include declining household size and increased appliance efficiency, it is likely that aggregate demand will level off in coming years in areas that are not experiencing rapid population growth [*Rockaway et al.*, 2011]. However, where urban population and per capita income are likely to continue to grow, it is imperative that cities find a blend of price and nonprice conservation measures that actually work to accomplish a reduction in water use.

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