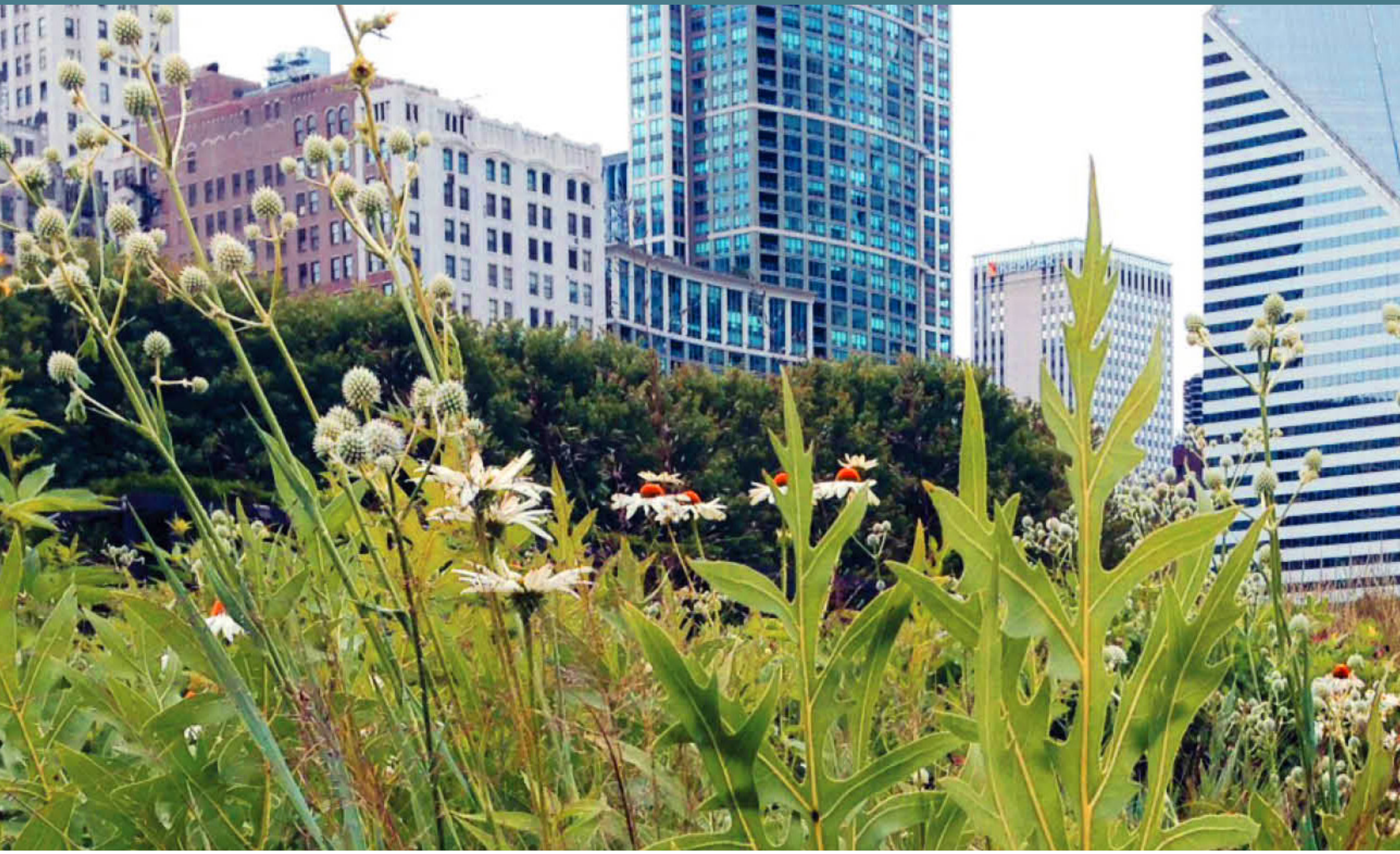
Alliance for Water Efficiency

An Assessment of Increasing Water-Use Efficiency on Demand Hardening



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Case Studies

Boulder, CO, City of

Irvine Ranch Water District, CA

Monte Vista Water District, CA

Petaluma, CA, City of

San Antonio Water System, TX

Santa Fe, NM, City of

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EXECUTIVE SUMMARY

Water suppliers remain concerned about the possibility that investments in water-use efficiency may make it harder for their customers to comply with voluntary or mandatory restrictions when such restrictions are needed to deal with extended periods of shortage. Water resource planners call this phenomenon demand hardening. Although the unease about demand hardening has never risen to the point of deterring investments in long-term water-use efficiency, neither has it quelled over time. Because prior published literature on demand hardening remains meager, this study attempts a fairly comprehensive, rigorous examination of the issues involved by focusing on the historical shortage experience of seven water suppliers (case studies) located throughout the arid Southwestern United States. These include the City of Boulder, Colorado; City of Santa Fe, New Mexico; San Antonio Water System, Texas; and four suppliers from California (from the north, City of Petaluma and City of Santa Rosa, from the south, Monte Vista Water District and Irvine Ranch Water District). These agencies, being located in drought-prone regions of the United States, and also having invested significantly in water-use efficiency over many years, make interesting test cases for the proposition that rising water-use efficiency may make dealing with extended periods of shortage more difficult.

Discussions about demand hardening and the impact of rising water-use efficiency often conflate “ability” with “willingness” of customers to make time-limited adjustments in behavior when required. They also often fail to appreciate that not all water-use efficiency programs are equal in terms of their implications for demand hardening, nor is demand hardening independent of the saved water’s fate. For example, it is self-evident that if all saved water is banked through surface or aquifer storage and recovery programs, a service area’s “ability” to deal with shortage emergencies could not be any worse than before. Similarly, water-use efficiency programs that neither require appliance and plumbing retrofits, nor behavior modification, cannot lessen a service area’s “ability” to weather shortages. Examples include real water loss reduction programs and small-scale water recycling (large-scale recycling can result in reduced availability of recycled water during shortages which contingency plans must both anticipate and incorporate). Even when savings from water-use efficiency programs are used to supply new growth, a service area is not likely to lose its “ability” to respond to shortage emergencies. Why is this so?

The purpose of long-term conservation programs (for example, plumbing codes and incentive-based or ordinance-based retrofit programs) is to bring about a steady decline in year-round per-capita water demand; and when focused on outdoor use, reduce peak-season demand as well. To deal with imminent shortages, however, water suppliers rely on customers’ ability to make time-limited adjustments to their behavior, such as significantly reducing irrigation in mild shortage events, or in more severe events completely discontinuing irrigation and reducing indoor use as well (by flushing less, washing fewer wash loads, etc.). Until now increases in indoor water-use efficiency have resulted mainly from replacement of old plumbing fixtures and appliances with newer, more efficient varieties. The latest end-use metering studies do not indicate that indoor water-using behavior is significantly different now compared to before, which leads to the surmise that in a pinch residential customers still retain considerable ability to change their indoor water-using behavior. Similarly, suppliers have pursued many long-term programs aimed at making outdoor water use much more efficient including promoting drought-tolerant plant species, turf removal, and cessation of wasteful irrigation practices. Nevertheless, outdoor water use is still considerable, which means that in a pinch customers can significantly reduce their total demand by making steep cuts in outdoor water use. In other words, evidence presented here does not support the notion that “ability” to make short-term adjustments in behavior is substantially less now.

This brings up the question of “willingness?” Is it possible that an increase in water-use efficiency makes customers less willing to change their behavior when faced with periods of shortage? This question is addressed in two ways: first, by examining the historical shortage record across our seven case studies between 1970 and 2013; and, second, by surveying single-family households in each case study to ascertain what they did to deal with the latest shortage to affect their service area, and what they would be willing to do in a future shortage?

Analysis of prior shortage episodes does not reveal a positive correlation between savings achieved during a shortage episode and the level of per-capita demand just prior to the shortage (that is, higher pre-shortage per-capita demand does not necessarily translate into greater savings during the subsequent shortage episode). What the historical record does suggest, however, is that customer response depends to a great extent on the vigor with which restrictions are enforced. Voluntary restrictions generate fewer savings; mandatory restrictions, much greater savings. The telephone surveys undertaken under the auspices of this study, and opinion polls undertaken earlier in San Diego and San Antonio, suggest that customers are very interested in keeping their water bills low. The telephone surveys also suggest that customers are willing to repeat the actions they undertook during the last shortage episode in a future episode and also try out additional coping strategies (for example, graywater reuse) in future shortage episodes. All these pieces of evidence suggest that considerable “willingness” to change behavior still remains in place in spite of large investments in water-use efficiency and in spite of significant declines in per-capita demand across our seven case studies.

Does this mean that water suppliers have nothing to worry about and can continue to plan for shortages like they have done so in the past? Well, not quite. The answer to this question is somewhat complicated, because as stated earlier, enforcement is the key factor that drives success when coping with shortage emergencies.

Cutting outdoor water use broadly, specifically irrigation, will remain the first priority for adapting to imminent shortages. Water suppliers in the past have relied either on time-of-day or day-of-week restrictions, or water budgets tied to steeply inclining rates, to bring about a reduction in outdoor water demand. These strategies will remain salient, but as irrigation potentially becomes a smaller component of total demand due to increasing prevalence of drought-tolerant landscapes, water shortage contingency plans will need to target indoor water use much sooner in a shortage cycle than in the past, and probably will also need to transition to mandatory restrictions much sooner than in the past. *In other words, as per-capita demand declines because of investments in water-use efficiency, it becomes necessary for suppliers to reconfigure their shortage contingency plans so as to fast forward to steps that normally would have been taken later in the more traditionally configured shortage plans.* Published guidelines available for the design of water shortage contingency plans usually speak of four triggering stages (voluntary, mandatory, severe, critical), but this conventional design may not work equally well for all water suppliers as the comparative analysis presented here demonstrates. To put it conversely, to ensure that demand does not exhibit hardening, water shortage contingency plans need to evolve along with investments in water-use efficiency. It is in the context of shortage contingency planning that demand hardening conceptually connects with water-use efficiency, which is why water suppliers will probably find themselves at different points on a continuum with regards to their concerns about demand hardening.

The key to incentivizing customers to reduce water demand during shortages requires a solid understanding about how water is being used, where it is being used, and customer preferences about the order in which cutbacks should be requested. If these are accurately reflected in a contingency plan with appropriate enforcement mechanisms, there is no reason why investments in long-term water-use efficiency should make time-limited shortage adaptation more difficult. Managing willingness to cut demand during shortages therefore remains the key to preventing demand hardening.

As mentioned earlier, this study's telephone survey respondents expressed a strong desire for keeping their water bills low even if that means practicing frugality during the occasional shortage. Water rates have increased significantly over the last few years, so this finding is both understandable and consistent with opinion polls conducted elsewhere. However, this preference for keeping water bills low should not be interpreted to mean that respondents have unlimited appetite for dealing with shortages through restrictions. Customers may wish to keep their water bills low, but they also wish to see savings yielded by their conservation efforts used to place local and regional water supplies on a more sustainable basis. As a result, shortage risk is reduced and the use of mandatory restrictions or rationing remains limited to the worst of situations. Suppliers already have strong incentives to do this on their own because mandatory restrictions are disruptive, difficult to enforce, and generate customer dissatisfaction. Thus, restrictions cannot be made into a frequently summoned tool for bridging gaps between supply and demand. Water suppliers perhaps need to do more about educating their customers, if customers have the mistaken belief that conservation only fuels new growth, that in actuality is not so. Compliance with mandatory restrictions may improve if customers both understand and trust their supplier's long-term water supply plan and also understand why the infrequent use of drought restrictions is ultimately in their own interest. After all, many areas have successfully increased their supply reliability and long-term sustainability by investing in conservation. This has allowed them to get through dry periods without having to declare shortages (e.g., Boulder in 2012; Irvine Ranch in 2009; Santa Fe in 2011; San Antonio in 2005-06). Although this study only explores customer ability and willingness to engage in frugality when faced with an imminent shortage, the other element—the risk of shortage itself—should not be forgotten.

To summarize, declining per-capita demand, the distribution of demand across customer classes, and the supply mix, all have implications for how water utilities plan to deal with extended shortage contingencies. These factors obviously vary across water utilities, so utilities will likely find themselves on a continuum with respect to concerns about demand hardening. For some, demand hardening is likely to be an issue of increasing salience, while for others it may remain a nascent issue for some more time. This report argues that with proper analysis and planning, it is possible to anticipate and mitigate demand-hardening effects associated with increasing water-use efficiency: The mitigation question requires conceptually linking water shortage contingency planning to water-use efficiency investments, and actively adapting contingency plans over time. Demand hardening concerns should not deter investments in water-use efficiency because past investments have generally improved both supply reliability and customer knowledge and attitudes about conservation. These two benefits alone far outweigh any concerns utilities may have about demand hardening.

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1. INTRODUCTION

Water suppliers have promoted conservation programs very vigorously over the last two decades. They have done so for different reasons. For some, conservation represents the most cost-effective, environmentally sound source of new water supply. For others, reducing water demand offers a cheaper way of dealing with emerging bottlenecks in their sewage treatment infrastructure, or for dealing with caps placed on discharges of treated sewage or irrigation runoff into public water bodies.

Some have cautioned that investments in long-term conservation programs will make achieving demand reductions more difficult during periods of extended shortage since there will be less discretionary use to cut back. Water conservation professionals call this effect demand hardening.[1] By and large water conservation professionals have not been deterred by these concerns, seeing long-term conservation as improving, not hampering, system reliability. Even those who were interviewed by Tabors Caramanis and Associates as far back as 1994 (*op cit.*) downplayed demand hardening's relevance. Nonetheless, concerns about demand hardening have not entirely vanished either. Moreover, in recent times new and novel meanings have begun to be ascribed to demand hardening than the one offered above, further muddying the waters.

This study was undertaken to fulfill two broad missions. First, it attempts to clarify what demand hardening means, and more importantly, what it does not. Second, it offers ideas for how to go about mitigating the effects of potential demand hardening. Water suppliers probably fall along a continuum, some for whom demand hardening is less salient, others for whom it may be an emerging issue, albeit one that can be managed. The management question takes us into the arena of water shortage contingency planning, which—as this report argues—is the proper arena for handling concerns about demand hardening.

DEMAND HARDENING: WHAT IS IT?

A customer's water demand is a function of both technological and behavioral components, with behavior partially driven by a customer's socio-economic characteristics. For example, the number of gallons that a toilet uses per flush, or the number of gallons a clothes washer uses per load, or the size and type of landscape, clearly influence a customer's water demands. But, so does behavior, such as number of flushes per day, number of washer loads per week, irrigation frequency, etc. To believe that prior conservation makes future demand reductions harder to achieve, whether as a matter of course, or when cutbacks are requested during droughts, implies one of two possibilities: either water-use efficiency among indoor and outdoor end uses is already at or near peak levels; or customers somehow become less amenable to changing their discretionary behavior during shortages when they live in homes fitted with more efficient fixtures, appliances and landscapes.

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[1] Tabors Caramanis and Associates, *Long-Term Water Conservation and Shortage Management Practices: Planning that Includes Demand Hardening,* A report prepared for California Urban Water Agencies, 1994.

Let us parse these ideas using a few real-world examples. When front loading clothes washers were introduced in the US during the 1990s, they brought a significant increase in water-use efficiency compared to the traditional top-loaders that until then had been the norm. Early evaluations suggest that these first generation front-loaders used about a third less water than traditional top-loaders. Left purely to intuition, it would be natural to surmise that the second generation front loaders would probably reduce per-cycle consumption by a smaller fraction relative to the first generation, because the easy opportunities had already been taken. Only trouble is, this assumption would be dead wrong! We are now using third-generation front loaders and each generation has managed to reduce water consumption per cycle by roughly the same percentage amount compared to the preceding one.[2] Of course, this cannot go on forever, nor is it true of all end uses. The first generation ultra-low flush toilets using 1.6 gallons per flush marked a dramatic rise in water-use efficiency compared to the 3.5-7 gallons-per-flush toilets in use until then. The next generation high-efficiency toilets using 1.28 gallons per flush will have a proportionally smaller impact (although note that single-flush high efficiency toilets using only 0.8 gallons per flush have already begun to enter the market). Eventually we may hit peak water-use efficiency in many individual applications, but as of now it is difficult to argue that we are nearing this point in some overall sense. Enormous conservation opportunities are still available to us in landscape-related end uses. Several opportunities have barely been scratched in the arid Southwestern US, such as graywater reuse, rain catchment, sewage and process water recycling, etc. Human ingenuity and adaptability know few bounds.

This study does not focus on questions, such as when shall we hit peak water-use efficiency? We possess no such crystal ball. However, international comparisons suggest that the arid Southwestern US can continue to conserve for many more years to come. Table 1 shows per-capita urban (municipal) water demand *circa* 2000 in California and a few other industrialized countries with a Mediterranean climate. Admittedly the data are a bit old; yet they provide a useful cross-sectional snapshot in time. These data hardly indicate that California, and by implication the Southwestern US, is rapidly approaching some technical frontier in terms of water-use efficiency.

Table 1. Urban Water Demand across Select Regions

Country‡ or Region†	Urban Water Demand *circa* 2000 Gallons/Capita/Day
Israel	80
Spain	96
Italy	115
Australia	130
California	192

‡Country data obtained from Food and Agriculture Organization's AQUASTAT database.
†California data taken from the *20x2020 Water Conservation Plan*, developed by interagency team headed by the California Department of Water Resources, 2010.

[2] Bamezai, A., *Residential Clothes Washers: An Update about Costs and Savings*, a report prepared for the California Urban Water Conservation Council, 2014.

Residential end-use studies convey a similar point. As per the original Residential End Uses of Water Study (REUWS), single-family homes subject to data logging in 1997 were shown to be using roughly 62 gallons per capita per day (GPCD) indoors for a family of three. In a more recent logging study of 25 new single-family homes, fitted entirely with WaterSense® endorsed plumbing fixtures and appliances, indoor use for a standardized family of three was estimated to be roughly 36 GPCD, a 42% reduction.[3] And that is savings potential available with today's technologies. Who knows where the indoor usage floor will be in a few more years? Comparable savings are available on the outdoor front through measures like the adoption of drought-tolerant plant species and irrigation efficiency improvements.

Yet another way to assess the issue of peak water-use efficiency is to look at aggregate water withdrawals and Gross Domestic Product in the United States and examine how they track one another. Figure 1 shows these trends. These data have been compiled by Peter Gleick of the Pacific Institute.[4] And they suggest that water use intensity of the US economy has been steadily dropping since the 1970s without hampering economic growth. Some of the reasons offered to explain the divergence between the two trend lines include passage of the Clean Water Act in 1972, constraints on new supplies, and changing structure of the US economy.[5]

All of the evidence offered above suggests that fears about approaching peak water-use efficiency are premature.

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[3] DeOreo, W. B. et al., *Analysis of Water Use in New Single Family Homes*, a report prepared for the Salt Lake City Corporation and the US Environmental Protection Agency, 2011. Water savings also reflect in part lower leakage prevalence in the new homes compared to the original REUWS study.

[4] Data and analysis provided by Peter Gleick, Pacific Institute, 2014. Water withdrawal data are from the US Geological Survey, Gross Domestic Product data are from US Bureau of Economic Analysis.

[5] Gleick, P. H. and M. Palaniappan, *Peak Water: Conceptual and Practical Limits to Freshwater Withdrawal and Use*, Proceedings of the National Academy of Sciences, Vol. 107, No. 25, pp. 11155-11162, Washington D.C., 2010.

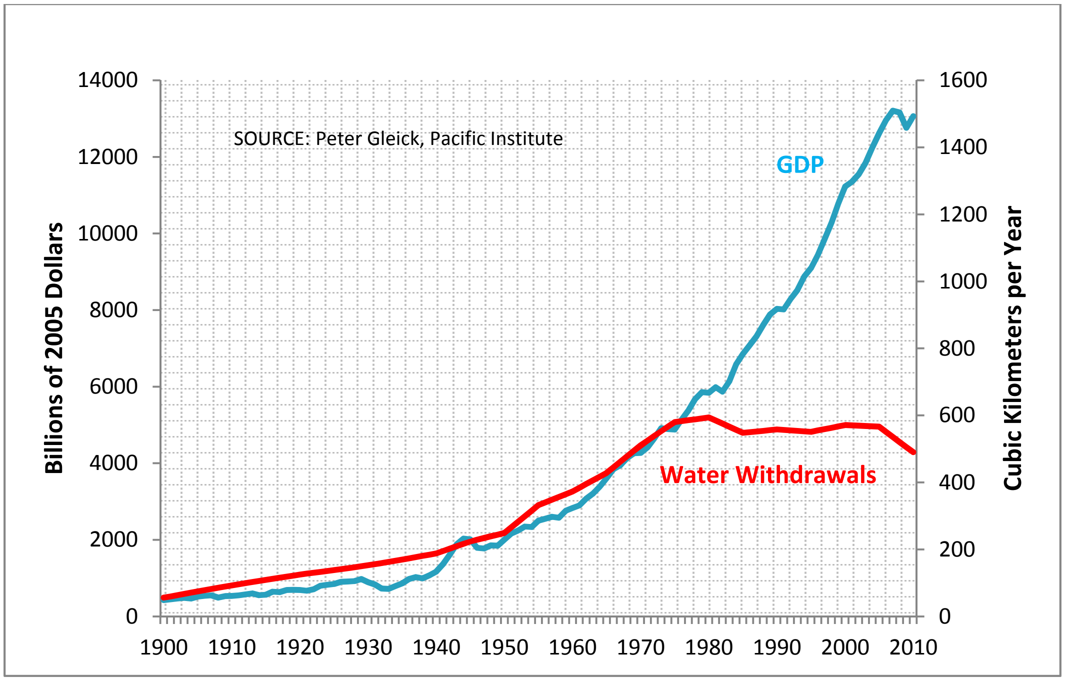


Figure 1. United States GDP versus Water Withdrawals

Now, it is entirely possible that although conservation opportunities remain aplenty, future savings will cost more on a per-unit basis. This phenomenon is by no means unique to water conservation. Most firms including utilities exhibit rising marginal costs associated with new supply. The field of economics offers ample concepts, reasoning, and nomenclature to describe this phenomenon. With appropriate data these future marginal costs can also be quantified. Therefore, demand hardening should not be conflated with rising per-unit costs of future conservation savings.

Published literature contains a second interpretation of demand hardening, namely, that responsiveness of demand to price may decrease in the future as customers become more efficient.[6] Perhaps this is true; perhaps not. Price elasticity (defined as the percent decline in demand caused by a 1 percent increase in price) is a function of many factors, such as income, cost of water relative to other utilities, the cost of implementing future conservation programs, customer education, environmental attitudes, and so on. If price elasticity declines because the marginal cost of future conservation rises, well, this would not be particularly surprising. In practice though, the magnitude of this effect cannot be very high because water demand is price inelastic to begin with.[7] The key point, however, is that conflating changes in price elasticity with demand hardening is conceptually misleading. Some utilities have attempted to account for demand hardening in their conservation master plans by using a price elasticity estimate significantly below published estimates.[8] The present study argues against such a practice, instead favoring

[6] San Francisco Public Utilities Commission, *Measures to Reduce the Economic Impacts of a Drought-Induced Water Shortage in the SF Bay Area*, 2007.

[7] Dalhuisen, J. M. et al., "Price and Income Elasticities of Residential Water Demand: A Meta-Analysis," *Land Economics*, Vol. 79, No. 2, 2003, pp. 292-308.

[8] Los Angeles Department of Water and Power, *Urban Water Management Plan*, 2010.

incorporation of demand hardening concerns into a water utility's shortage contingency plan (more on this later).

The third manner in which demand hardening is invoked is to voice concerns about how customers will respond to requested cutbacks during droughts, or shortages caused by other natural calamities, once they have squeezed out inefficiencies—the fear being that efficient customers lack the ability to scale back demand. This is how water conservation professionals have traditionally understood demand hardening, but its full meaning remains unclear. So, let us unpack it.

If customers save water by participating in retrofit or other types of conservation programs, the savings can end up in one of three places. They can either be stored in surface or sub-surface reservoirs, used to supply new growth, used to remedy past environmental damage, or some combination thereof. If all savings are banked, it is self-evident that conservation cannot make a water supplier's ability to deal with future shortages any worse than before, so concerns about demand hardening should not arise.

In the second case—where savings are used to supply new growth—difficulties may arise, but not necessarily. To see the point heuristically, imagine a service area where during the baseline period a water supplier serves X individuals, each using 200 gallons per capita per day (GPCD). After some number of years, improvements in water-use efficiency indoors and outdoors brings normal-year usage down to 100 GPCD, except now 2X individuals call this service area home. Total demand remains unchanged. Let us further assume that normal year, indoor water using behavior stays the same. If residents flushed the toilet 5 times a day before, they do the same later when total water use has dropped to 100 GPCD. In other words, normal year water demand is assumed to drop from 200 to 100 GPCD mainly because of plumbing and appliance retrofits, as well as significant landscape modifications. Had a drought occurred during the baseline period let us assume individuals would alter their behavior by flushing only half as much, washing only half their normal laundry loads per week, irrigating their landscape half as frequently, and so on. In this hypothetical scenario, during the earlier period customers would have reduced their use by 100 GPCD. Does that mean that at a later date when normal use has dropped to 100 GPCD, customers have lost the ability to make similar proportional adjustments when a drought hits? Well, not really. If we assume that customers are willing to modify their behavior exactly as they did in the past (flush half as often, launder half as frequently, etc.) the net result remains the same. They would halve their water use. Of course, during the later period these behavioral adaptations will only generate 50 GPCD of savings per individual, unlike 100 GPCD before, except now the service area has 2X individuals saving 50 GPCD instead of X individuals saving 100 GPCD. Under either scenario, total quantum of water saved within a service area remains the same as long as willingness to change behavior during shortages also remains unchanged.

One can ask—in the context of supplying new growth via conservation—whether it matters with respect to demand hardening if new supplies are generated through reductions in existing potable water demand, or through recycling and reusing water discharged by existing customers? If new supplies are generated through recycling without improvements in existing customers' water-use efficiency, it follows that the ability of existing customers to deal with shortages cannot be any worse than before. However, new customers reliant on recycled water, especially in the commercial, industrial and institutional (CII) sector, may not be as willing to alter their demand when an area faces a shortage. Could this be a problem? Well, that depends on the proportion of sewer flows being recycled. In agencies with small-scale recycling programs, even during shortages residential customers are likely to generate sewage at a level likely to exceed a supplier's recycling capacity, ensuring that CII customers reliant on recycled water can continue to operate normally. Therefore, in such agencies recycled water can be seen as a "drought proof" supply. However, when agencies begin to recycle very large fractions of their sewer flows (per anecdotal evidence, some agencies are approaching the point of recycling their entire sewer flows) extended periods of shortage may cause a decline in recycled water availability, which must be taken into account while crafting water shortage contingency plans.

The third case—savings get diverted toward environmental restoration—is a variation on the second. Assume X customers reduce their normal year water demand to 100 GPCD by investing in indoor and outdoor efficiency from an earlier baseline demand of, say, 200 GPCD. The area does not grow; all savings are diverted to environmental improvements. If willingness to change behavior during shortages remains the same between the baseline and later periods, the percentage reduction achieved by customers in either time period would remain the same, but the quantum of water saved would be halved during the later period. However, if the pain of dealing with shortages is equitably split between people and the environment, the total quantum of water saved within a service area once again remains the same. Can a water supplier that seriously invests in conservation to help the environment count on this equitable sharing? That is hard to predict because it involves taking up matters of policy and politics on a case-by-case basis. All one can say is that if a water supplier's drought cutback goal is defined in percentage terms, instead of the quantity of water saved, perhaps no problem need arise.

So far, the above discussion has made a critical assumption, namely, that willingness to modify behavior during droughts remains unchanged over time even as water-use efficiency rises. Is this really true? What might cause it to not be true? We do not really know. Once customers invest in water-efficient fixtures, appliances, and landscapes, they may begin to feel as if they have done their part and consequently become less willing to inconvenience themselves during droughts. They may wrongly believe that conservation savings are being banked to deal with dry years, or they may resent that conservation savings are not being banked, instead are being used to supply new growth, which in turn may make them less willing to comply with voluntary restrictions. In other words, hardening of attitudes could create problems for dealing with temporary water shortages and this can legitimately be called demand hardening. But, one can also posit the opposite effect. Customers who are well educated about conservation techniques and about a water supplier's shortage contingency plans may become more amenable to modifying their behavior during droughts. For example, if more customers have knowledge about the drought tolerance of various turfgrass species and other plant material, have incorporated this knowledge into their own landscapes, and know how to operate a landscape in deficit-irrigation or survival mode to generate steep savings during shortages,[9] they may be able to shed fears about total landscape loss and instead cooperate when asked to reduce irrigation. Scaling back irrigation is usually

[9] Harivandi, M. A. et al., *Managing Turfgrasses during Drought*, Division of Agriculture and Natural Resources, University of California, Publication # 8395, 2009.

the first directive a supplier issues when a shortage is imminent. In other words, any definition or analysis of demand hardening must make customer attitudes and behavior its main focus.

The above discussion shows that long-term conservation programs are more about altering the characteristics of the installed stock of plumbing fixtures, appliances and landscapes, whereas dealing with shortages depends on time-limited behavioral change that goes well beyond the normal level of care we expect customers to show while using scarce water. As long as room to change behavior remains the same over time, demand hardening should not be a major concern in spite of rising water-use efficiency, although this cannot be assumed *a priori*. It merits analysis. For the average water supplier, water-use efficiency so far has increased largely as a result of plumbing fixture and appliance retrofits, not behavioral changes. For example, the average number of flushes, clotheswasher loads, or showering minutes per day were found to be very comparable among the 25 high-efficiency homes fitted with WaterSense® endorsed plumbing fixtures and appliances compared to the original REUWS study (see DeOreo, W.B., 2011 *op cit.*). A forthcoming update of the original REUWS study further confirms this point, that indoor water-using behavior is really no different today compared to the mid-to-late 1990s when field work for the original REUWS study was undertaken.[10] Therefore, ability to change behavior if circumstances warrant is probably no different now than before. Exceptions to this general observation are water suppliers that may be operating under drought restrictions on a year-round basis. What if supply conditions were to further deteriorate? Would customers in such service areas be able to react and further adjust? We believe careful analysis can shed light on this question. The analysis would first have to measure how customers are using water with drought restrictions in place on an ongoing basis and, second, assess customer attitudes about whether and what additional steps they would be willing to take if necessary. For example, are residential customers flushing 5 times per person a day on average with drought restrictions in place, which is what end use studies say residential customers normally do? Or have they already reduced their flushes to, say, 3 times a person per day? If the latter, further reductions in indoor use may be more difficult to obtain. Similarly, has the average customer reduced their outdoor use to a point where further reductions would result in total loss of landscape? Or, have they replaced turf with drought-resistant native vegetation, and as a result could perhaps reduce irrigation further if asked to. These are examples of the kinds of information that one would need to collect to assess how much additional room there is to reduce demand in the case of already restricted suppliers. But such an assessment can only be performed on a case-by-case basis; a general answer is not forthcoming.

So far in this discussion, demand hardening has been traced mostly to adverse attitudinal changes over time, but this need not be the entire story. Demand could harden through an alternative pathway, for example, if customer attitudes toward drought adaptation vary significantly across customer classes and the relative weight of these classes change over time. For example, multifamily customers may show less inclination to respond to voluntary or even mandatory restrictions during droughts since most do not see a sub-metered water bill. If over time multifamily housing grows significantly faster than other types of housing, total demand may exhibit reduced adaptability to droughts, all else being equal. Similarly, while commercial, industrial and institutional (CII) sectors include many end uses similar to those found in the

[10] DeOreo, W. et al., *Residential End Uses of Water Update*, sponsored by the Water Research Foundation (forthcoming).

residential sector, such as toilets, laundry, landscape, etc., they also include process water. Requiring process water reductions during shortages can impose significant economic costs on affected customers. Therefore, in the past it has generally been soft-pedalled. Getting CII customers to reduce their residential-like end uses to the same degree as single-family customers may also be difficult. Once again, all else being equal, if the CII share or process water share of total potable demand increases over time, demand may exhibit reduced adaptability to droughts. (Increased use of recycled water can partially offset this effect although as mentioned earlier recycled water's availability during droughts partially depends on the percentage of sewer flows being recycled.)

Agricultural water demand is not covered here given this study's focus on urban water suppliers. However, demand hardening may be relevant for this sector as well if farmers "switch from field and row crops to permanent plantings of orchards and vineyards. A field normally planted in row crops can be fallowed in a water-short year. In contrast, withholding water from permanent plantings will ultimately result in loss of a grower's capital investment."[11]

Finally, there is the question of countermeasures. What can suppliers do to reduce the impact of potential demand hardening if analyses indicate that such a phenomenon is occurring? We argue later that the question of mitigation requires that planners learn to connect demand hardening concerns with water shortage contingency planning, a point not obvious at the outset.

KEY STUDY QUESTIONS

Among the various interpretations of demand hardening the one about the relationship between rising water-use efficiency and an area's capacity to respond to shortages merits the most attention. This is generally how water conservation professionals have traditionally understood demand hardening. The previous discussion explicates the various pathways through which it can operate. Central to the traditional interpretation of demand hardening, which we also favor over the alternatives, is the question about how customers respond, or intend to respond, to future shortages.

This study's core objective then is to shed light on the following key questions:

1. Do long-term increases in water-use efficiency influence an area's ability to adapt to water shortages?
2. Is the customer's willingness and ability to scale back consumption less now than before because of participation in conservation programs?
3. How much reduction can water suppliers expect from their customers during future drought episodes?

These questions are important because supply reliability assessments must grapple with probability and levels of shortage associated with alternative supply scenarios. Designing a least-cost capital

[11] California Department of Water Resources, *Preparing for California's Next Drought: Changes Since 1987-92*, July 2000.

improvement plan is difficult without knowing a community's perceptions about acceptable shortage levels and risks. Most water utilities plan for an above-zero level of shortage risk. The City of Boulder undertook a supply reliability assessment during 2003-2004 based on an explicit understanding that driving the risk of shortage to zero would be cost prohibitive.[12] A recent national survey shows,[13] in a clear break from the past, that more and more water suppliers are developing shortage contingency plans. (California suppliers are already required to develop such a plan as one component of their broader urban water management plan.) And suppliers are doing so in order to reflect what their customers want—which is to keep their water bills low—even if that means practicing frugality during the occasional shortage. Recent opinion polls in San Diego[14] and San Antonio[15] support these views. Water policy makers ought to be interested in knowing if customer preferences are changing in ways that will make dealing with future shortages more difficult.

[12] City of Boulder, *Drought Plan, Volumes 1 and 2*, prepared by Hydrosphere Resource Consultants and Aquacraft, Inc., 2004.
[13] American Water Works Association, *2014 Water Shortage Preparedness Survey Results*, 2014.
[14] Probe Research Inc., *2014 Water Issues Public Opinion Poll*, a report prepared for the San Diego County Water Authority, 2014.
[15] Wilson Perkins Allen Opinion Research, *San Antonio Water System Conservation Study*, 2012.

2. ANALYTIC APPROACH AND SETTING

Given this study's primary focus, several decisions and tradeoffs were made while developing the research design. First, it was self-evident that a focus on shortage adaptation requires examination of a long water demand history covering multiple episodes of drought. How an area deals with a single shortage episode does not reveal much about changes over time. Accordingly, it was decided to compile water demand histories and other related data going back to 1970. The other data include demographics, socio-economic characteristics, rate histories, conservation histories, and so on to provide context for understanding long-term trends in water-use efficiency and inter-area differences in the telephone survey responses. As discussed below, the study design includes a telephone survey of single-family households.

Second, analyses presented here treat a water supplier, not a household, as the basic unit of analysis. To find and study a large sample of households that have lived at the same address for over 40 years is not practical. Virtually no water supplier maintains billing records at the customer level covering such long periods of time. Moreover, such an immobile sample would become less and less representative of their service area as time wears on. At the supplier level, on the other hand, it is often possible to construct long histories of basic metrics, such as total demand and water sales by customer class. The study budget allowed a total of seven water suppliers to be recruited for this study. The case study sample includes four suppliers from California, two northern (City of Santa Rosa and City of Petaluma), two southern (Irvine Ranch Water District and Monte Vista Water District), one from Colorado (City of Boulder), one from New Mexico (City of Santa Fe), and one from Texas (San Antonio Water System). Selection of these case studies was based on several criteria, such as location, prior drought experience, quality of historical data, willingness to participate in and contribute funds towards the study, and so on. An effort was made to have good coverage of the arid Southwestern US within the allowable budget.

Third, given the central place of customer behavior in understanding current and future drought response, the research design includes a telephone survey of randomly selected single-family households that experienced their area's most recent drought. Surveying of multifamily or CII customers was not attempted because in such cases finding a relevant point of contact involves high search costs, which in turn significantly drives up surveying costs. Simply put, a tight budget makes choosing necessary, and it is only logical to give the single-family sector greater attention since it represents the single largest slice of total water demand. However, that does not mean that nothing meaningful can be said about the behavior of multifamily and CII sectors without surveys. After all, water demand histories by customer class lend themselves to several useful analyses.

The water demand data compiled for this study are used in the following way: to examine how demand adjusted during each previous drought episode since 1970, overall, and where possible by customer class. Not all suppliers were able to provide water sales by customer class going back to 1970. We use as much of these customer class demands as are available. The purpose of these analyses is to assess whether adaptation to successive droughts indicates a significant diminution in willingness to cut back demand during shortages, or not.

The purpose of the telephone survey is to evaluate what single-family customers actually did during the latest drought, what they are willing to do to adapt to a future drought, their perceptions about how easy it was to scale back their demand, and whether they would prefer to continue to practice frugality during shortages or pay for the development of new supplies. The design of the telephone survey and results are described in greater detail later.

Even though a lot of data were collected for this study, the purpose here is to cast a wide exploratory net, not engage in statistical model-based hypothesis testing. Until now very little empirical work has been undertaken to corroborate demand hardening with real world experience and data. It therefore seemed premature to opt for a tightly defined modeling framework when even formulating the correct questions remains somewhat elusive at this stage. This study's larger purpose, then, is to delineate the lay of the land and suggest fruitful lines of inquiry for future studies to take up, if possible, within a more rigorous modeling framework. For all these reasons, the analytic methods used here retain somewhat of a qualitative flavor.

SETTING

The Southwestern US offers fertile ground for studying the linkage between long-term conservation and an area's ability to respond to shortages. By and large, severe shortages are caused by droughts, although other natural calamities—that destroy infrastructure—can also be causative factors. This region has grown rapidly and is home to a large portion of the nation's population. It is one of the most drought-prone regions of the US as Figure 2 indicates.[16] And, because of this, water suppliers have invested in long-term conservation over many years.

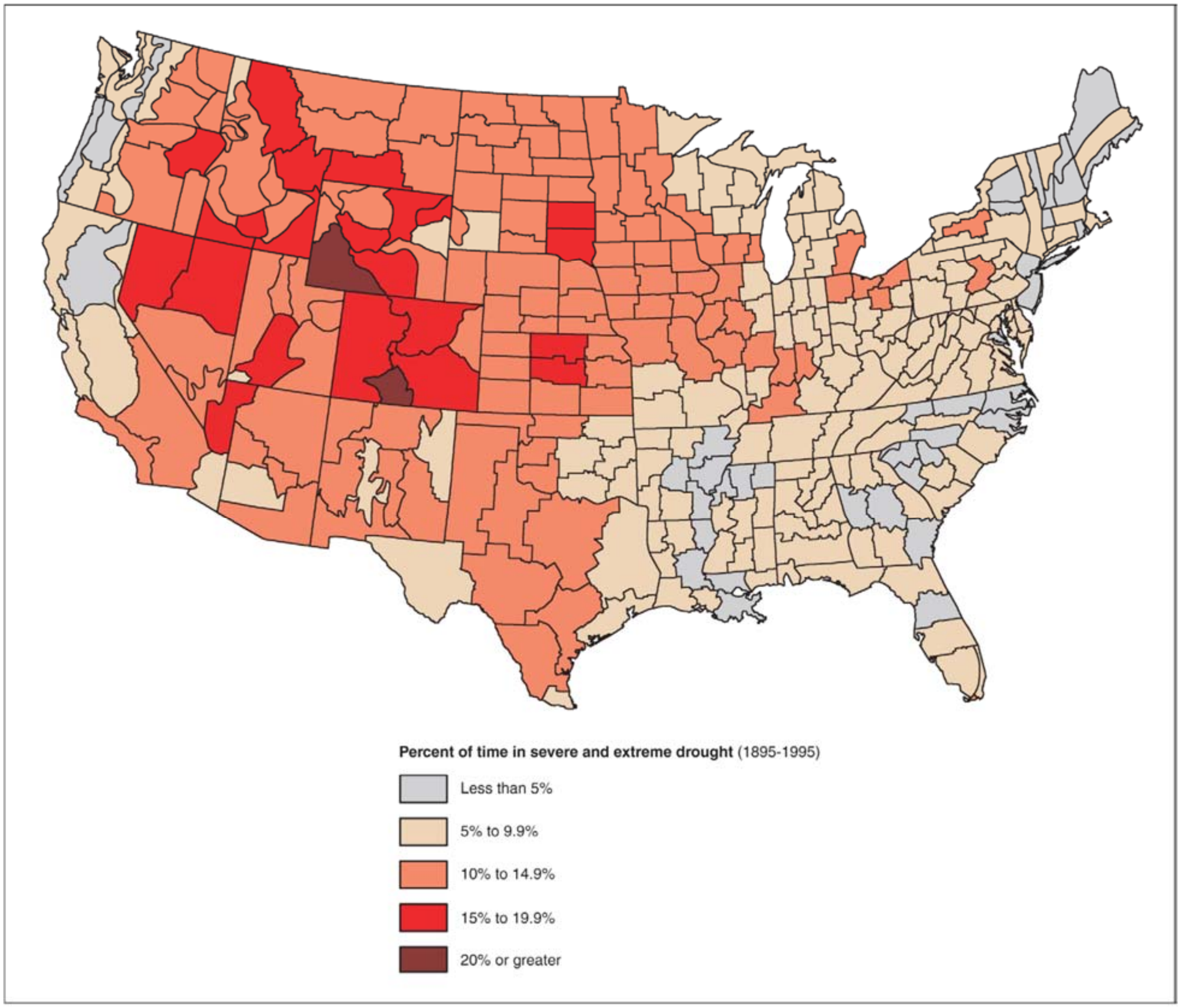
A total of seven water suppliers were selected for detailed assessment (case studies). These include:

1. City of Boulder, CO
2. City of Santa Fe, NM
3. San Antonio Water System, TX
4. Irvine Ranch Water District, CA
5. Monte Vista Water District, CA
6. City of Petaluma, CA
7. City of Santa Rosa, CA

Since this study's focus is on shortages, it is best to rely on each water supplier's self-assessment as to when it faced serious shortages. Droughts, whether caused by meteorological or hydrological conditions, do not automatically equate to declared shortages. It is well understood that drought impacts can be localized geographically (for example, rural systems dependent on marginal supplies may feel the pain before better endowed urban ones), or by sector (for example, agriculture may feel greater pain

[16] This figure is taken from *Freshwater Supply: States' Views of How Federal Agencies Could Help Them Meet the Challenges of Expected Shortages*, report # GAO-03-514 prepared by the United States General Accountability Office, 2003.

than the urban sector during a hydrological drought). Not all inhabitants of a drought-stricken region may be equally affected. Localized conditions having to do with water in storage or available in the form of ground water may allow some water suppliers to escape the worst even though the larger region may be drought-stricken. Shortages result from a combination of "natural forces, system component failure or interruptions, or regulatory actions."[17] For these reasons it is best not to get hung up on questions about appropriate drought definitions, and instead simply rely on supplier self-assessments about when they faced shortages. Among the selected water suppliers, none faced shortages because of non-drought related natural events, such as earthquakes, etc.



Source: National Drought Mitigation Center, University of Nebraska-Lincoln.

Figure 2. Prevalence of Drought by Region in the United States

[17] Many sources shed light on drought definition and preparation. These include two publications issued by the California Department of Water Resources including the *Urban Drought Guidebook: 2008 Updated Edition* and *Drought in California (2012)*. The National Drought Mitigation Center, University of Nebraska-Lincoln's website also offers numerous useful resources.

Table 2 shows a few key characteristics about these seven case studies, such as their current size and growth since 1970, relative customer class shares of water sales, and the year each first began to make significant investments in conservation either through retrofit programs or by adopting conservation rate structures. The water suppliers selected for detailed analysis exhibit considerable variation on these dimensions. The City of Boulder has grown the slowest, while the Irvine Ranch Water District's service area has multiplied many-fold. A good portion of the latter's growth has occurred because of consolidation with other smaller water districts, so in that sense Irvine's data do not altogether represent organic growth. But it is safe to assert that Irvine has grown faster than the other six suppliers by at least an order of magnitude as it has transformed from an agricultural to a highly urbanized area. The selected suppliers also exhibit considerable variation in terms of customer class shares of total billed use, with Santa Fe having insignificant multifamily water demand, while Boulder and Irvine have the largest. As discussed earlier, adaptation to shortages can vary by customer class, an issue examined in the next section.

The selected case studies also exhibit variation as to when they began to pay significant attention to water conservation. Suppliers located either in the most drought prone areas of the country (Figure 2), or those that have grown the fastest, have generally initiated their conservation programs and/or conservation rate structures earlier in time. The case studies also differ in terms of affluence and how hard they were hit by the recession that began in 2008. Some of these socioeconomic characteristics are useful in explaining inter-case study differences observed in the telephone survey results discussed later.

Table 2. Selected Characteristics of Case Studies

Case Study	Population in 2011	Population Growth Between 1970 and 2011	Per Capita Income 2010	Unemployment Rate 2010	Share of Billed Potable Water Sales in 2011			Beginning Year of Significant Conservation Programs	Year Switched to Inclining Rate Structure
					Single Family	Multi Family	CII & Large Landscape		
Boulder	116,628	57%	$50,095	8.0%	41%	22%	37%	1992	1988
Irvine Ranch	341,745	4074%	$49,863	7.1%	40%	22%	39%	1991	1991
Monte Vista	52,821	79%	$29,609	13.6%	56%	15%	29%	1996	2010
Petaluma	60,154	125%	$44,186	9.5%	60%	12%	28%	1999	2003
San Antonio	1,300,689	133%	$34,969	7.3%	58%	13%	28%	1994	1989
Santa Fe	79,627	93%	$43,389	6.1%	68%	3%	29%	1997	1995
Santa Rosa	168,856	238%	$44,186	10.4%	56%	18%	26%	1992	2007

SOURCE: Per-capita income from Bureau of Economic Analysis; unemployment rate from Bureau of Labor Statistics; all other data from water suppliers.

3. GPCD TRENDS AND THE ABILITY TO SAVE WATER DURING SHORTAGES

This section reviews the drought and shortage history of each case study since 1970, including savings achieved during each period of declared shortage. After this, the analysis compares and contrasts the experience of each case study vis-à-vis the other. The main question this section addresses is whether water suppliers are facing diminished ability to curtail demand in future contingencies.

DROUGHT AND SHORTAGE HISTORY BY CASE STUDY

How customers react to a shortage in part depends upon what their water supplier tells them about the severity of the situation and the guidance it offers them about how aggressively to cut back. By and large most water utilities have emergency regulations on their books giving them the authority to declare a shortage on a four-point scale, each progressively requesting or mandating greater and greater cuts to water demand. Stage 1 commonly requests voluntary cutbacks to the tune of 10%, advising customers to show greater diligence in how they use water, to stop hosing sidewalks, driveways and cars, reduce irrigation, not irrigate during daylight hours, eliminate runoff, fix leaks, not serve water in restaurants until asked, recommend multi-day use of bed linen to hotel guests, etc. The emphasis during Stage 1 largely is on “encouraging” compliance through drought messaging. A Stage 2 shortage is usually declared when demand needs to be scaled back between 10-25%. To achieve this higher level of savings, additional mandatory restrictions kick in beyond all the steps required in Stage 1. Automatically controlled irrigation is restricted to no more than two or three days a week (manual, drip and recycled water irrigation usually remains unrestricted during this stage). Stage 2’s mandatory restrictions on irrigation and other wasteful practices are usually enforced through fines and penalties. From Stage 2 onward, the emphasis shifts from “encouraged” to “required.” The level of effort expended on enforcement can be a key driver of achieved savings. A Stage 3 shortage is declared when demand needs to be scaled back between 25-40%. This usually involves limiting automatic irrigation to no more than one day a week and imposing water rations on households (GPCD quotas) and on businesses (requiring drought use to be cut by some percentage relative to the year before). Manual irrigation may also be limited. Drought surcharges usually become necessary during Stage 3 as an enforcement tool and to help the supplier maintain financial health amidst dwindling sales. The highest shortage declaration, Stage 4, is used when demand needs to be dialed back more than 40%; this usually requires imposing even tighter rationing goals on indoor use and prohibition of all irrigation. During Stages 2 through 4, the level of enforcement vigor greatly influences compliance.

Although the above scheme is fairly representative of how the typical water shortage contingency plan is configured, important variations also exist across suppliers. For example, a few suppliers rely on water budgets tied to rates, allowing suppliers to ratchet down these budgets during shortages to signal the desired level of cutbacks. Some plans have fewer than four stages, etc. These variations are explored in greater detail later and have much to teach about how to mitigate potential demand hardening.

The reason for opening this section with a description of the typical shortage contingency plan is to bring some consistency to the classification of prior shortage episodes. This study is particularly interested in assessing whether differences exist between the impact of voluntary and mandatory actions, and between restrictions and rationing. In the discussion that follows, each participating case study's drought history is classified according to the voluntary versus mandatory and restrictions versus rationing schema, which occasionally results in minor reclassification compared to how a case study's own documents may describe a previous shortage episode. The reasoning for this reclassification is made clear in the discussion below. Following a consistent definition is necessary for comparing and contrasting shortage episodes across the different case studies.

BOULDER

The City of Boulder has faced several droughts since 1970, most recently in 2012, including one episode that lasted 8 years between 1987 and 1994. However, Boulder was forced to declare a shortage only in one instance (2002-03). The long drought that began in 1987 was instrumental in focusing Boulder's attention on the importance of water conservation (**Figure 3**). The city switched from a uniform rate to a 3-tier inclining rate structure in 1988 and started implementing retrofit programs in 1992. These efforts have continued and strengthened over time. As a result overall GPCD has continued to decline.

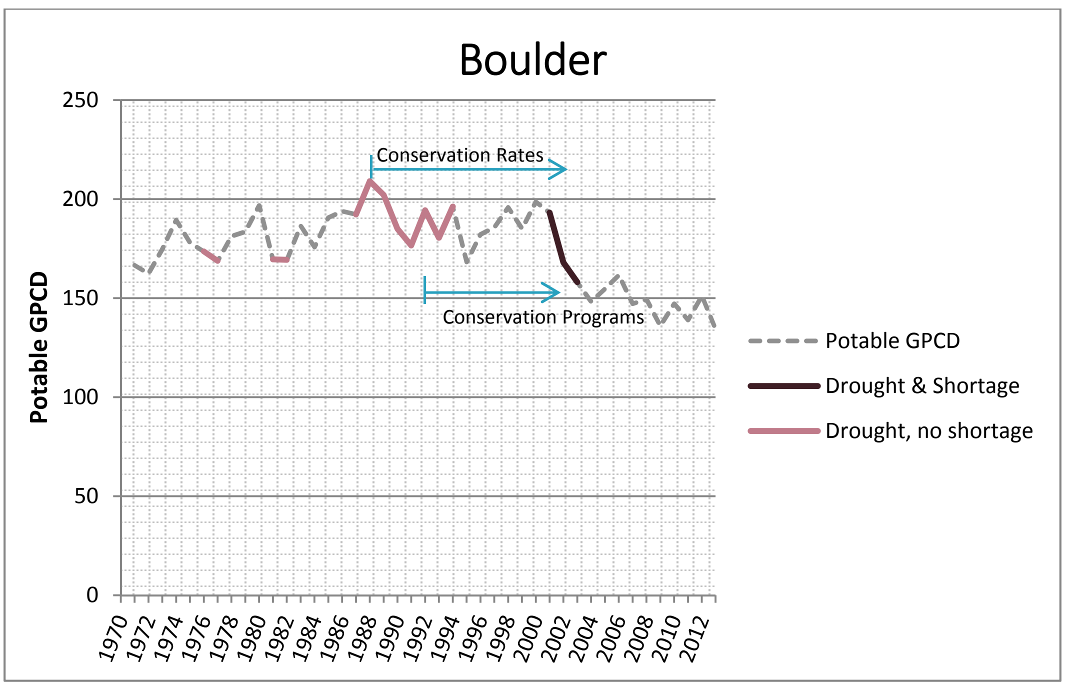


Figure 3. Boulder: GPCD, Drought and Shortage History (1970-2013)

The only shortage episode that Boulder experienced since 1970 was a serious one. Boulder declared mandatory restrictions in June, 2002, and followed up with an aggressive compliance effort. According to

Boulder's own emergency regulations, this event was classified as a Stage 3 shortage. However, since the emphasis was mostly on reducing outdoor use—indoor rationing was not undertaken—we classify this as a "mandatory restrictions" episode. Boulder restricted automatic irrigation to no more than two days a week, neither day to exceed 15 minutes per sprinkler zone. Daytime irrigation was prohibited. Typical Stage 1 prohibitions on water waste of the kind described earlier, such as no irrigation runoff, no washing of patios, driveways, or cars were also in effect. Penalties ranging from $50-300 were levied on violators (City of Boulder's *Drought Plan, op cit.*).

By late 2003 drought conditions eased and mandatory restrictions were lifted, but water demand continued to drop through 2004. In response to mandatory restrictions, residents successfully reduced their per-capita demand by 18% between 2001 and 2003 and by 23% if the comparison is made between 2001 and 2004. In 2007, Boulder switched to a 5-tier water budget-based rate structure, in part as a lesson drawn from the 2002-03 shortage. During periods of shortage, a budget-based rate structure can help maintain compliance and equity in a far more effective manner. Since 2003, Boulder has not had to impose emergency restrictions on water use even though 2012 was a drought year in that region.

IRVINE RANCH

Irvine Ranch Water District has faced two shortage events, one during 1976-77 and the other during the 6-year drought that began in 1987 and lasted through 1992 (Figure 4). Drought conditions affected many parts of California once again between 2007 and 2009, but Irvine did not have to declare a shortage during this time period due to substantial local and regional investments in storage, local supplies, water banking, water recycling and conservation.

Regarding the two earlier shortage episodes, agency documents suggest that Irvine Ranch invested in customer education and took actions to prevent water waste but was not significantly impacted by the drought of 1976-77.[18] Because of its insignificant impact, this early episode is classified as one involving "voluntary restrictions" even though Irvine imposed a 10% drought surcharge (usually a Stage 3 feature in a conventional shortage contingency plan). As Figure 4 suggests, Irvine probably still retained much of its agricultural character during the 1976-77 drought (very high GPCD), so it is not clear what one can learn from this episode. However, because of rapid urbanization and population growth, Irvine was impacted much more seriously during the second major drought (1987-92) to hit California during the study period. During this episode, Irvine Ranch was forced to reduce its water demand by over 20% in response to 30% supply cuts from its regional water purveyor, the Metropolitan Water District of Southern California. To deal with this second shortage, Irvine Ranch had to enforce mandatory restrictions on water use, but it chose not to do so in the traditional way, such as by limiting irrigation to 1-2 days a week, etc. Instead, it chose to incentivize efficiency and enforce restrictions for *all* customer classes through the budget-based rate structure it adopted in 1991 at the peak of the drought. And this is how Irvine Ranch's water shortage contingency plan is configured to the present day, with most of the heavy lifting earmarked for the budget-based rate structure instead of "overt" mandatory restrictions. The shortage episode of 1990-

[18] Irvine Ranch Water District, *Urban Water Management Plan*, 1995.

92 is better classified as a "mandatory restrictions" episode because the switch from uniform rates to budget-based steeply inclining rates in 1991 marked a huge change for Irvine's customers.

The second shortage episode of the early 1990s caused Irvine Ranch to initiate and aggressively invest in water conservation programs. These included retrofit and education programs and the aforementioned budget-based rate structure, both put in place for the first time in 1991. The water budgets have been adjusted downward over time, to reflect rising water-use efficiency among Irvine's customers (and partially in response to drought conditions, first in 2009 and then again in 2014). The downward adjustment made to water budgets in 2009 was not rescinded once drought conditions ended. Irvine Ranch also augmented and greatly diversified its water supply, with recycled water now accounting for almost a quarter of its total water supply (excluded from potable GPCD on account of being a "drought proof" supply). All of these prior and continuing investments have helped Irvine Ranch to sidestep the need for undertaking "overt" mandatory restrictions during the more recent drought events, although many Irvine residents believe otherwise. This is in part a result of the routine emphasis that water conservation receives in Irvine. It also results from Irvine being located in a larger media market. When Irvine's neighboring cities undertake drought messaging or announce mandatory restrictions this messaging influences Irvine Ranch customers as well (more on this in the telephone survey section).

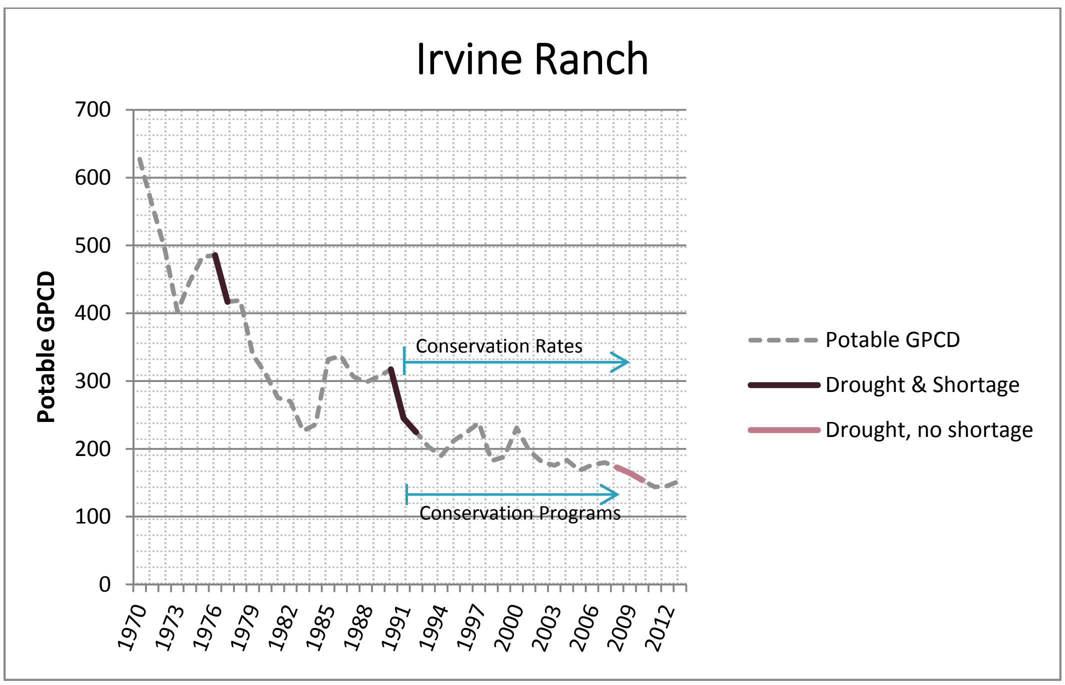


Figure 4. Irvine Ranch: GPCD, Drought and Shortage History (1970-2013)

After two successive very dry winters (2012-13 and 2013-14) followed by Governor Brown's call early in 2014 urging all Californians to reduce their water use by 20%, Irvine first announced voluntary restrictions in June 2014, but then also followed up by reducing customer water budgets in July 2014 to signal their customers about the need to cut back their water demand.[19] Irvine Ranch has successfully made the case that its budget-based approach is more effective at curtailing demand than imposing mandatory irrigation restrictions. As a result Irvine Ranch is in compliance with statewide emergency regulations enacted in May 2014. Although customer compliance is based on voluntary response to price signals, the penalties can be steep if customers exceed their water budgets.

During the first shortage episode, per-capita demand dropped by roughly 14% between 1976 and 1977, and during the second episode by roughly 29% between 1990 and 1992. Irvine Ranch's performance in 2014 compared to 2013 is discussed later.

MONTE VISTA

Since 1970, Monte Vista Water District has experienced three significant drought episodes (**Figure 5**). These include the droughts of 1976-77, 1987-92, and 2007-09. Monte Vista's historical documents do not offer a clear picture as to what steps were undertaken to curtail water demand during the 1976-77 and the 1987-92 droughts, but fairly sizeable savings were achieved during both episodes. Whether these savings were achieved through voluntary or mandatory actions remains unresolved. However, drought messaging was very strong statewide in California during both of these severe episodes. This may have generated the type of compliance that one normally associates with mandatory restrictions.

In response to drought conditions in 2007, Monte Vista announced voluntary restrictions in April 2008, which were replaced with more stringent mandatory restrictions a year later.[20] Apart from normal prohibitions on water waste, irrigation was prohibited during daylight hours and restricted to no more than three days a week during the mandatory restrictions phase. Large landscape accounts were also required to reduce their water use by 25% compared to the previous year. These mandatory restrictions proved quite effective in reducing per-capita water demand, so in 2010 Monte Vista made many of the mandatory restrictions into permanent, year-round best practices (codified in Monte Vista's Ordinance 33) as part of an overall effort to improve water supply sustainability. As per this ordinance, daylight irrigation is prohibited as is irrigation overspray and runoff. Leaks are required to be fixed within 7 days. Recirculating or reuse systems must be installed within cooling towers, evaporative coolers, decorative fountains, and commercial car washes, etc. Ordinance 33 is one component of a portfolio of conservation programs that also include traditional retrofit and education programs. Implementation of these traditional conservation programs began in 1996. Enforcement of year-round best practices (Ordinance 33) that originally started out as drought restrictions are carried out in two ways: violations reported by customers or noticed by district staff trigger a notice. Fines are levied if problems remain unresolved after two notices. Also, in 2010 Monte Vista adopted a water budget-based rate structure for its residential customers in lieu of uniform rates. Budget-based rates structures are yet another way of identifying and penalizing water wasters.

[19] Irvine Ranch Water District, *Alternate Plan for Implementation of Emergency Drought Regulations*, submitted to the California State Water Resources Control Board, 2014.
[20] Monte Vista Water District, *2010 Urban Water Management Plan*, June 2011.

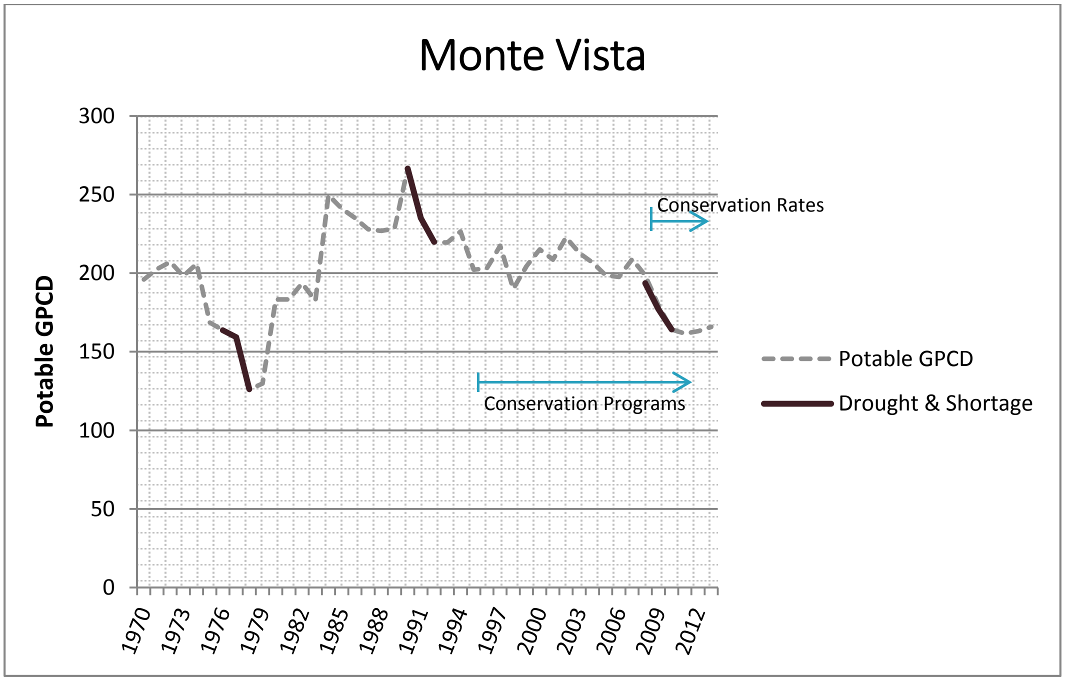


Figure 5. Monte Vista: GPCD, Drought and Shortage History (1970-2013)

After two successive very dry winters (2012-13 and 2013-14) followed by Governor Brown's call early in 2014 urging all Californians to reduce their water use by 20%, Monte Vista determined that its year-round best practices were sufficient to comply with state law. In other words, Monte Vista advised its customers to maintain their vigilant water practices, but did not ask its customers to reduce their use by some target percentage.

Between 2008 and 2010, per-capita potable demand dropped by roughly 17%. Some of this decline was probably a result of the worsening economy since demand continued to drop until 2012. However, if the focus is on assessing ability to curtail demand, distinguishing between the impact of mandatory restrictions and worsening economic conditions is not critical. Either way, it indicates that customers retain the ability to scale back demand when advised by their supplier to do so. Loss in business output probably influences overall indoor water use very little under the reasonable surmise that rising unemployment causes many indoor uses to merely shift from the CII sector to the residential sector. Bad economic conditions may cause both residential and CII customers to dial back irrigation as a way of trimming expenses, but mandatory restrictions would have had the same effect in the absence of bad economic conditions—either way one is capturing the ability to dial back irrigation. Only reduction in process water represents a pure economic effect that drought restrictions would not replicate. Process water, however, is a small fraction of total water demand, so inability to tease out this last component cannot introduce a large bias. This latest demand cutback of 17% compares favorably to what Monte Vista achieved during the two previous shortage episodes: (1) 23% reduction in per-capita production between 1976 and 1978; and (2) 17% reduction in per-capita production between 1990 and 1992. Monte Vista's performance in 2014 relative to 2013 is discussed later.

PETALUMA

During the study period, Petaluma has faced two significant shortage events, once during the drought of 1976-77 and the other during the drought of 2007-09 (Figure 6). The 6-year drought that began in 1987 and ended in 1992 did not lead to shortage declarations in Petaluma because Petaluma's wholesale water purveyor (Sonoma County Water Agency) undertook several capital improvement projects to augment its water supplies after the experience of 1976-77.

Petaluma faced very serious shortages in 1977 when its wholesale purveyor cut back Petaluma's supply by 90%. In response, Petaluma declared an emergency in early 1977 and adopted mandatory *rationing.*[21] A limit of 50 GPCD was placed on residential consumption. Business and industry was required to reduce its base (winter) use by 50%. *All* irrigation was prohibited, including hand watering. And, of course, the normal prohibitions on water waste that always apply in such situations, such as no car, driveway or sidewalk hosing, etc. also remained in place. The emergency was declared over during the following year. In contrast, only voluntary restrictions were announced in March 2009 to deal with the drought of 2007-09, and these too were lifted by October 2009.

However, after two very dry winters, 2012-13 and 2013-14, followed by Governor Brown's call early in 2014 urging all Californians to reduce their water use by 20%, Petaluma once again announced mandatory restrictions on water use in June 2014 as required by state law. Petaluma asked its customers to reduce demand by 20%, and also instituted mandatory restrictions that prohibit irrigation between 8 a.m. and 7 p.m., prohibit irrigation runoff and overspray, prohibit washing of sidewalks and other hardscape, and washing of cars unless the hose has a hose-end nozzle and shutoff. Utility staff enforces these regulations by issuing citations and levying fines on violators.

[21] City of Petaluma, *Drought Emergency Water Rationing Regulations (Ordinance #1233)*, February, 1977.

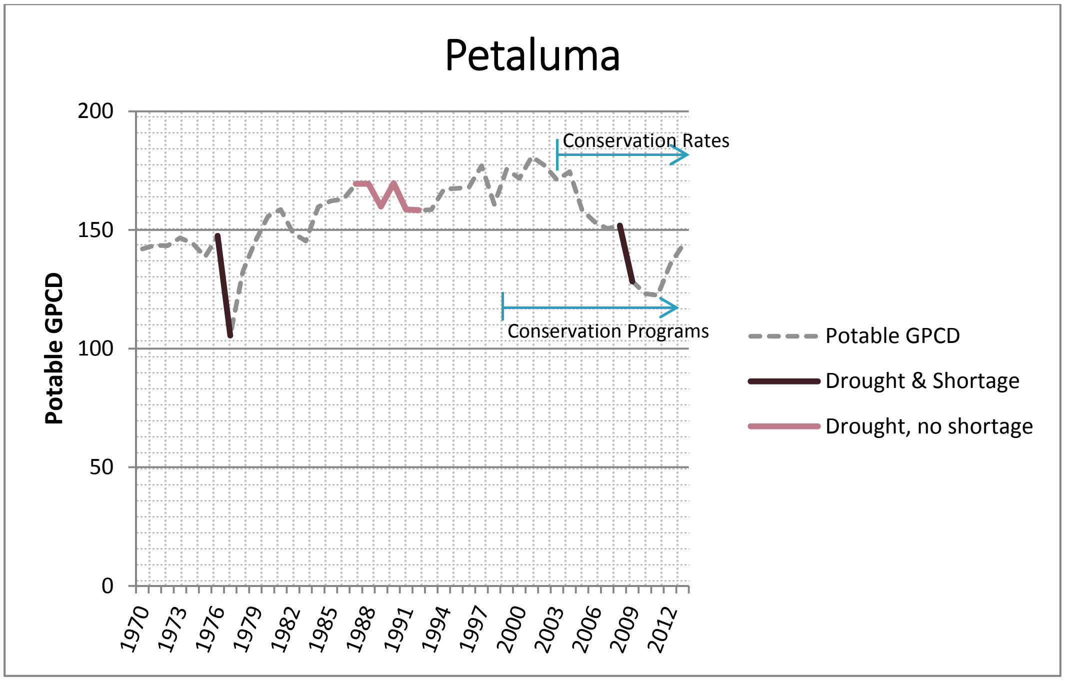


Figure 6. Petaluma: GPCD, Drought and Shortage History (1970-2013)

Petaluma began to undertake significant conservation in the form of retrofits and customer education in 1999, and adopted an inclining rate structure in 2003 for single-family customers. Since these steps were undertaken GPCD has started to trend down, whereas before 2003 it was trending up.

Petaluma successfully reduced its per-capita total demand by roughly 28% between 1976 and 1977 during the first shortage episode and by roughly 15% between 2008 and 2009 during the second such episode. Petaluma's performance in 2014 relative to 2013 is discussed later.

SAN ANTONIO

San Antonio has relied on the Edwards Aquifer for its water supply for over a century. Weather conditions can substantially influence this aquifer's yield. Although the drought of record in the Edwards Aquifer watershed occurred during the 1950s, well before the time frame of this study, San Antonio's concerns with shortages began in the early 1990s when Federal courts and the State legislature established limits on what San Antonio could pump from the Edwards Aquifer to protect endangered species also dependent upon said aquifer for their sustenance. There are periods when San Antonio's allocation from the aquifer exceeds its needs, but this allocation during severe dry years may be reduced up to 44% by the Edwards Aquifer Authority, the regulatory agency.

Water conservation was quickly identified as a cost-effective means for reducing demand and the associated risk of shortages, after limits were placed on San Antonio's draw from the Edwards Aquifer. San Antonio has had a 4-tier inclining rate structure since 1989 and began implementing several retrofit and education programs in 1994. Customer demand, in gallons per capita per day, has consistently declined since these measures went into effect (**Figure 7**). In addition, San Antonio has expanded its supply sources including recycled water, so that it is no longer solely dependent on Edwards Aquifer to meet its entire water demand as it was until the early 1990s.[22]

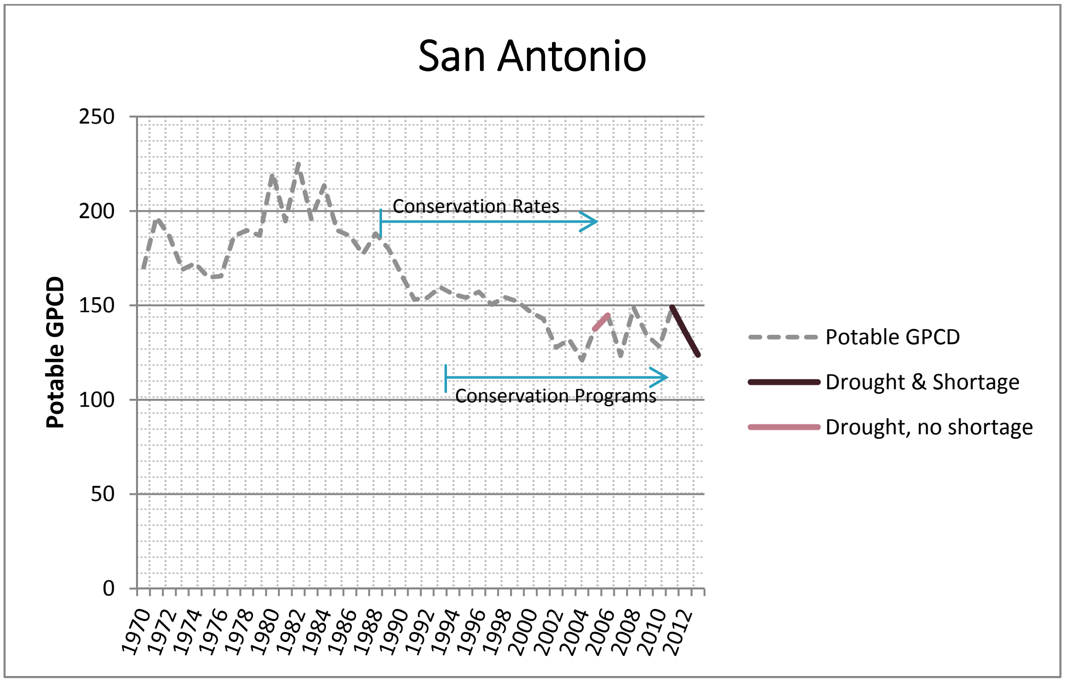


Figure 7. San Antonio: GPCD, Drought and Shortage History (1970-2013)

Drought restrictions in San Antonio are tied to water levels in the Edwards Aquifer, still the primary source of water. When drought restrictions are in effect, irrigation is limited to one day a week in Stages 1 and 2, and only one day every other week in Stages 3 and 4. Successive stages include additional provisions aimed at reducing water use, while general prohibitions against water waste apply year round. Only Stage 1 or 2 shortage declarations have been required thus far. San Antonio faced drier than normal conditions in 2005-06 without needing to resort to restrictions. However, drought restrictions were necessary to cope with the dry summer of 2009. And since 2011 until present time, Stage 2 drought restrictions have been continuously in effect, as San Antonio has faced weather conditions comparable to its drought of record which occurred during the 1950s.

San Antonio enforces its drought restrictions vigorously through its own staff and part-time police officers who are authorized to file municipal citations. Coordination with the police department and the municipal courts greatly deters noncompliance with drought restrictions.

[22] San Antonio Water System (SAWS), *Water 2012 Management Plan*.

Although San Antonio has a 4-stage scheme for declaring shortage severity similar to the one described at the beginning of this section, it is notably different in one important regard. Automatic irrigation is restricted to no more than one day a week right from Stage 1. It is a mandatory requirement. For the average water supplier this requirement usually kicks in at Stage 2 or 3. This has interesting implications for the main question that this study is wrestling with, the connection between water-use efficiency and demand hardening. We return to it later in the section.

Between 2011 and 2013, total potable per-capita production declined by roughly 17%. Preliminary evidence, discussed later, suggests it has continued to do so through 2014 in response to drought restrictions remaining in effect.

SANTA FE

Detailed water use data for Santa Fe are available only from 1995 when the City purchased its privately-owned water supplier from the Public Service Company of New Mexico (PNM), which at the time was a large electric, gas and water utility. While it was possible to obtain historical production data from the water utility's data archives and from the New Mexico Office of the State Engineer to develop long-term GPCD trends, much of the pre-1995 institutional memory has been lost. For example, it appears as if a severe shortage occurred in Santa Fe during the mid-1970s. But we were unable to find documentation detailing what happened, what steps PNM took or how Santa Fe coped. For this report, we therefore ignore this earlier shortage episode.

During more recent times Santa Fe has faced two drought-related shortage episodes—one in 1996 and the other that began in 2000 and continued until 2006.[23] The drought of 1996 was preceded by many wet years in the Santa Fe river basin (**Figure 8**). In 1996, customers were asked to reduce their demand by 25% over the previous year. Irrigation during daylight hours was prohibited and restricted to no more than three days a week. These restrictions were enforced through penalties and fines. Drought surcharges were also levied. Most of the emphasis of the restrictions was on outdoor use. Indoor rationing was not undertaken. We characterize this as a "mandatory restrictions" shortage episode.

[23] City of Santa Fe, *Water Conservation and Drought Management Plan*, 2010.

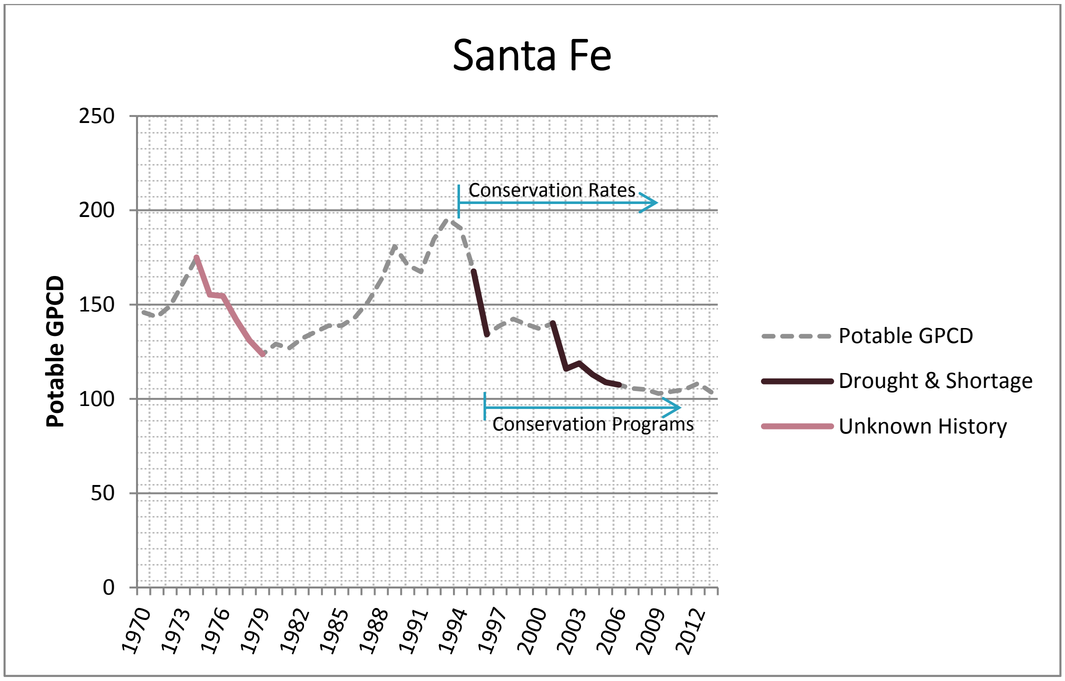


Figure 8. Santa Fe: GPCD, Drought and Shortage History (1970-2013)

To prevent per-capita demand from once again rising after the drought restrictions were lifted, the City adopted an ordinance (Comprehensive Water Conservation Requirements Ordinance) in 1997. This ordinance includes many mandatory requirements and has been amended over time. But the key point is that it applies year round. Specific recommendations are that irrigation be limited to no more than 3 times a week and prohibited during daylight hours; requires elimination of runoff and others forms of water waste; and requires all CII customers to retrofit their inefficient plumbing fixtures with the latest efficient kind by the end of 2002. This ordinance has allowed the City to maintain the lower GPCD levels achieved by 1996 through short-term drought restrictions.

Drought conditions returned to Santa Fe in 2000 prompting new voluntary restrictions. As supply conditions worsened, these voluntary restrictions were converted into mandatory restrictions in 2002. Enforced via penalties and fines, per-capita demand once again began to trend downward. Drought surcharges were also levied. Irrigation was restricted to no more than once per week through the middle of 2003. After this time irrigation restrictions were relaxed to no more than three times a week. These drought surcharges and restrictions remained in place until 2006. Once again, Santa Fe has been able to prevent a rebound in per-capita demand by engaging in comprehensive conservation through both ordinances and retrofit programs; by switching to recycled water for large landscape irrigation in public places; and most notably, by initiating a conservation offsets program in 2003 for new construction. As a result of substantially lowering its per-capita demand, and also by augmenting and diversifying its supplies, Santa Fe was able to cope with 2011, one of the driest years on record in the Santa Fe river basin, without having to impose drought restrictions on its customers.

Santa Fe modified its emergency shortage regulations in 2006, condensing its original 4-stage shortage declaration plan into a 2-stage plan. The original plan resembled to a great extent the generic plan that this section described at the beginning. However, Santa Fe now declares an "orange" alert when demand needs to be scaled back by up to 20%. This requires residential customers to reduce irrigation to no more than two days a week instead of what is normally recommended by the City to its customers (no more than three days a week). If more than a 20% cutback is necessary, a "red" alert is issued which outright prohibits all residential irrigation. This is an interesting development with considerable bearing on the question about demand hardening, to which we return later in this section.

Santa Fe reduced its per-capita demand by roughly 20% between 1995 and 1996 during the first shortage episode and by roughly 23% between 2001 and 2006 during the second episode.

SANTA ROSA

During the study period, Santa Rosa faced two significant shortage events, once during the drought of 1976-77 and the other during the drought of 2007-09 (**Figure 9**). The 6-year drought that began in 1987 and ended in 1992 did not lead to shortage declarations in Santa Rosa because its wholesale water purveyor (Sonoma County Water Agency) undertook several capital improvement projects to augment its water supplies after the experience of 1976-77.

Santa Rosa faced a serious shortage in 1977 and as a result asked its customers to reduce their demand by 30%. While Santa Rosa did not adopt mandatory rationing like Petaluma, the documentation remains somewhat ambiguous about how to characterize Santa Rosa's approach—voluntary or mandatory restrictions.[24] Given the drought's severity in 1976-77, the intense statewide messaging that followed, and the example of many of Santa Rosa's neighbors (City of Petaluma, Marin Municipal Water District) in moving toward mandatory rationing, it is reasonable to surmise that Santa Rosa residents had very strong incentives to conserve even though, strictly speaking, the water supplier may only have requested voluntary restrictions. Given the milieu of the times, it is most appropriate to characterize this period as a "mandatory restrictions" shortage episode. The emergency response was declared over during the following year. In contrast, only voluntary restrictions were requested to deal with the drought of 2007-09. In May of 2007, Santa Rosa adopted a resolution requesting a community-wide reduction of 15% in water use. In March of 2009, Santa Rosa declared a Stage 1 shortage per its shortage contingency plan. These voluntary restrictions were lifted by October 2009.

However, after two very dry winters during 2012-13 and 2013-14, followed by Governor Brown's call early in 2014 urging all Californians to reduce their water use by 20%, Santa Rosa requested a voluntary 20% community-wide reduction in February 2014. It then adopted Stage 1-Mandatory 20% community-wide reduction in August 2014. These mandatory restrictions prohibit the following: irrigation between 6 a.m. and 8 p.m.; irrigation runoff and overspray; washing of sidewalks and other hardscape and washing of cars unless the hose has an auto shut-off hose-end nozzle; the serving of water in restaurant unless requested; and wasting water. Utility staff enforces these regulations by issuing citations to violators.

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[24] Sonoma County Water Agency, *Urban Water Management Plan*, 1985.

Santa Rosa began to undertake significant conservation in the form of retrofits and customer education in 1992. It also adopted an inclining rate structure that took effect in January 2007 for single-family residential and dedicated irrigation customers. Since these steps were undertaken GPCD has steadily trended down.

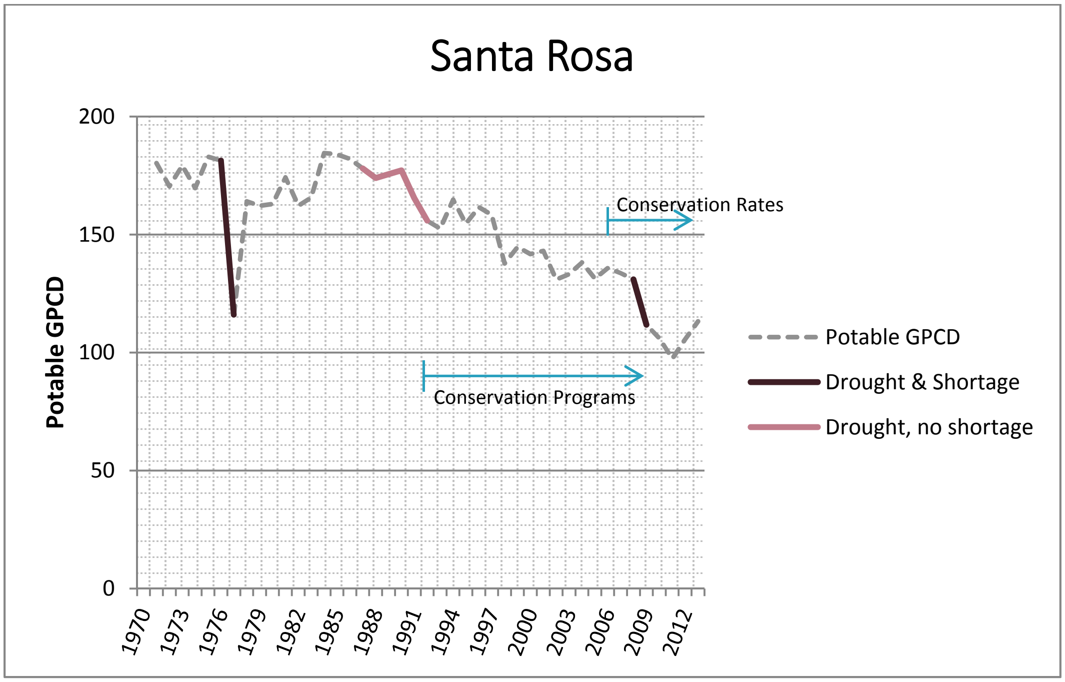

Figure 9. Santa Rosa: GPCD, Drought and Shortage History (1970-2013)

Santa Rosa reduced per-capita demand by roughly 36% between 1976 and 1977 (the first shortage episode) and by roughly 15% between 2008 and 2009 (the second episode). Some of the decline in demand during the second episode probably captures the effects of the recession since water demand continued to drop until 2011. As mentioned earlier the distinction between the drought's and the recession's impact is not so critical if the focus is on evaluating the ability rather than the willingness to save during shortages. Either way, it indicates that customers retain the ability to scale back demand when advised by their supplier to do so. Loss in business output possibly influences overall indoor water use very little under the reasonable surmise that rising unemployment causes many indoor uses to merely shift from the CII sector to the residential sector. Bad economic conditions may cause both residential and CII accounts to reduce irrigation as a way of trimming expenses, but mandatory restrictions would have had the same effect in the absence of bad economic conditions—either way one is capturing the ability to reduce irrigation. Only reduction in process water represents a pure economic effect that drought restrictions would not replicate. Process water, however, is a small fraction of total water demand, so inability to tease out this last component cannot introduce a large bias. Santa Rosa's performance in 2014 relative to 2013 is discussed later.

ANALYSIS OF PRIOR SHORTAGE EVENTS

Table 3 assembles water savings achieved by each case study during their prior shortage episodes, overall and by customer class, in cases where the latter data were available (which they generally were not for the earlier episodes). Recycled water is excluded from these analyses since it is generally seen as a "drought proof" supply. What can we learn from these data?

Table 3. Demand Reductions Achieved During Previous Shortages

Supplier & Comparison Years	Change in Potable GPCD				Type of Shortage Declared
	Total	Single Family	Multi Family	CII & Large Landscape	
Boulder					
2001-2003	-18%	-20%	-17%	-17%	Mandatory Restrictions
Irvine Ranch					
1976-1977	-14%				Voluntary Restrictions
1990-1992	-29%	-25%	-24%	-30%	Mandatory Restrictions
Monte Vista					
1976-1978	-23%				Unclear
1990-1992	-18%				Unclear
2008-2010	-17%	-10%	-8%	-31%	Mandatory Restrictions
Petaluma					
1976-1977	-28%				Mandatory *Rationing*
2008-2009	-15%	-19%	-5%	-12%	Voluntary Restrictions
San Antonio					
2011-2013	-17%	-21%	-9%	-13%	Mandatory Restrictions
Santa Fe					
1995-1996	-20%				Mandatory Restrictions
2001-2006	-23%	-16%	---[1]	-32%	Mandatory Restrictions
Santa Rosa					
1976-1977	-36%				Mandatory Restrictions
2008-2009	-15%	-15%	-5%	-19%	Voluntary Restrictions

[1]Santa Fe had no multifamily classification in 2001 and very few such accounts even in 2006. These have been rolled into the single-family sector.

The data in Table 3 lend themselves to several observations. In general, voluntary restrictions seem to be associated with a lower level of total savings compared to mandatory restrictions, not surprising since performance is often driven by how high one sets the bar.[25] Shortage episodes involving mandatory restrictions are in some ways more useful to look at because the stakes are higher. Do the data offer evidence that falling GPCD due to investments in water-use efficiency are indicative of less ability to save during periods of mandatory restrictions? **Figure 10** plots total consumption in gallons per capita per day in the year just before mandatory restrictions were declared against savings that resulted from those restrictions. Figure 10 combines information from Figures 3 through 9 and Table 3.

[25] This general observation also matches with what others have concluded. See, for example, Kenney, D. S. et al., "Use and Effectiveness of Municipal Water Restrictions During Drought in Colorado," *Journal of the American Water Resources Association*, Vol. 40, No. 1, 2004, pp. 77-87.

There is no compelling pattern to these data, and what little pattern there is suggests that in fact savings were greater in those episodes where GPCD was already lower to begin with. This counterintuitive finding probably does not mean that adapting to shortages becomes easier with rising water-use efficiency, but that with the application of sufficient enforcement vigor—the key unobserved yet critical factor in our analysis—substantial demand reductions can still be achieved in spite of low per-capita demand. A clue to this hypothesis is offered by the position of Petaluma and Santa Rosa in Figure 10. During the shortage episode of 1976-77 Petaluma imposed mandatory indoor rationing and prohibited all irrigation. Of all the episodes shown in Figure 10 this probably marks the case where pressure to curtail demand was at its greatest. Santa Rosa's residents probably felt pressure to conserve (even though their supplier did not impose rationing), being aware that neighboring water districts such as the City of Petaluma and the Marin Municipal Water District had both imposed rationing. So perhaps it is unsurprising that Petaluma achieved the greatest savings when compared to other similar episodes within its GPCD band and Santa Rosa leads in the higher GPCD band.

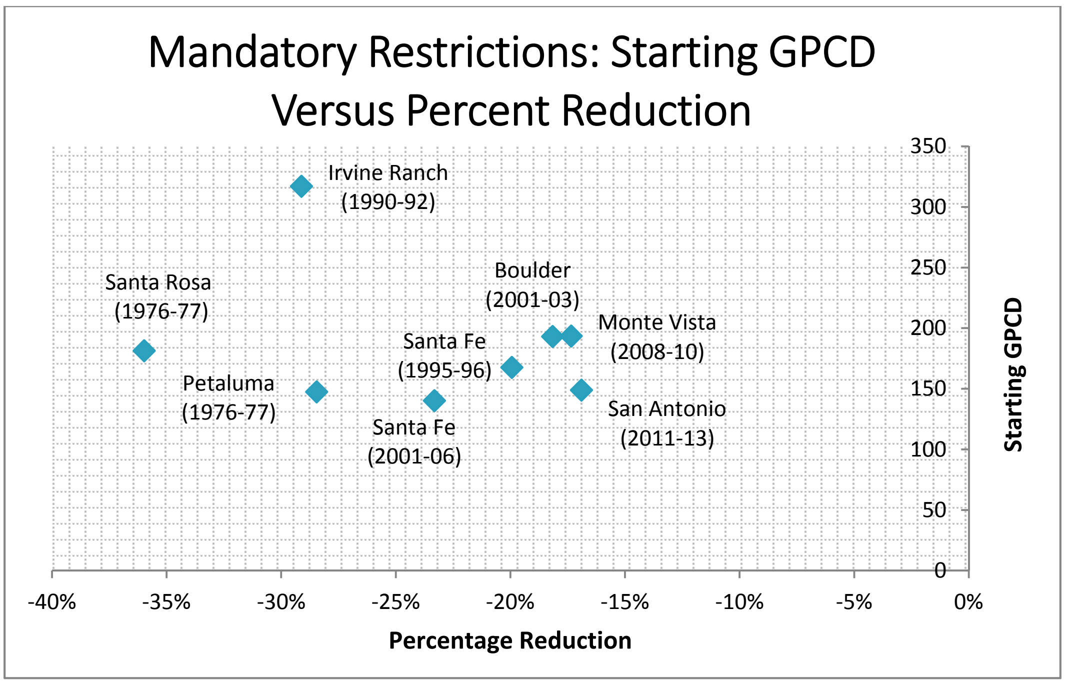

Figure 10. Starting GPCD versus Percentage Reduction in Demand

Given that shortage episodes are infrequent, it is difficult to observe back-to-back events within the same service area to evaluate evidence for and against demand hardening. Apart from the evidence offered in Figure 10 two granular comparisons, however, are noteworthy. The first occurs in Santa Fe, where, in fact, two back-to-back shortage events took place both involving mandatory restrictions. Evidence shows that Santa Fe was able to cut back its demand almost a little more during the later (2002-2006) shortage episode than the earlier (1996) one. Another noteworthy comparison is between Petaluma and Santa Rosa because they purchase water from the same wholesaler and are thus subject to similar drought messaging. In 1977, Santa Rosa was able to save more water without resorting to rationing because its GPCD was significantly higher than Petaluma's indicating Santa Rosa had much higher outdoor use, therefore, greater room to cut quickly when needed. By 2009, the tables had turned and Santa Rosa's GPCD was lower than Petaluma's because of steady investments in water-use efficiency (Figures 6 and 9). Nonetheless, both were able to scale back demand by about the same percentage (15%) in response to the 2009 drought via voluntary restrictions. Overall, then, it appears that customer response to an emergency is driven by the perceived severity of the emergency itself and steps taken by a supplier to enforce restrictions on water use. For example, customers served by the Marin Municipal Water District (MMWD), one of the worst affected water suppliers during the California drought of 1976-77, reduced their demand by 52% between 1976 and 1977 in response to mandatory rationing. This is particularly notable because MMWD's per-capita demand was only 126 GPCD in 1976.[26]

Examining variation in how different customer classes respond to shortages, the data do seem to support anecdotal reports that multifamily customers often do not comply with shortage restrictions as diligently as others because residents do not receive a bill based on their own metered use. The CII and large landscape sector taken together, however, appear to be roughly as responsive as the single-family sector except in Monte Vista during the 2008-10 episode, and in Santa Fe during the 2001-06 episode, where they appear to be more responsive. This is because in both instances large landscapes were specifically targeted for irrigation cuts. Monte Vista's mandatory restrictions required large landscape accounts to reduce their irrigation by 25% relative to the previous year, whereas Santa Fe switched most of its public landscapes to recycled water. Irvine's water budgets also appear to have had a significant impact on large landscapes, but not completely out of line with the impact of budget-based rates on the other two sectors (budget-based rates were implemented simultaneously for all customer classes). CII and large landscape sectors are lumped together to maintain a tighter apples-to-apples comparison across different shortage episodes over time. Many large landscape accounts with dedicated meters today were probably supplied by mixed use CII meters in the past.

Finally, there is the issue of post-drought demand rebound. By and large, plumbing codes, active retrofit programs, and conservations rates were mostly unheard of during the 1970s and 1980s. Shortage episodes occurring during that era clearly show demand rebounding to almost pre-drought levels as short-term conserving behavior reverted to the then long-run norm. However, demand rebound is not as pronounced, and in some cases entirely absent, for shortage events that occur during the 1990s and later. Availability of constantly improving water-efficient plumbing fixtures and appliances since 1992, and availability of incentives to finance retrofits, has meant that periods of shortage are opportune moments to drive the uptake of these efficient fixtures and appliances. Savings associated with these retrofits remain locked in place even after the shortage event has passed. Suppliers can influence the level of rebound considerably as the example of Santa Fe shows. To improve supply reliability, Santa Fe has had a goal of driving demand under 110 GPCD. After both shortage events analyzed here, it put into place conservation programs and policies precisely to prevent demand from rebounding. So demand rebound is another outcome that suppliers can greatly influence.

[26] California Department of Water Resources, *The 1976-1977 California Drought: A Review*, May 1978.

IMPLICATIONS FOR DEALING WITH FUTURE SHORTAGES

THE IMPACT OF FALLING GPCD ON WATER SHORTAGE CONTINGENCY PLANS

Analysis of prior shortage episodes is unable to offer compelling evidence in favor of demand hardening. Even low GPCD suppliers can cause demand to adjust downward with sufficient restrictions and enforcement. Does this mean that water suppliers have nothing to worry about and can continue to plan for shortages like they have done in the past? Well, probably not, as the analysis below attempts to show.

Table 4 shows the residential share of total potable production expressed in terms of GPCD for each of the seven case studies in 2013, the latest full year of data available. This is derived by estimating the share of total billed consumption accounted for by the single and multifamily sectors, then applying this ratio to total potable production. These estimates of residential GPCD therefore include both indoor and outdoor usage, as well as proportionally allocated non-revenue water. In 2013, residential customers in Santa Fe used the least amount of water, while Monte Vista used the most. From the high-efficiency new single-family homes study (DeOreo, 2011) we have an estimate of how low indoor usage could be with today's technology in homes fully outfitted with WaterSense®-endorsed plumbing fixtures and appliances. This is estimated to be roughly 40 GPCD (derived by taking metered usage from abovementioned study, 36 GPCD, and bumping it up by a guesstimated 10% to account for non-revenue water). The gap between what residential customers are using at present and what they could get by with in a fully efficient home where all outdoor use had been prohibited because of an emergency gives us a sense for how much demand can be cut in an emergency. So, for example, in theory Santa Fe could cut its residential demand roughly 44% by going from 72 GPCD to 40 GPCD, and Monte Vista could cut its residential demand 65% by going from 116 GPCD to 40 GPCD, and so on. This is assuming no change in indoor water-using behavior during the emergency. Higher cuts could be obtained if one factors in short-term behavioral adjustment, such as fewer flushes and fewer wash loads per capita, etc.

Table 4. Evaluating Stages of a Shortage Contingency Plan

Case Study	2013 Residential GPCD	WaterSense® Efficient Indoor Residential Use (GPCD)	Current Likely Indoor Residential Use (GPCD)	Outdoor Use as a Percentage of current GPCD
Boulder	84			29%
Irvine Ranch	94			36%
Monte Vista	116			48%
Petaluma	99	40	60	39%
San Antonio‡	89			33%
Santa Fe	72			17%
Santa Rosa	83			28%

‡Mandatory restrictions in effect in 2013.

At an abstract level the above argument may be correct, but it says little about timing (how soon can a supplier reduce its demand?) and what steps would it need to take to reduce its demand (how should a supplier structure its emergency regulations/drought restrictions and then enforce them?). While the above examples indicate ample scope for significant further reductions in per-capita use, increasing the penetration of WaterSense® fixtures and appliances is a multi-year process. To deal with emergent shortages suppliers have to react fast. When a supplier determines that a shortage is imminent, irrigation is usually the first item to be restricted. But, the impact of these irrigation restrictions can vary significantly across suppliers. To illustrate this point, let us assume that residential indoor use was roughly 60 GPCD[27] in 2013 for all case studies until better information becomes available. Table 4 shows that prohibiting residential irrigation completely will likely generate very different levels of savings for different suppliers. For example, Santa Fe's residential customers could save up to 17% while Monte Vista's could save up to 48%. This disparity does not mean that Santa Fe cannot adapt to a contingency that requires demand to be curtailed, say, by 30%. The difference is that a supplier such as Monte Vista could rely entirely on irrigation cuts to deal with a 30% shortage, whereas Santa Fe would have to impose restrictions on indoor water using behavior, or promote rapid retrofits, or some combination. In other words, in this hypothetical example both Monte Vista and Santa Fe retain the "ability" to reduce their demand by 30%, but how they go about it would have to be different. Monte Vista could follow the traditional approach of limiting irrigation to some number of days a week. Santa Fe would have to prohibit irrigation almost immediately, something that traditional drought emergency plans would not consider until Stage 4. Similarly, Santa Fe would have to find ways to rapidly alter indoor water-using behavior through rationing, requiring the setup of equitable water budgets tied to inclining rates or surcharges much sooner—in the past such steps would have been postponed until a Stage 3 shortage declaration.

The above discussion is meant to illustrate that while investments in water-use efficiency do not necessarily limit a water supplier's ability to respond to shortage emergencies, the configuration of shortage contingency plans do depend in part on per-capita demand. *As per-capita demand falls* ***because***

[27] DeOreo, W. B., *California Single-Family Water Use Efficiency Study*, 2011, prepared for the California Department of Water Resources. The indoor per-capita consumption estimate from this study was bumped up 10% to account for non-revenue water.

of investments in water-use efficiency, it becomes necessary for suppliers to fast forward to steps that normally would have been taken later in the more traditionally configured shortage plans. Water suppliers are, of course, figuring this out for themselves. For example, Santa Fe's emergency water regulations only include two stages ("orange alert" or "red alert") with the second stage kicking in if demand needs to be cut by more than 20%. The second stage immediately prohibits all residential irrigation, a policy that seems well grounded in Table 4's data.

San Antonio's drought restrictions limit automatic irrigation to one day a week as soon as a Stage 1 shortage is declared, not a feature generally found in the more traditionally configured shortage plans (although drip and manual irrigation with hose is permitted on any day in Stages 1 and 2). San Antonio has discovered a great disparity in water use between older homes without automatic irrigation systems and new ones that do have such systems. Their drought restrictions are configured in a way to curtail wasteful irrigation associated with automatic irrigation. Total per-capita demand in 2013 was 17% below 2011's (Table 4). The bulk of these savings likely result from irrigation restrictions. However, Table 4 suggests that almost a third of residential demand probably is still devoted to outdoor use (assuming our indoor GPCD estimate is reasonably correct), so there is additional room to cut irrigation in case conditions turn more severe.

Santa Rosa's emergency regulations, from Stage 2 onward, begin water rationing via budgets tied to rates, also requiring new construction to meet their projected demand through conservation offsets. Irvine Ranch has relied on water budgets tied to rates for curtailing demand during emergencies from the get go. These budget based approaches offer a great deal of flexibility for signaling the level of cuts a supplier wants its customers to make.

DESIGNING APPROPRIATE WATER SHORTAGE CONTINGENCY PLANS

There are many guidelines available for designing water shortage contingency plans, such as the American Water Works Association's drought preparedness manual[28] or the California Department of Water Resources 2008 *Urban Drought Guidebook* (*op cit.*). Real world examples are discussed in a separate report published by the Alliance for Water Efficiency.[29] While all these information sources are valuable, the key point that emerges from the research presented in this study is that a generic 4-stage contingency plan may not always be appropriate for a water supplier. Suppliers need to tailor their contingency plans to how water is being used in their service area and to revise these plans as customers become more efficient. These plans also need to reflect customer preferences about how to respond to shortages. In some areas customers may prefer to entirely rely on irrigation cuts rather than change their indoor water-using behavior during shortages. In other areas, customers may prefer a more balanced approach between indoor and outdoor cuts. Without a lot more data about how water is being used in a service area, and information about customer preferences regarding alternative drought shortage plans, it is difficult to provide water suppliers a detailed template to follow. The previous subsection is only meant to offer a conceptual framework for how to think about the issues.

[28] American Water Works Association, *Drought Preparedness and Response Manual, M60*, 2011.
[29] Alliance for Water Efficiency, *Considerations for Drought Planning in a Changing World*, 2014.

The water shortage contingency plans followed by our case studies differ considerably relative to the generic 4-stage plan described at the beginning of this section. There is much that can be learned from their example. As water suppliers continue to invest in water-use efficiency and GPCD continues to drop, perhaps the experience of these seven case studies can offer useful lessons for how to refine contingency plans over time. A summary of each case study's philosophical approach and contingency plan's distinctive features is offered below. Appendix C includes hyperlinks to original documents to facilitate deeper reviews.

- Boulder's contingency plan relies on water budgets tied to rates and surcharges to adapt to shortages in the future. The water budget becomes progressively smaller as the severity of the imminent shortage increases. Boulder's shortage contingency plan explicitly calls out for periodic reexamination and adjustment of these budgets to reflect changing water use patterns among its customers.
- Irvine Ranch's contingency plan from the beginning has relied on water budgets tied to rates, both to improve year-round water-use efficiency as well as to signal customers how much they need to cut their water demand during and prior to an imminent shortage.
- Monte Vista's plan is closest to a traditional contingency plan with high reliance on progressively more stringent restrictions on outdoor use as expected shortage severity rises.
- Petaluma's contingency plan includes both traditional and novel elements. As expected, the plan proscribes more and more outdoor water uses as the expected severity of a shortage rises. However, it also lays out demand reduction goals at each stage that its customers must meet in any way they see fit, to be enforced by bill analysis compared to the previous year. Thus, customers have some flexibility in how they choose to reduce their demand in case large reductions are required (water budget-based approaches also permit this flexibility).
- San Antonio's contingency plan relies largely on outdoor water use restrictions of increasing intensity to curtail demand depending upon shortage severity. A notable feature is that automatically-controlled irrigation is reduced to no more than one day a week right from a Stage 1 shortage declaration.
- Santa Fe's contingency plan is unique insofar it only includes two stages. The second stage kicks in if a shortage of 20% or more is expected, which immediately triggers a complete ban on residential irrigation.
- Santa Rosa's contingency plan relies on prescriptive measures targeting outdoor use to deal with mild shortages, but then transitions to water budgets tied to rates and surcharges to signal and enforce larger demand cutbacks. Provisions for offsetting new demand are also included in Stages 2-4 of the shortage contingency plan.

WHAT CAN WE LEARN FROM 2014?

During 2014 all the California case studies imposed restrictions on water use, but they did it in different ways. Petaluma and Santa Rosa announced mandatory restrictions when none existed in 2013, both asking their customers to cut demand by 20%. In other words, both Santa Rosa and Petaluma asked their customers to achieve a clearly stated numerical goal.

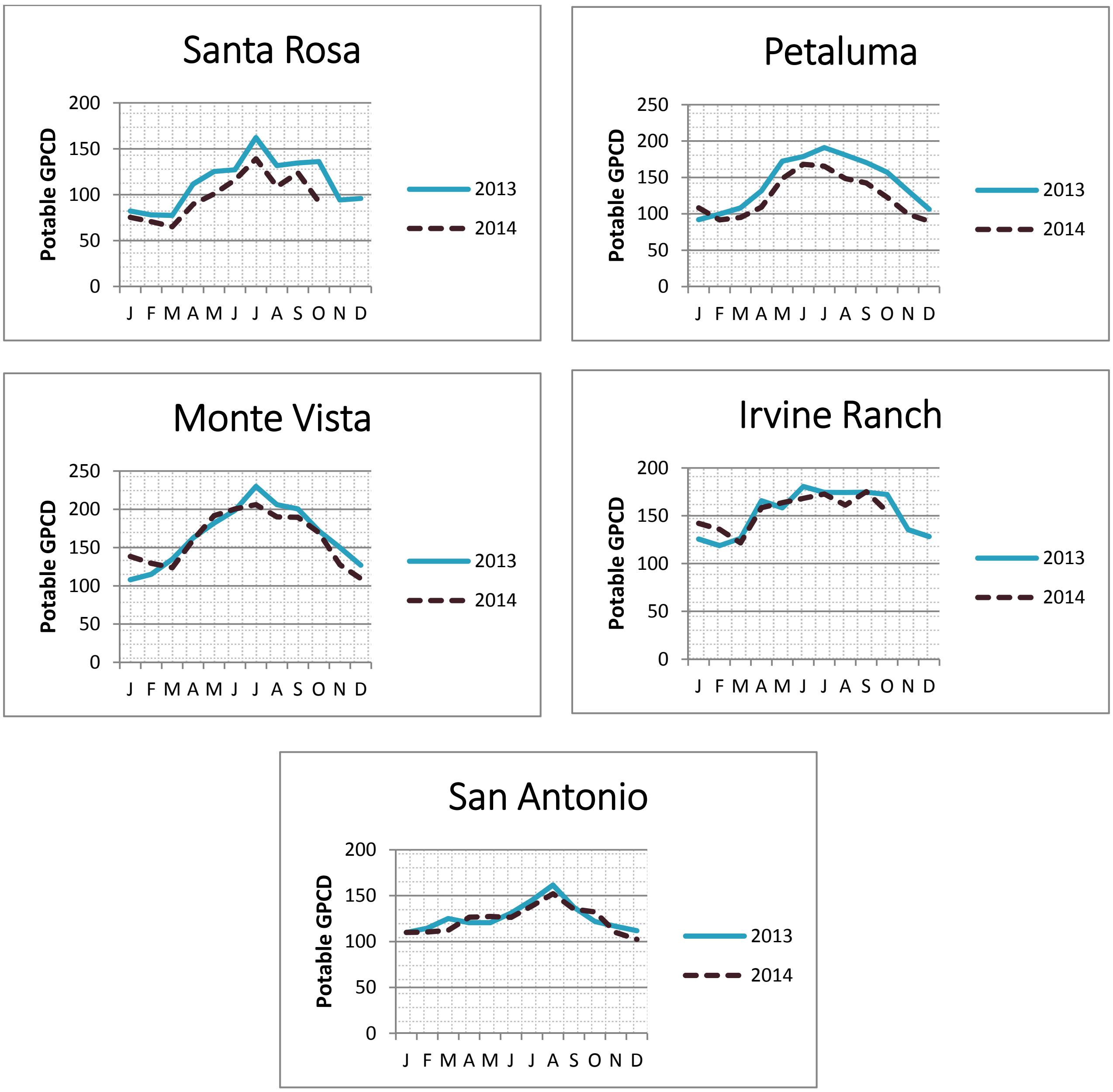

Figure 11. Impact of 2014 Restrictions

Irvine Ranch reduced water budgets for its residential customers to signal that customers needed to scale back their demand. Monte Vista determined that their budget-based rate structure and year-round outdoor "best practices," respectively were sufficient to meet the statewide emergency first declared by Governor Brown in January 2014, then followed up with mandatory restrictions in July 2014. San Antonio has been under drought restrictions continuously since 2011.

Comparisons across these five case studies once again show that customers retain the ability to make significant cuts in demand when given clear instructions by their water supplier to do so. San Antonio customers were able to reduce their summer demand some more in 2014 relative to 2013 continuing a trend that began in 2011 when drought restrictions first went into effect. It is too soon to tell how these agencies will perform going forward. Figure 11 only provides an early glimpse (based on available 2014 data) into how each agency's strategy will fare. But, the early evidence suggests that customers can and do respond to shortage conditions, even in areas that have made a long-term commitment to improving water-use efficiency. The key remains clear communication of expectations followed by vigorous enforcement.

MANAGING WILLINGNESS TO CONSERVE IS THE KEY

The analyses presented thus far show that in spite of rapid improvements in water-use efficiency, ample ability still exists to adapt to shortages. The key is managing willingness. Previous opinion polls conducted in San Diego and San Antonio (*op cit.*) indicate that residential customers would rather deal with the inconvenience of an occasional shortage than pay high water bills regularly. So, in a sense the willingness is already there. But, the level of shortage risk that is acceptable may differ from area to area, so suppliers first have to determine that, and then also determine where customers would prefer to make the most adjustments during a shortage. It then becomes a matter of configuring a set of tools that incentivize customers to follow through behaviorally. When these tools are not properly configured, failure is blamed on the pursuit of water-use efficiency. But this is misplaced. After all, many areas have successfully increased their supply reliability and long-term sustainability by investing in conservation and banking a significant portion of the resultant savings through aquifer storage and recovery programs. This has allowed them to get through dry times much better now without having to declare shortages (e.g., Boulder in 2012; Irvine Ranch in 2009 and 2014; Santa Fe in 2011; San Antonio in 2005-06). Although this paper only explores customer ability and willingness to engage in frugality when faced with an imminent shortage, the other element—the risk of shortage itself—should not be forgotten, which probably has dropped with rising water-use efficiency. Water suppliers are leery as they should be of becoming excessively dependent upon mandatory restrictions to bridge supply/demand gaps. Mandatory restrictions are disruptive and expensive to enforce. As a result suppliers already have incentives to use a significant portion of conserved water to improve system reliability, in turn making the demand hardening issue somewhat less salient.

Cutting outdoor water use broadly, specifically irrigation use, will remain the first priority for adapting to imminent shortages. Water suppliers in the past have relied either on time-of-day or day-of-week restrictions, or water budgets tied to steeply inclining rates to bring about a reduction in outdoor water demand. These strategies will remain salient, but as irrigation becomes a smaller component of total demand on account of drought-tolerant landscapes becoming more prevalent, emergency water regulations will need to target indoor water use much sooner in a drought cycle than in the past, which is where budget-based approaches become more attractive. Water suppliers also implement conservation programs aimed at promoting drought-tolerant plant species in landscapes. While drought-tolerant landscapes are often marketed on the basis of their year-round lower water use, perhaps not enough attention is paid to educating customers about how to operate such a landscape in deficit or survival mode (Harivandi et al., 2009 *op cit.*). In fact, willingness to cut irrigation during shortage periods could markedly improve if customers understood that an important virtue of drought-tolerant plant species is not simply their lower year-round use, but their ability to go dormant without dying when irrigation is steeply cut.[30] For example, irrigation can be cut by up to 80% in the case of warm-season turf grasses without compromising their ability to revive upon the resumption of normal irrigation.

It is also important that suppliers think in terms of customer class while analyzing their shortage plans. For example, data presented earlier and anecdotal evidence suggests that multifamily customers do not comply with shortage restrictions as well as single-family customers. Suppliers can consider many options for improving compliance in the multifamily sector. This includes promoting submetering in new apartment buildings. Retrofitting old apartment buildings with submeters is probably still too expensive,[31] although submetering technology continues to improve and retrofits may become cost-effective in the future. Suppliers can also require that landscapes in large multifamily complexes and homeowner associations be placed on dedicated meters, and proscribe building owners from transferring irrigation costs to renters as direct passthroughs. These measures would considerably align incentives between the water supplier, building owners and tenants, during normal times and especially during shortages. Assigning water budgets to all large landscape accounts, coupled with automated metering infrastructure at least for these accounts can help to improve compliance with shortage regulations applicable to this customer class.

The CII sector also deserves careful scrutiny. Water shortages in the CII sector can cause business output to decline, so it is quite possible that CII customers may have a lower tolerance for shortage risks.[32] They may in fact be willing to pay more to drought-proof their water supply, for example, by placing more of their indoor end uses on recycled water and possibly by engaging in on-site process water recycling.[33] Other regulatory constraints, such as the ones imposed by the Clean Water Act on effluent discharges, have for many decades caused industry to engage in greater on-site recycling anyway. As a result, freshwater withdrawal necessary per unit of gross domestic product continues to decline (Figure 1). As was pointed out in the introductory section, promoting recycled water involves little risk of demand

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[30] Albuquerque Bernalillo County Water Utility Authority appears to be an exception in this regard. Customers are offered a $20 incentive if they take a course geared towards imparting knowledge about landscape care during droughts. Additional details can be found in their strategy document entitled, *Water Resources Management Strategy Implementation: Drought Management Strategy, 2012*.

[31] Bamezai, A., *Submetering of Multi-Family Residential Properties*, 2006, a Potential Best Management Practices report prepared for the California Urban Water Conservation Council.

[32] California Department of Water Resources, 1978 *op cit.* This report cites results from a survey of industries conducted during this episode where 79% reported being able to reduce water demand by 25% without any impact on business output. This estimate is probably dated, but indicates the kind of information that suppliers need to develop to put their shortage plans on a sound footing.

[33] Wade, W., Hewitt, J. and M. Nussbaum, *Cost of Industrial Water Shortages*, 1991, a report prepared for the California Urban Water Agencies.

hardening until the fraction of sewer flows being recycled reaches such high levels that sewer flow reductions during periods of extended shortage begin to influence availability of recycled water. Water shortage contingency plans need to adequately take these factors into account. Several of the case studies are already promoting recycled water aggressively, and at least two (Irvine Ranch and Santa Rosa) have had difficulty meeting their recycled water goals because of reduced sewer flows during the latest California drought.

4. SINGLE FAMILY TELEPHONE SURVEY

A plan to deal with shortages must successfully combine several elements. First, water suppliers must have a good understanding of their customers' appetite for shortage risk. Without this understanding, it is difficult to develop a long-term water supply plan that balances cost with shortage risk. Second, suppliers must have water shortage contingency plans configured in a way that is consistent with both per-capita demand and with customer preferences about the order in which end uses should be targeted for cuts. Third, suppliers must have a good communication and enforcement strategy to unambiguously signal their expectations, which could include an explicit statement about the sought after percentage reduction goal, but even without such a statement suppliers need to set clear expectations about what they want their customers to do in response.

The telephone survey implemented under the auspices of this study attempts to get at some of these issues. As mentioned earlier, it is limited to single-family customers because of budget constraints. The survey enquires into actions respondents took to adapt to the latest drought, as well as what actions they would be willing to take during a new shortage episode. The survey includes questions aimed at assessing attitudes toward shortage risk. Some questions examine how best to communicate with customers during droughts.

TELEPHONE SURVEY METHODOLOGY

In each of the seven case studies it was necessary to target only those customers that actually were living in the area prior to the onset of the latest shortage event. The screening criterion therefore had to be different across case studies. The potential pool of respondents was identified by the account set up date. Only those single-family customers that had set up new accounts two years or earlier before the onset of the latest drought were allowed into the potential pool of respondents. Properties where the mailing address did not match the street address were also screened out under the surmise that residents at such properties probably were not paying their water bill. Accounts without telephone contact information were excluded as well. From this screened pool a subset was randomly drawn for the telephone survey, with the aim of completing 100 surveys per case study. Another set of 200 customers per case study was also randomly selected from this screened pool to serve as a validation group. Water use histories of the validation group and telephone survey respondents were compared to assess representativeness of the telephone survey sample. A list-based sampling approach was favored over random-digit-dialing (RDD) because of cost. An RDD approach could have potentially picked up residents that had moved within a service area after experiencing an area's last shortage episode, possibly improving representativeness. Giving up this RDD benefit, however, was considered a small price to pay in the context of this first-of-its-kind exploratory study.

Customers were screened based on the account turn on date and were queried about the following drought events:

1. Boulder, drought of 2002-03 *(account turn on date 2000 or earlier)*
2. Irvine Ranch, drought of 2007-09 *(account turn on date 2005 or earlier)*
3. Monte Vista, drought of 2007-09 *(account turn on date 2005 or earlier)*
4. Petaluma, drought of 2007-09 *(account turn on date 2005 or earlier)*
5. San Antonio, drought of 2011-13 *(account turn on date 2002 or earlier)*
6. Santa Fe, drought of 2002-2006 *(account turn on date 2000 or earlier)*
7. Santa Rosa, drought of 2007-09 *(account turn on date 2005 or earlier)*

Irvine Ranch did not declare a shortage during the California drought of 2007-09, but a large share of respondents thought otherwise because of drought messaging received from Irvine's neighbors. Querying customers in Irvine about the more serious drought of 1987-92 when Irvine Ranch did indeed declare a shortage was not feasible on account of the long interval that had elapsed. San Antonio had experienced drought conditions during 2005-06 without declaring shortages. It was considered useful to focus on the group that had gone through these earlier droughts as well while inquiring about their response to San Antonio's 2011 water shortage.

The survey instrument included a screening question at the beginning asking respondents to confirm that they were living in the area when a specific drought event occurred (the surveyor identified each drought event by referring to exact years, which varied by case study as described above). If the respondent could not remember a stated drought event, the survey was discontinued. Fewer than 10% of the cases could not remember the drought they were being asked about. In Irvine Ranch this screening question was asked but ignorance of the California drought of 2007-09 did not lead to survey termination because the supplier did not declare a shortage (although the supplier did adjust water budgets downward somewhat in 2009).

Santa Rosa needed authorization from their customers before releasing contact information for this study. An opt-in letter was sent by the City to a randomly selected, screened pool of 600 single-family customers. Slightly over 140 opted to participate in the telephone survey. However, many of these did not follow through later on. As a result only 75 surveys could be completed in Santa Rosa. The screener question about whether the respondent remembered experiencing the drought of 2007-09 was also not included in Santa Rosa's telephone survey because this subject was covered in the City's opt-in letter.

Pollsters have noted that it has become increasingly difficult to obtain high response rates from telephone surveys, and our experience was no different.[34] Response rate was highest in Santa Rosa (12.5%); of the 600 customers that were originally invited to participate in the survey through the opt-in letter, 75 completed the survey. In the other case studies response rate was 9% or lower. It is therefore necessary to assess the validity of the samples. This was done by requesting billing histories of survey participants and a validation group for each case study. Comparison of billing histories across the two groups showed a good match, both in terms of consumption level per account and trend over time. Thus, the completed surveys appear to be sufficiently representative of the larger group of single-family customers about whose behavior we wish to draw inferences. Survey derived estimates of the saturation of efficient toilets and clothes washers were also compared with device turnover model results, as yet

[34] Kohut, A. et al., *Assessing the Representativeness of Public Opinion Surveys*, a report published by The Pew Research Center, 2012.

another validation step. The match was good here as well: These results are discussed in greater detail later.

The surveying was completed from late summer through fall of 2012. The survey was offered in both English and Spanish, with roughly 98% opting for English. Each randomly selected case was dialed until a survey was completed or a maximum of six call attempts had been made (varied by time and day), whichever occurred first. Detailed tabulations of the survey responses are included in Appendix A. In the main body of the report we only highlight the key findings, organized according to a set of questions that motivate the discussion.

TELEPHONE SURVEY RESULTS

HOW MUCH DO RESPONDENTS THINK THEY CAN CONSERVE DURING A FUTURE SHORTAGE COMPARED TO THE PREVIOUS ONE?

The survey includes two questions (Q. 5: How much would you estimate your household reduced water use during the ________ drought? and Q. 16: If a more severe drought occurred in the future, how much of your normal water use do you estimate you could save?) that gather perceptions about how much water respondents saved during the previous drought, and how much they think they would be able to save during a future severe drought.

Table 5 shows the percentage of respondents that reported having cut their water demand by up to 20% and by up to 30% during the last drought (former percentage is a subset of the latter), and the percentage that believe it is possible for them to make similar cuts in the future. These are aggregations of the detailed answers that respondents provided (shown in Appendix A). Some believed they had, or would be able to make greater than 30% cuts in demand, but for the sake of comparison we have selected this maximum threshold. A shortage that requires a 30% cut can be considered quite severe.

Although Table 5's data are based only on respondent perceptions, it is notable that in every case study a higher fraction of respondents thought they would be able to meet either a 20% or 30% shortage event in the future compared to their self-perception about how they had performed during the prior drought. This is true even among those case studies that had imposed mandatory restrictions, such as Boulder, San Antonio and Santa Fe. Furthermore, responses to Q. 5 and Q. 16 at the respondent level are positively correlated (correlation coefficient ≈ 0.25). A positive correlation, even if not very high, indicates lack of pessimism among the high savers about what they would be able to do in the future. These conclusions are bolstered by responses to another question that is included in the survey (Q. 6: On a scale of 1 to 5, with 5 being very difficult, how difficult was it to meet the water use reduction requested by the water utility in ________?). Roughly 60% of respondents selected 1 or 2 on the 5-point scale in response to Q. 6 indicating the vast majority did not find it very difficult to adapt to drought restrictions.

Table 5. Aggregate Tabulations for Q. 5 and Q. 16

Case Study	Q. 5: Reduced Past Demand By Up To 20%	Q. 16: Can Reduce Future Demand By Up To 20%	Q. 5: Reduced Past Demand By Up To 30%	Q. 16: Can Reduce Future Demand By Up To 30%
Boulder	41%	56%	61%	73%
Irvine	62%	70%	70%	82%
Monte Vista	46%	59%	54%	69%
Petaluma	56%	66%	70%	81%
San Antonio	52%	62%	67%	70%
Santa Fe	36%	50%	50%	64%
Santa Rosa	51%	65%	63%	81%
Total	49%	61%	62%	74%

WHAT ACTIONS DID RESPONDENTS TAKE DURING OR BEFORE THE PREVIOUS DROUGHT AND WHAT WOULD THEY BE WILLING TO DO IN THE FUTURE?

The survey includes two questions (Q. 7: Which of the following steps did your household take to reduce water use during the ________ drought? and Q. 15: You already told us about steps to save water in a past drought. But if a more severe drought occurred, would your household consider doing the following steps to save water?). Respondents were asked about 17 items in total including some pertaining to landscape, some to indoor water using behavior and some to retrofits. For each item in Q. 7 a respondent had three options including, “yes,” “no,” or “did before drought.” For each item in Q. 15 a respondent had four options including, “yes,” “no,” “don’t know—need more information to decide,” or “already do it.” The last response category in Q. 15 is necessary to capture actions a respondent may have taken between the last shortage event and 2012 when the survey was undertaken.

These two questions were expected to take a significant amount of time to work through. To keep the length of the survey within a reasonable time limit, Q. 15 was asked only of those that responded with a “no” to Q. 7. The purpose of Q. 15 is to ascertain whether non-cooperating respondents during the previous drought could be converted into cooperative customers in a future drought through messaging and enforcement. Because Table 5’s data show that respondents are quite optimistic about being able to save as much or more in a future drought as the last one, it is reasonable to surmise that those that responded with a “yes” to many of Q. 7’s items would be willing to repeat them in a future drought.

Table 6 shows aggregate tabulations. Detailed tabulations, by case study, are included in Appendix A. The items about which respondents were queried have been grouped into three general categories including landscape, behavior, and retrofits. These tabulations show that self-reported compliance with irrigation cuts, usually the first item to be targeted during shortages, was very high. Less than 10% responded by saying they had done nothing to curtail irrigation. The remaining 90% either cut irrigation after their supplier declared a drought shortage, or the respondents were already practicing deficit irrigation. Such a high level of compliance suggests that one of the main tools available for making short-term adjustments to water demand is likely to remain available. Rainwater harvesting and graywater reuse were not used much by respondents in the past, but respondents are willing to try these options in a future drought as corresponding responses to Q. 15 indicate. Indeed, of all the pick-list items included in Q. 15 customers seem most hungry for information about how to improve outdoor water-use efficiency.

Table 6. Tabulation of Responses to Q. 7 and Q. 15

Measure Type[‡]	Pick List Items	Q. 7 Yes	Q. 7 No	Q. 7 Did Before Drought	Q. 15 Yes	Q. 15 No	Q. 15 Need More Inform.	Q. 15 Already Do It
L	Stopped or cut way back on watering lawn	72%	7%	21%	63%	26%	6%	6%
L	Less watering for all landscaping	71%	9%	20%	78%	10%	10%	2%
L	Replaced lawn and high water-use plants with drought tolerant plants	25%	54%	21%	43%	37%	10%	10%
L	Saved and used graywater (shower and laundry water) for landscaping	18%	76%	6%	38%	42%	18%	2%
L	Captured rainwater and used it for landscaping	20%	70%	10%	50%	40%	9%	1%
B	Shorter showers	51%	29%	20%	57%	36%	1%	7%
B	Turned off water in the shower while soaping up	23%	65%	11%	56%	41%	1%	1%
B	Washed fewer loads of clothes	47%	33%	20%	43%	43%	2%	12%
B	Flushed the toilet less often	47%	34%	20%	43%	52%	1%	4%
B	Careful to use less water washing dishes	53%	18%	29%	70%	22%	0%	8%
B	Careful to not let faucet run while washing, shaving, brushing teeth	44%	10%	46%	68%	23%	0%	9%
B	Washed the car less frequently	46%	22%	32%	43%	35%	3%	20%
R	Replaced clothes washer with front loader or ENERGY STAR® model	25%	51%	24%	35%	41%	8%	16%
R	Replaced toilets with more efficient models	33%	36%	31%	43%	36%	6%	16%
R	Installed a high efficiency or ENERGY STAR dishwasher	21%	55%	24%	29%	51%	6%	14%
R	Fixed leaky fixtures	32%	19%	49%	72%	12%	1%	15%
R	Saved and used cold water while waiting for hot water arrive at the tap	28%	53%	19%	55%	36%	6%	3%

NOTE: Rainwater harvesting question not asked in Boulder because state law disallows it.

[‡]L indicates landscape measure; B indicates behavioral measure; and R indicates retrofit measure.

With regards to indoor water using behavior, close to half of all respondents reported adjusting their behavior, such as taking shorter showers, flushing less often, washing fewer loads, etc. This is notable on account of being a voluntary response. None of the shortage episodes being researched through the telephone survey involved mandatory indoor rationing. Moreover, among those that did not make these indoor behavioral adjustments voluntarily last time, a large percentage is willing to do so in a future severe shortage event.

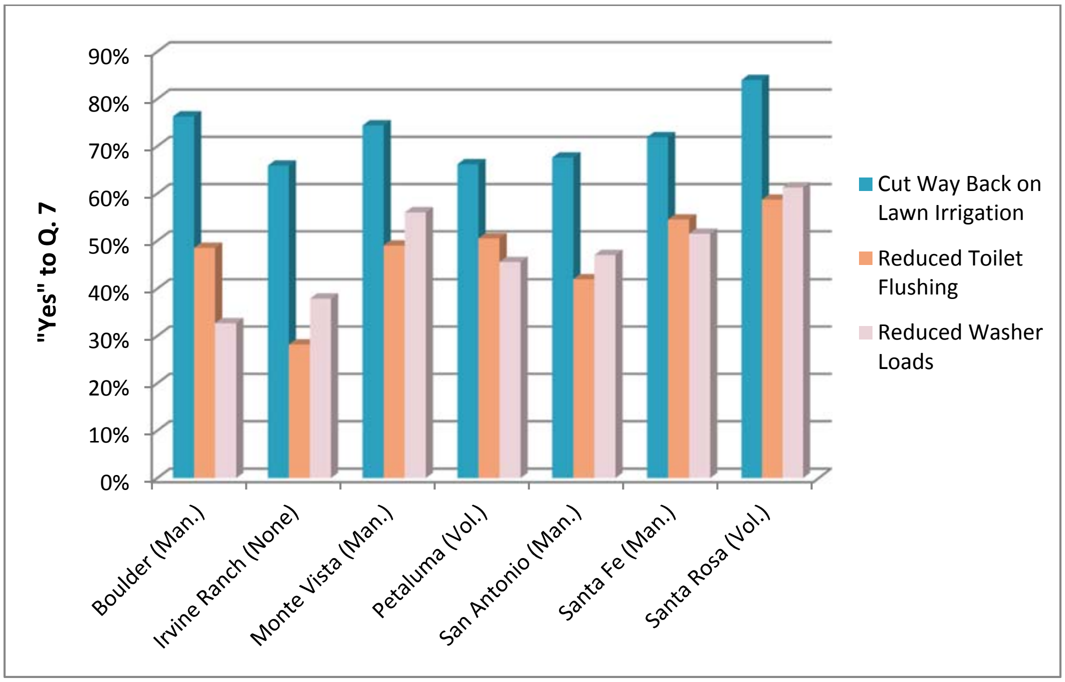

Figure 12. Comparison of Key Behaviors Across Case Studies

It is useful to examine the variation in a few key indoor and outdoor water using behaviors across the seven case studies to examine the difference in impact of voluntary and mandatory restrictions. Figure 12 shows the percentage that responded with a "yes" to three behavioral items included in Q. 7: whether they substantially cut back irrigation, flushed toilets less often, or washed fewer loads of laundry. Both irrigation and indoor water using behavior shows a slightly greater adjustment when mandatory restrictions were imposed, but the voluntary restrictions episodes are not far behind. Santa Rosa appears to have achieved the highest compliance with only voluntary restrictions. Indoor water using behavior did not adjust much in Irvine Ranch, but then no restrictions were in effect (during the 2007-09 drought, focus of the survey). Whatever response we observe in Irvine Ranch is a result of spillover drought messaging. These patterns do not indicate that customers are reluctant to modify their behavior when shortages necessitate them.

Periods of shortage are also an excellent time to persuade customers to replace their old inefficient plumbing fixtures and appliances with the latest efficient ones. With respect to the two most intensive indoor uses today, toilets and clothes washers, many respondents appear to have done precisely that.

Table 6’s data provide a way of estimating saturation of water-efficient toilets and clothes washers. If one adds the fraction of respondents that replaced either toilets or clothes washers during the last drought (Q. 7=“Yes”) with the fraction that already had completed these retrofits prior to the last drought (Q. 7=“Did before drought”) with the fraction that had done so by the time of the survey (Q. 15=“Already do it” multiplied by Q. 7=“No”), one can estimate efficient toilet and clothes washer saturation among respondents in 2012. Calculating a saturation estimate in this way does not require enquiring about exact fixture makes and models, which past research has shown can be unreliable.

Table 7 shows these estimates by case study. None of the case studies is approaching full saturation, which means ample cushion still exists for adjusting to a future shortage through emergency retrofits. The time required to bring down demand through retrofits is obviously much longer than with behavior, but perhaps with adequate warning and lead time, the potential savings implied by Table 7’s data can be useful for adjusting to a future shortage.

Table 7. Efficient Toilet and Clothes Washer Saturation among Respondents

Case Study	Efficient Toilet Saturation in 2012	Efficient Clothes Washer Saturation in 2012
Boulder	55%	52%
Irvine Ranch	74%	74%
Monte Vista	69%	61%
Petaluma	66%	65%
San Antonio	66%	39%
Santa Fe	81%	48%
Santa Rosa	77%	65%

Are observed saturation differences across the survey respondents indicative of meaningful service-area wide differences, or just an artifact of the respondent samples themselves? To address this question detailed data were collected about each case study’s active retrofit programs going back to the earliest year possible. These were run through turnover models that capture the impact of natural turnover and active retrofit programs for all single-family customers in a service area. Predictions from these turnover models track Table 7’s data quite well (Appendix B describes these models and results in greater detail). Where the telephone survey indicates a higher saturation, so do the turnover models, and vice versa. In other words, while Table 7’s estimates cannot be viewed as service area-wide best estimates of saturation, they probably do indicate how case studies would stack up against one another on either metric. The good correspondence between survey-based and turnover model-based saturation estimates suggests that respondent samples are fairly representative of their service areas.

Another way to examine sample representativeness is to compare estimates of the share of residential GPCD devoted to irrigation (Table 4) with differences in the turf orientation of respondent landscapes (Q. 13: Please estimate how much of your landscape that you water is lawn or turf grass?). Tabulations shown in Appendix A indicate that among all case studies Santa Fe’s landscapes have the least turf orientation, Monte Vista’s landscapes the greatest, matching Table 4’s patterns.

WHAT DO RESPONDENTS INDICATE ABOUT THEIR APPETTITE FOR SHORTAGE RISK?

The preferred approach for assessing customer risk tolerance, or willingness-to-pay to lessen shortage risk to some acceptable level, is to conduct a Contingent Valuation survey. These types of studies have been undertaken in the past by water agencies.[35] Incorporating rigorous Contingent Valuation techniques into this study was not feasible because of budgetary constraints. However, the above issues were not altogether ignored either. The survey instrument includes a few questions aimed at gauging respondent price sensitivity and preferences regarding paying more to lessen shortage risk.

The survey includes two questions that enquire about the impact of water rates and the recession on water use (Q. 14: Water rates may affect water use patterns. On a scale of 1 to 5, with 5 being the most important, has the cost of water bills been an important factor for your household in reducing water use in recent years? And Q. 17: The recession may have affected water use for some customers. On a scale of 1 to 5, with 5 as the most important, how important was the recent recession for your water use in recent years?) Table 8 compares responses to these two questions: Only the aggregated tail ends of the response distribution are shown here. For detailed tabulations by each response category please refer to Appendix A.

Table 8's data suggest that in most case studies respondents think rising water bills have impacted their water use far more than the recent recession. Notable exceptions include Boulder where far fewer respondents seemed to be concerned about water bills than in the other case studies, and Monte Vista where as many seemed to be concerned about the recession than not. Boulder switched from a 3-tier to 5-tier inclining rate structure in 2007 that probably lowered bills for those not falling into the new penalty tiers just before the recession's onset. Perhaps, this is what explains respondent perceptions about water bills in Boulder. Why Monte Vista's respondents give greater importance to the recession than other case studies is not difficult to understand. Among the seven case studies, Monte Vista has the lowest per-capita income and a local unemployment rate that surged to 13.6% by the recession's peak in 2010 (Table 2).

Table 8. Impact of Water Rates and Recession on Water Use

	Q. 14: Water Bills Important?		Q. 17: Recession Important?	
	Least Important (No Impact, 1 or 2)	Most Important (4 or 5)	Least Important (No impact, 1 or 2)	Most Important (4 or 5)
Boulder	53.5%	28.7%	82.2%	9.0%
Irvine Ranch	34.0%	40.8%	67.9%	22.4%
Monte Vista	26.0%	60.0%	39.0%	38.0%
Petaluma	22.2%	57.6%	50.6%	25.3%
San Antonio	35.0%	52.0%	63.0%	22.0%
Santa Fe	30.7%	58.4%	56.4%	29.7%
Santa Rosa	21.3%	64.0%	66.7%	17.3%

[35] Barakat and Chamberlin, Inc., *The Value of Water Supply Reliability: Results of a Contingent Valuation Survey of Residential Customers*, 1994, a report prepared for California Urban Water Agencies.

Overall, the greater impact of water rates is not entirely surprising. Water rates have increased markedly over the last two decades. Prior to the mid-1990s, rates exhibit very little growth in real terms. As a result, water rates in the past have not been treated as important drivers of customer behavior, especially given repeated findings of low price-elasticity of demand. This likely is no longer true. Figure 13 shows how the single-family marginal price of water has changed between 1995 and 2012. Three case studies have experienced a doubling in marginal price (Petaluma, San Antonio and Santa Rosa). Santa Fe has the highest marginal price of all. It has been high throughout this time period. And Santa Fe has been quick to levy drought surcharges during shortage periods, which Figure 13 does not reflect.

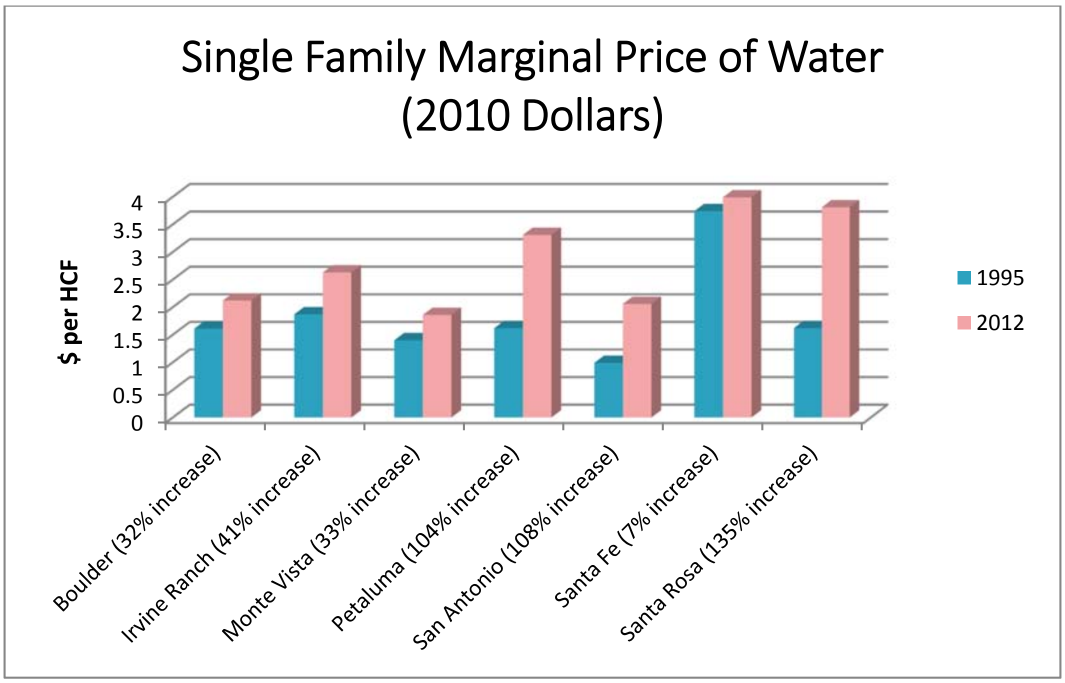

Figure 13. Trends in the Price of Water

Responses to Q. 14 (water bills important?) and water rate increases shown in Figure 13 suggest that customers are probably strongly motivated to keep a lid on their water bills and as a result might be willing to engage in occasional frugality instead of paying for new expensive supplies. A question included in the survey instrument specifically enquires about this (Q. 18: Would you prefer to use less water in a drought, or have the utility spend more money on a new water supply project that may only be needed in drought years, but would increase the costs of water bills every year and may have environmental impacts?) In every case study (except Irvine Ranch where the question was not asked), over two-thirds stated a preference for using less water in a drought than paying higher bills, with this fraction hitting a high of 87% in Monte Vista (Appendix A).

However, this preference for keeping water bills low should not be interpreted to mean that respondents have unlimited appetite for dealing with shortages through short-term measures. A follow-up question was included to get at this (Q. 19: Do you agree or disagree with the following statement: Your household would be willing to conserve more water in wet years if the water utility would hold it as a reserve for future drought years. Do you agree or disagree?). Overwhelming majorities across all case studies (70-85%) agreed with Q. 19's premise.

One way to interpret responses to Q. 18 and 19 is that while customers wish to keep their water bills low, they also wish to see savings that result from their conservation efforts be used to place local and regional water supplies on a more sustainable basis so that shortage risk is reduced and that mandatory restrictions or rationing is required only in the worst of situations. As was mentioned earlier, suppliers already have strong incentives to do this on their own because mandatory restrictions are disruptive, difficult to enforce, and generate customer dissatisfaction. Thus, restrictions cannot be made into a frequently summoned tool for bridging supply/demand gaps. Water suppliers perhaps need to do more about educating their customers, if customers have the mistaken belief that conservation only fuels new growth, that conservation also improves supply reliability. Compliance with mandatory restrictions may improve if customers both understand and trust their supplier's long-term water supply plan and also understand why the infrequent use of drought restrictions is ultimately in their own interest.

5. CONCLUSIONS

This study was undertaken to address whether long-term increases in water-use efficiency influence an area's ability to adapt to extended water shortages? Data about water use trends going back to 1970 including drought and shortage histories were compiled from seven water suppliers located throughout the arid Southwestern United States. Developing a sufficiently long historical record is necessary to have a suitable number of shortage episodes to study because not all droughts lead to shortage declarations. These historical shortage episodes were classified by whether the supplier imposed voluntary or mandatory restrictions on outdoor water use, or went a step further and imposed mandatory indoor rationing as well.

In terms of achieved savings, voluntary restrictions unsurprisingly produce smaller adjustments in demand because they signal to customers an expectation of a mild shortage. On the other hand, while mandatory restrictions or rationing produce greater adjustments, there seems to be no clear relationship between average per-capita demand just prior to the shortage and the percent reduction in demand that is achieved as a result of the shortage declaration. The data suggest that in large part how customers respond to shortages depends on the perceived severity of the shortage and on the vigor with which mandatory restrictions are enforced. In other words, it does not appear that ability to curtail demand during shortages is weakened as a result of investment in long-term conservation programs. Why is this so?

The purpose of long-term conservation programs (for example, plumbing codes and incentive-based or ordinance-based retrofit programs) is to bring about a steady decline in year-round per-capita water demand; and when focused on outdoor use, conservation programs reduce peak-season demand as well. To deal with extended shortages, however, water suppliers rely on customers' ability to make time-limited adjustments to their behavior, such as significantly reducing irrigation in mild shortage events, or in more severe events completely discontinuing irrigation and reducing indoor use as well (by flushing less, washing fewer wash loads, etc.). Until now increases in indoor water-use efficiency have resulted mainly from replacement of old plumbing fixtures and appliances with newer, more efficient varieties. The latest end-use metering studies do not indicate that indoor water-using behavior is that different now compared to before. Thus, in a pinch residential customers retain considerable ability to change their indoor water-using behavior. Similarly, suppliers have pursued many long-term programs aimed at making outdoor water use much more efficient including promoting drought-tolerant plant species, turf removal, and cessation of wasteful irrigation practices. Once again though, a significant amount of water is still used outdoors, which means that in a pinch customers can significantly reduce their total demand by making steep cuts in outdoor water use. In other words, there is no reason to believe that ability for making short-term adjustments in behavior is any less now than in the past.

Does this mean that water suppliers have nothing to worry about and can continue to plan for shortages like they have done in the past? Well, probably not. Cutting outdoor water use broadly, specifically irrigation, will remain the first priority for adapting to imminent shortages. In the past, water suppliers have relied either on time-of-day or day-of-week restrictions, or on water budgets tied to steeply inclining rates to bring about a reduction in outdoor water demand. These strategies will remain salient, but as irrigation becomes a smaller component of total demand, water shortage contingency plans will need to target indoor water use much sooner in a shortage cycle than in the past. In other words, as per-capita demand falls because of investments in water-use efficiency, it will become necessary for suppliers to reconfigure their shortage contingency plans so as to fast forward to steps that normally would have been taken later in the more traditionally configured shortage plans.

The best laid contingency plans, however, require customer cooperation to succeed. Managing willingness to cut demand during shortages therefore remains the key to preventing demand hardening. Previous opinion polls conducted in San Diego and San Antonio (*op cit.*) and the survey conducted under the auspices of this study already indicate that residential customers would rather deal with the inconvenience of an occasional shortage than pay high water bills regularly. The level of acceptable shortage risk, however, may differ from area to area, so suppliers first have to determine that. Suppliers also have to determine which end uses customers would prefer to adjust the most during a shortage. It then becomes a matter of configuring water shortage contingency plans with effective enforcement mechanisms to incentivize customers to follow through behaviorally. When these contingency plans and enforcement mechanisms are not properly configured, failure is blamed on the pursuit of water-use efficiency, but this is misplaced.

Is there evidence to suggest that participation in long-term conservation programs makes customers less willing to practice frugality during occasional shortage events? A telephone survey of single-family customers in each case study was undertaken to assess this and related questions. The survey enquired into actions respondents took to adapt to the last drought, as well as what actions they would be willing to take during a new shortage episode. Survey responses show that self-reported compliance with irrigation cuts, usually the first item to be targeted during shortages, was very high. Less than 10% responded by saying they had done nothing to curtail irrigation. The remaining 90% reported either cutting irrigation after their supplier declared a drought shortage, or the respondents were already practicing deficit irrigation. Such a high level of reported compliance suggests that one of the main tools available for making short-term adjustments to water demand is likely to remain available. Other options, such as graywater reuse were not used much by respondents in the past, but respondents are willing to try these options in a future drought. Indeed, customers seem most hungry for information about how to improve outdoor water-use efficiency. While drought-tolerant landscapes are often marketed on the basis of year-round lower water use, perhaps not enough attention is paid to educating customers about how to operate such a landscape in deficit or survival mode. In fact, willingness to cut irrigation during shortage periods could markedly improve if customers understood that an important virtue of drought-tolerant plant species is not simply their lower year-round use, but their ability to go dormant without dying when irrigation is steeply cut.

With regards to indoor water-using behavior, close to half of all respondents reported adjusting their behavior, such as taking shorter showers, flushing less often, washing fewer loads, etc. This is notable on account of being a voluntary response. None of the shortage episodes being researched through the telephone survey involved mandatory indoor rationing. Moreover, among those that did not make these indoor behavioral adjustments voluntarily last time, a large percentage is willing to do so in a future severe shortage event.

Survey respondents expressed a strong desire for keeping their water bills low even if that meant practicing frugality to deal with the occasional shortage. Water rates have increased significantly over the last few years, so this finding is both understandable and consistent with opinion surveys conducted elsewhere. However, this preference for keeping water bills low should not be interpreted to mean that respondents have unlimited appetite for dealing with shortages through restrictions. Customers may wish to keep their water bills low, but they also wish to see savings that result from their conservation efforts be used to place local and regional water supplies on a more sustainable basis so that shortage risk is reduced and that mandatory restrictions or rationing is required only in the worst of situations. Suppliers already have strong incentives to do this on their own because mandatory restrictions are disruptive, difficult to enforce, and generate customer dissatisfaction. Thus, restrictions cannot be made into a frequently summoned tool for bridging gaps between supply and demand. Water suppliers perhaps need to do more about educating their customers, if customers have the mistaken belief that conservation only fuels new growth, that conservation also improves supply reliability. Compliance with mandatory restrictions may improve if customers both understand and trust their supplier's long-term water supply plan and also understand why the infrequent use of drought restrictions is ultimately in their own interest. After all, many areas have successfully increased their supply reliability and long-term sustainability by investing in conservation. This has allowed them to get through dry times much better now without having to declare shortages (e.g., Boulder in 2012; Irvine Ranch in 2009 and 2014; Santa Fe in 2011; San Antonio in 2005-06). Although this paper only explores customer ability and willingness to engage in frugality when faced with an imminent shortage, the other element—the risk of shortage itself—should not be forgotten.

As mentioned in the beginning, designing a least-cost capital improvement plan is difficult without knowing customer-class specific perceptions about acceptable shortage levels and risks. Contingent Valuation techniques are one way to improve our knowledge about these matters. It is also important that water resource planners continue to study the relative efficacy of differently configured water shortage contingency plans to isolate which features work better than others. A key point this study has emphasized is that relying on generic shortage contingency plans is unwise. It is necessary to test whether savings expectations at each trigger point in a shortage contingency plan can actually be achieved given overall GPCD and mix of customer classes. Water shortage contingency plans and associated enforcement mechanisms should be regularly updated to favor curtailment strategies that both minimize economic costs and are consistent with the changing mix of discretionary and non-discretionary uses of water. At present not enough is known to simulate the impact of alternative contingency plan designs. To facilitate such analyses it is necessary to compile and maintain a database of shortage events, the severity of the event, water supplier response, enforcement methods used, and effectiveness by customer class. Analyses of several such shortage events over time we expect will yield guidance about best practices that water suppliers should follow while configuring their water shortage contingency plans at different GPCD levels. The ongoing drought in California, now with statewide restrictions in effect, will hopefully add to the evidence available from prior shortage episodes, and thereby improve our ability to address these questions in the future.

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Q2: For ___ (years), how serious of a drought would you rate it?

	Not Very Serious	Moderate	Very Serious	Severe	Do Not Remember/ No Opinion	n=
Boulder, 2002-2003	5.9%	38.6%	37.6%	13.9%	4.0%	101
Irvine Ranch, 2007-2009	16.5%	48.5%	24.3%	6.8%	3.9%	103
Monte Vista, 2009-2010	18.0%	54.0%	23.0%	4.0%	1.0%	100
Petaluma, 2009	21.2%	59.6%	13.1%	4.0%	2.0%	99
San Antonio, 2011	3.0%	21.0%	47.0%	29.0%	0.0%	100
Santa Fe, 2002-2006	5.9%	32.7%	43.6%	16.8%	1.0%	101
Santa Rosa, 2007-2009	9.3%	54.7%	25.3%	4.0%	6.7%	75
Aggregate	11.5%	43.7%	30.78	11.49	2.5%	679
n=	78	297	209	78	17	

Q3: Where did you get information about the drought?

	Water Utility Bill or Newsletter	Water Utility Website	TV News	Local Newspaper	Radio Announcements and News	Internet Searches and Sources	Discussions with Friends and Neighbors	Directly Experienced the Weather and Its Effects	n=
Boulder	48.5%	6.9%	72.3%	85.1%	27.7%	19.8%	64.4%	87.1%	101
Irvine Ranch	61.2%	6.8%	73.8%	52.4%	35.9%	23.3%	37.9%	65.0%	103
Monte Vista	63.0%	5.0%	75.0%	50.0%	28.0%	9.0%	40.0%	62.0%	100
Petaluma	57.6%	7.1%	70.7%	72.7%	36.4%	14.1%	55.6%	76.8%	99
San Antonio	58.0%	9.0%	94.0%	65.0%	49.0%	29.0%	69.0%	86.0%	100
Santa Fe	67.3%	2.0%	85.1%	85.1%	43.6%	13.9%	78.2%	91.1%	101
Santa Rosa	62.7%	10.7%	65.3%	86.7%	38.7%	17.3%	50.7%	68.0%	75
Aggregate	59.6%	6.6%	77.0%	70.4%	37.0%	18.1%	56.7%	76.9%	679
n=	405	45	523	478	251	123	385	522	

Q4: Which of the following best describes the effort your household made to reduce water in the ___ (years varied per utility) drought?

	Too busy with other priorities and didn't do anything different to save water	Did a few things, but not that much	Did a lot of things, but probably could have done more	Did everything we could	n=
Boulder	2.0%	21.8%	46.5%	29.7%	101
Irvine Ranch	2.9%	45.6%	26.2%	25.2%	103
Monte Vista	4.0%	28.0%	25.0%	43.0%	100
Petaluma	0.0%	26.3%	43.4%	30.3%	99
San Antonio	5.0%	17.0%	23.0%	55.0%	100
Santa Fe	3.0%	10.9%	42.6%	43.6%	101
Santa Rosa	1.3%	20.0%	45.3%	33.3%	75
Aggregate	**2.7%**	**24.5%**	**35.6%**	**37.3%**	**679**
n=	18	166	242	253	

Q5: How much would you estimate your household reduced water use during the ___ (years varied) drought?

	None	5-10%	11-20%	21-30%	31-40%	41-50%	>50%	Don't know/Unable to estimate	n=
Boulder	4.0%	10.9%	29.7%	20.8%	2.0%	2.0%	2.0%	28.7%	101
Irvine Ranch	6.8%	36.9%	25.2%	7.8%	2.9%	1.9%	0.0%	18.5%	103
Monte Vista	8.0%	24.0%	22.0%	8.0%	4.0%	3.0%	1.0%	30.0%	100
Petaluma	1.0%	25.3%	30.3%	14.1%	3.0%	1.0%	0.0%	25.3%	99
San Antonio	3.0%	28.0%	24.0%	15.0%	5.0%	4.0%	0.0%	21.0%	100
Santa Fe	2.0%	14.9%	20.8%	13.9%	9.9%	5.0%	1.0%	32.7%	101
Santa Rosa	1.3%	28.0%	22.7%	12.0%	4.0%	1.3%	0.0%	30.7%	75
Aggregate	**3.8%**	**23.9%**	**25.0%**	**13.1%**	**4.4%**	**2.7%**	**0.6%**	**26.5%**	**679**
n=	26	162	170	89	30	18	4	180	

Notes: Q5 responses were recoded into categories to capture the open ended responses and depict them with the pick list responses.

Q6: On a scale of 1 to 5, with 5 being very difficult, how difficult was it to meet the water use reduction requested by the water utility in ___ (most recent drought) years?

	Don't know/ unsure	1 = Least difficult	2	3	4	5 = Most difficult	n=
Boulder	4.0%	43.6%	20.8%	21.8%	7.9%	2.0%	101
Irvine Ranch	1.9%	44.7%	20.4%	16.5%	7.8%	8.7%	103
Monte Vista	5.0%	42.0%	11.0%	28.0%	8.0%	6.0%	100
Petaluma	9.1%	49.5%	15.2%	17.2%	5.1%	4.0%	99
San Antonio	2.0%	39.0%	19.0%	18.0%	9.0%	13.0%	100
Santa Fe	3.0%	45.5%	14.9%	20.8%	7.9%	7.9%	101
Santa Rosa	6.7%	44.0%	9.3%	32.0%	4.0%	4.0%	75
Aggregate	4.4%	44.0%	16.1%	21.7%	7.2%	6.6%	679
n=	30	299	109	147	49	45	

Notes: Q6 was phrased differently for San Antonio: "On a scale of 1 to 5, with 5 being the most, how much hardship was it to comply with the water use restrictions mandated by the San Antonio Water System in 2011?"

Q7: Which of the following steps did your household take to reduce water use during the ___ (most recent drought years) drought?

AGGREGATE

	Yes	No	Did before drought	n=
Stopped or cut way back on watering lawn	71.9%	7.3%	20.8%	481
Less water for all landscaping	71.2%	8.6%	20.2%	594
Replaced lawn and high-water-use plants with drought tolerant plants	24.9%	54.4%	20.7%	594
Shorter showers	51.1%	29.2%	19.7%	679
Turned off water in the shower while soaping up	23.4%	65.2%	11.3%	679
Washed fewer loads of clothes	46.8%	33.1%	20.0%	679
Replaced clothes washer with a more efficient front loader or ENERGY STAR® model	25.0%	50.7%	24.3%	679
Flushed the toilet less often	46.8%	33.6%	19.6%	679
Replaced toilets with more efficient models	32.7%	36.1%	31.2%	679
Careful to use less water washing dishes	53.2%	17.5%	29.3%	679
Installed a high-efficiency or ENERGY STAR dishwasher	20.8%	55.1%	24.2%	679
Careful to not let faucet run while washing, shaving, and brushing teeth	44.0%	9.6%	46.4%	679
Saved and used graywater (shower and laundry water) for landscaping	18.0%	75.8%	6.2%	594
Captured rainwater and used it for landscaping	20.2%	69.6%	10.2%	500
Washed the car less frequently	45.7%	22.1%	32.3%	679
Fixed leaky fixtures	32.0%	19.3%	48.7%	679
Saved and used cold water while waiting for hot water arrive at the tap	27.5%	53.5%	19.0%	679

Notes: The Landscape measures were screened to exclude "no" responses in Q8. The rainwater collection steps (Q15_14) was not asked for Boulder since Colorado water rights law prohibits it.

Q7: Which of the following steps did your household take to reduce water use during the 2002 to 2003 drought?

Boulder

	Yes	No	Did before drought	n=
Stopped or cut way back on watering lawn	76.3%	8.6%	15.1%	93
Less water for all landscaping	72.3%	10.9%	16.8%	101
Replaced lawn and high-water-use plants with drought tolerant plants	17.8%	62.4%	19.8%	101
Shorter showers	48.5%	31.7%	19.8%	101
Turned off water in the shower while soaping up	18.8%	72.3%	8.9%	101
Washed fewer loads of clothes	32.7%	53.5%	13.9%	101
Replaced clothes washer with a more efficient front loader or ENERGY STAR® model	13.9%	68.3%	17.8%	101
Flushed the toilet less often	48.5%	21.8%	29.7%	101
Replaced toilets with more efficient models	21.8%	59.4%	18.8%	101
Careful to use less water washing dishes	41.6%	32.7%	25.7%	101
Installed a high-efficiency or ENERGY STAR dishwasher	8.9%	67.3%	23.8%	101
Careful to not let faucet run while washing, shaving, and brushing teeth	43.6%	11.9%	44.6%	101
Saved and used graywater (shower and laundry water) for landscaping	33.7%	64.4%	2.0%	101
Captured rainwater and used it for landscaping	N/A	N/A	N/A	101
Washed the car less frequently	43.6%	22.8%	33.7%	101
Fixed leaky fixtures	25.7%	27.7%	46.5%	101
Saved and used cold water while waiting for hot water arrive at the tap	29.7%	53.5%	16.8%	101

Notes: Landscape measures screened to exclude "no" responses in Q8.

Q7: Which of the following steps did your household take to reduce water use during the 2007 to 2009 drought?

Irvine

	Yes	No	Did before drought	n=
Stopped or cut way back on watering lawn	65.9%	9.4%	24.7%	85
Less water for all landscaping	75.7%	4.9%	19.4%	103
Replaced lawn and high-water-use plants with drought tolerant plants	19.4%	59.2%	21.4%	103
Shorter showers	52.4%	29.1%	18.4%	103
Turned off water in the shower while soaping up	25.2%	66.0%	8.7%	103
Washed fewer loads of clothes	37.9%	35.0%	27.2%	103
Replaced clothes washer with a more efficient front loader or ENERGY STAR® model	30.1%	35.9%	34.0%	103
Flushed the toilet less often	28.2%	56.3%	15.5%	103
Replaced toilets with more efficient models	30.1%	35.0%	35.0%	103
Careful to use less water washing dishes	45.6%	18.4%	35.9%	103
Installed a high-efficiency or ENERGY STAR dishwasher	25.2%	38.8%	35.9%	103
Careful to not let faucet run while washing, shaving, and brushing teeth	43.7%	7.8%	48.5%	103
Saved and used graywater (shower and laundry water) for landscaping	4.9%	91.3%	3.9%	103
Captured rainwater and used it for landscaping	6.8%	86.4%	6.8%	103
Washed the car less frequently	36.9%	24.3%	38.8%	103
Fixed leaky fixtures	29.1%	15.5%	55.3%	103
Saved and used cold water while waiting for hot water arrive at the tap	20.4%	59.2%	20.4%	103

Notes: Landscape measures screened to exclude "no" responses in Q8.

Q7: Which of the following steps did your household take to reduce water use during the 2009 to 2010 drought?

Monte Vista

	Yes	No	Did before drought	n=
Stopped or cut way back on watering lawn	74.4%	3.7%	22.0%	82
Less water for all landscaping	67.0%	10.0%	23.0%	100
Replaced lawn and high-water-use plants with drought tolerant plants	31.0%	56.0%	13.0%	100
Shorter showers	60.0%	22.0%	18.0%	100
Turned off water in the shower while soaping up	27.0%	60.0%	13.0%	100
Washed fewer loads of clothes	56.0%	22.0%	22.0%	100
Replaced clothes washer with a more efficient front loader or ENERGY STAR® model	35.0%	41.0%	24.0%	100
Flushed the toilet less often	49.0%	37.0%	14.0%	100
Replaced toilets with more efficient models	38.0%	32.0%	30.0%	100
Careful to use less water washing dishes	64.0%	14.0%	22.0%	100
Installed a high-efficiency or ENERGY STAR dishwasher	21.0%	66.0%	13.0%	100
Careful to not let faucet run while washing, shaving, and brushing teeth	50.0%	8.0%	42.0%	100
Saved and used graywater (shower and laundry water) for landscaping	15.0%	78.0%	7.0%	100
Captured rainwater and used it for landscaping	21.0%	73.0%	6.0%	100
Washed the car less frequently	52.0%	15.0%	33.0%	100
Fixed leaky fixtures	37.0%	12.0%	51.0%	100
Saved and used cold water while waiting for hot water arrive at the tap	21.0%	58.0%	21.0%	100

Notes: Landscape measures screened to exclude "no" responses in Q8.

Q7: Which of the following steps did your household take to reduce water use during the 2009 drought?

Petaluma

	Yes	No	Did before drought	n=
Stopped or cut way back on watering lawn	66.2%	8.5%	25.4%	71
Less water for all landscaping	67.7%	9.1%	23.2%	99
Replaced lawn and high-water-use plants with drought tolerant plants	25.3%	54.5%	20.2%	99
Shorter showers	53.5%	25.3%	21.2%	99
Turned off water in the shower while soaping up	25.3%	61.6%	13.1%	99
Washed fewer loads of clothes	45.5%	38.4%	16.2%	99
Replaced clothes washer with a more efficient front loader or ENERGY STAR® model	24.2%	42.4%	33.3%	99
Flushed the toilet less often	50.5%	25.3%	24.2%	99
Replaced toilets with more efficient models	29.3%	39.4%	31.3%	99
Careful to use less water washing dishes	57.6%	13.1%	29.3%	99
Installed a high-efficiency or ENERGY STAR dishwasher	19.2%	48.5%	32.3%	99
Careful to not let faucet run while washing, shaving, and brushing teeth	41.4%	2.0%	56.6%	99
Saved and used graywater (shower and laundry water) for landscaping	16.2%	79.8%	4.0%	99
Captured rainwater and used it for landscaping	12.1%	83.8%	4.0%	99
Washed the car less frequently	49.5%	16.2%	34.3%	99
Fixed leaky fixtures	32.3%	19.2%	48.5%	99
Saved and used cold water while waiting for hot water arrive at the tap	30.3%	57.6%	12.1%	99

Notes: Landscape measures screened to exclude "no" responses in Q8.

Q7: Which of the following steps did your household take to reduce water use during the 2011 drought?

San Antonio

	Yes	No	Did before drought	n=
Stopped or cut way back on watering lawn	67.6%	7.6%	25.0%	68
Less water for all landscaping	66.0%	14.0%	20.0%	100
Replaced lawn and high-water-use plants with drought tolerant plants	19.0%	64.0%	17.0%	100
Shorter showers	42.0%	42.0%	16.0%	100
Turned off water in the shower while soaping up	20.0%	63.0%	17.0%	100
Washed fewer loads of clothes	47.0%	29.0%	24.0%	100
Replaced clothes washer with a more efficient front loader or ENERGY STAR® model	13.0%	63.0%	24.0%	100
Flushed the toilet less often	42.0%	41.0%	17.0%	100
Replaced toilets with more efficient models	27.0%	34.0%	39.0%	100
Careful to use less water washing dishes	47.0%	19.0%	34.0%	100
Installed a high-efficiency or ENERGY STAR dishwasher	15.0%	63.0%	22.0%	100
Careful to not let faucet run while washing, shaving, and brushing teeth	33.0%	17.0%	50.0%	100
Saved and used graywater (shower and laundry water) for landscaping	8.0%	82.0%	10.0%	100
Captured rainwater and used it for landscaping	20.0%	68.0%	12.0%	100
Washed the car less frequently	46.0%	25.0%	29.0%	100
Fixed leaky fixtures	29.0%	21.0%	50.0%	100
Saved and used cold water while waiting for hot water arrive at the tap	27.0%	53.0%	20.0%	100

Notes: Landscape measures screened to exclude "no" responses in Q8.

Q7: Which of the following steps did your household take to reduce water use during the 2002 to 2006 drought?

Santa Fe

	Yes	No	Did before drought	n=
Stopped or cut way back on watering lawn	71.9%	6.3%	21.9%	32
Less water for all landscaping	59.4%	7.9%	32.7%	101
Replaced lawn and high-water-use plants with drought tolerant plants	28.7%	35.6%	35.6%	101
Shorter showers	47.5%	23.8%	28.7%	101
Turned off water in the shower while soaping up	22.8%	66.3%	10.9%	101
Washed fewer loads of clothes	51.5%	24.8%	23.8%	101
Replaced clothes washer with a more efficient front loader or ENERGY STAR® model	28.7%	58.4%	12.9%	101
Flushed the toilet less often	54.5%	23.8%	21.8%	101
Replaced toilets with more efficient models	49.5%	21.8%	28.7%	101
Careful to use less water washing dishes	50.5%	12.9%	36.6%	101
Installed a high-efficiency or ENERGY STAR dishwasher	26.7%	53.5%	19.8%	101
Careful to not let faucet run while washing, shaving, and brushing teeth	30.7%	12.9%	56.4%	101
Saved and used graywater (shower and laundry water) for landscaping	24.8%	61.4%	13.9%	101
Captured rainwater and used it for landscaping	40.6%	35.6%	23.8%	101
Washed the car less frequently	38.6%	24.8%	36.6%	101
Fixed leaky fixtures	23.8%	14.9%	61.4%	101
Saved and used cold water while waiting for hot water arrive at the tap	29.7%	40.6%	29.7%	101

Notes: Landscape measures screened to exclude "no" responses in Q8.

Q7: Which of the following steps did your household take to reduce water use during the 2007 to 2009 drought?

Santa Rosa

	Yes	No	Did before drought	n=
Stopped or cut way back on watering lawn	84.0%	6.0%	10.0%	50
Less water for all landscaping	81.3%	8.0%	10.7%	75
Replaced lawn and high-water-use plants with drought tolerant plants	29.3%	53.3%	17.3%	75
Shorter showers	54.7%	30.7%	14.7%	75
Turned off water in the shower while soaping up	25.3%	68.0%	6.7%	75
Washed fewer loads of clothes	61.3%	28.0%	10.7%	75
Replaced clothes washer with a more efficient front loader or ENERGY STAR® model	32.0%	44.0%	24.0%	75
Flushed the toilet less often	58.7%	28.0%	13.3%	75
Replaced toilets with more efficient models	33.3%	29.3%	37.3%	75
Careful to use less water washing dishes	70.7%	10.7%	18.7%	75
Installed a high-efficiency or ENERGY STAR dishwasher	32.0%	46.7%	21.3%	75
Careful to not let faucet run while washing, shaving, and brushing teeth	73.3%	6.7%	20.0%	75
Saved and used graywater (shower and laundry water) for landscaping	20.0%	76.0%	4.0%	75
Captured rainwater and used it for landscaping	17.3%	74.7%	8.0%	75
Washed the car less frequently	56.0%	28.0%	16.0%	75
Fixed leaky fixtures	52.0%	26.7%	21.3%	75
Saved and used cold water while waiting for hot water arrive at the tap	37.3%	52.0%	10.7%	75

Notes: Landscape measures screened to exclude "no" responses in Q8.

Q8: Does your yard have a landscape area that you water?

	Yes	No	n =
Boulder	93.1%	6.9%	101
Irvine Ranch	93.2%	6.8%	103
Monte Vista	90.0%	10.0%	100
Petaluma	96.0%	4.0%	99
San Antonio	69.0%	31.0%	100
Santa Fe	80.2%	19.8%	101
Santa Rosa	92.0%	8.0%	75
Total	87.5%	12.5%	679
n=	594	85	

Q9: How do you water your landscaping?

	Manual irrigation or sprinkler system	Automatic irrigation or sprinkler system	Hand water with a hose	n =
Boulder	29.8%	69.1%	51.1%	141
Irvine Ranch	15.6%	82.3%	62.5%	154
Monte Vista	31.1%	51.1%	68.9%	136
Petaluma	30.5%	62.1%	56.8%	142
San Antonio	37.7%	30.4%	79.7%	102
Santa Fe	38.3%	38.3%	71.6%	120
Santa Rosa	26.1%	65.2%	49.3%	97
Aggregate	29.5%	58.2%	62.5%	892
n=	350	692	742	

Q10: Does your household hire a professional landscaper to maintain your landscaping?

	Yes, a professional landscaper does most or all of it	No, we do it all ourselves	We hire a professional for a few landscaping tasks	n =
Boulder	9.6%	73.4%	17.0%	94
Irvine Ranch	47.9%	36.5%	15.6%	96
Monte Vista	23.3%	72.2%	4.4%	90
Petaluma	27.4%	62.1%	10.5%	95
San Antonio	11.6%	78.3%	10.1%	69
Santa Fe	8.6%	84.0%	7.4%	81
Santa Rosa	15.9%	75.4%	8.7%	69
Aggregate	21.6%	67.7%	10.8%	594
n=	128	402	64	

Q11: Who waters your landscape?

	A professional landscaper does all the watering	We do it all ourselves	The watering is split between us and the professional landscaper	n =
Boulder	1.1%	95.7%	3.2%	94
Irvine Ranch	2.1%	91.7%	6.3%	96
Monte Vista	1.1%	94.4%	4.4%	90
Petaluma	1.1%	94.7%	4.2%	95
San Antonio	2.9%	94.2%	2.9%	69
Santa Fe	1.2%	93.8%	4.9%	81
Santa Rosa	4.4%	92.8%	2.9%	69
Aggregate	1.9%	93.9%	4.2%	594
n=	11	558	25	

Q12: Please estimate the size of your lot or landscape area that is actually watered or irrigated

	Less than 1/4 acre	1/4 to 1/2 acre	1/2 to 1 acre	More than 1 acre	Don't know/ Unable to estimate	n =
Boulder	85.1%	10.6%	1.1%	0.0%	3.2%	94
Irvine Ranch	92.7%	5.2%	1.0%	0.0%	1.0%	96
Monte Vista	84.4%	10.0%	3.3%	0.0%	2.2%	90
Petaluma	91.6%	3.2%	1.1%	1.1%	3.2%	95
San Antonio	69.6%	23.2%	2.9%	0.0%	4.4%	69
Santa Fe	90.1%	3.7%	6.2%	0.0%	0.0%	81
Santa Rosa	85.5%	8.7%	5.8%	0.0%	0.0%	69
Aggregate	86.2%	8.8%	2.9%	0.2%	2.0%	594
n=	512	52	17	1	12	

Q13: Please estimate how much of your landscape area that you water is lawn or turf grass

	None	Less than 25%	25% to 50%	50% to 75%	75% or more	Don't know/ Unable to estimate	n =
Boulder	1.1%	18.1%	24.5%	35.1%	19.2%	2.1%	94
Irvine Ranch	11.5%	36.5%	26.0%	16.7%	9.4%	0.0%	96
Monte Vista	8.9%	26.7%	33.3%	8.9%	21.1%	1.1%	90
Petaluma	25.3%	37.9%	17.9%	4.2%	10.5%	4.2%	95
San Antonio	1.5%	27.5%	30.4%	18.8%	21.7%	0.0%	69
Santa Fe	60.5%	25.9%	8.6%	3.7%	1.2%	0.0%	81
Santa Rosa	27.5%	26.1%	23.2%	13.0%	10.1%	0.0%	69
Aggregate	19.0%	28.6%	23.4%	14.5%	13.3%	1.2%	594
n=	113	170	139	86	79	7	

Q14: Water rates may affect water use patterns. On a scale of 1 to 5, with 5 as the most important, has the cost of water bills been an important factor for your household in reducing water use in recent years?

	Don't know/ Unsure	Did not make effort to reduce water use	1 = Not very important	2	3	4	5 = Cost of water bills very important	n =
Boulder	1.0%	3.0%	36.6%	13.9%	16.8%	15.8%	12.9%	101
Irvine Ranch	1.0%	3.9%	17.5%	12.6%	24.3%	11.7%	29.1%	103
Monte Vista	1.0%	0.0%	22.0%	4.0%	13.0%	15.0%	45.0%	100
Petaluma	3.0%	1.0%	19.2%	2.0%	17.2%	21.2%	36.4%	99
San Antonio	2.0%	1.0%	26.0%	8.0%	11.0%	10.0%	42.0%	100
Santa Fe	1.0%	0.0%	23.8%	6.9%	9.9%	12.9%	45.5%	101
Santa Rosa	0.0%	0.0%	17.3%	4.0%	14.7%	26.7%	37.3%	75
Aggregate	1.3%	1.3%	23.4%	7.5%	15.3%	15.8%	35.4%	679
n=	9	9	159	51	104	107	240	

Q15: You already told us about steps to save water in a past drought. But if a more severe drought occurred, would your household consider doing the following steps to save water?

AGGREGATE

	Yes	No	Need more info to decide	Already do it	n=
Stop or cut way back on watering the lawn	62.9%	25.7%	5.7%	5.7%	35
Less watering for all landscaping	79.5%	12.8%	5.1%	2.6%	39
Replace lawn and high-water-use plants with drought tolerant plants	45.4%	37.1%	10.3%	7.2%	291
Shorter showers	56.6%	35.9%	0.5%	7.1%	198
Turn off water in the shower while soaping up	56.0%	41.3%	1.4%	1.4%	443
Wash fewer loads of clothes	42.7%	43.1%	2.2%	12.0%	225
Replace clothes washer with a more efficient front loader or ENERGY STAR® model	34.9%	41.0%	8.1%	16.0%	344
Flush the toilet less often	43.0%	51.8%	1.3%	4.0%	228
Replace toilets with more efficient models	44.6%	31.8%	5.6%	17.1%	321
Careful to use less water washing dishes	69.8%	21.9%	0.0%	8.4%	119
Install a high-efficiency or ENERGY STAR dishwasher	28.6%	50.5%	6.4%	14.4%	374
Careful to not let faucet run while washing, shaving, and brushing teeth	67.7%	23.1%	0.0%	9.2%	65
Save and use graywater (shower and laundry water) for landscaping	39.5%	41.9%	17.5%	1.0%	291
Capture rainwater and use it for landscaping	50.4%	39.4%	9.6%	0.7%	282
Wash the car less frequently	42.7%	34.7%	2.7%	20.0%	150
Fix leaky fixtures	71.8%	12.2%	0.8%	15.3%	131
Save and use cold water while waiting for hot water arrive at the tap	54.6%	36.4%	5.8%	3.3%	363

Notes: All Q15 questions screened for "no" on corresponding Q7 pick list. All landscape questions are screened for a "no" response on Q8. Q15_1 & Q15_3 are screened for "none" for amount of lawn or turf grass in Q13. As with Q7, the rainwater collection measure was not offered for Boulder. The graywater measure (Q15_13) was not offered for Irvine Ranch.

Q15: You already told us about steps to save water in a past drought. But if a more severe drought occurred, would your household consider doing the following steps to save water?

Boulder

	Yes	No	Need more info to decide	Already do it	n=
Stop or cut way back on watering the lawn	37.5%	37.5%	12.5%	12.5%	8
Less watering for all landscaping	72.7%	18.2%	9.1%	0.0%	11
Replace lawn and high-water-use plants with drought tolerant plants	42.1%	42.1%	5.3%	10.5%	57
Shorter showers	50.0%	46.9%	0.0%	3.1%	32
Turn off water in the shower while soaping up	37.0%	58.9%	2.7%	1.4%	73
Wash fewer loads of clothes	37.0%	48.2%	3.7%	11.1%	54
Replace clothes washer with a more efficient front loader or ENERGY STAR® model	24.6%	31.9%	13.0%	30.4%	69
Flush the toilet less often	22.7%	68.2%	4.6%	4.6%	22
Replace toilets with more efficient models	27.6%	39.5%	6.6%	26.3%	76
Careful to use less water washing dishes	66.7%	30.3%	0.0%	3.0%	33
Install a high-efficiency or ENERGY STAR dishwasher	23.5%	38.2%	10.3%	27.9%	68
Careful to not let faucet run while washing, shaving, and brushing teeth	41.7%	41.7%	0.0%	16.7%	12
Save and use graywater (shower and laundry water) for landscaping	30.8%	47.7%	21.5%	0.0%	65
Capture rainwater and use it for landscaping	N/A	N/A	N/A	N/A	N/A
Wash the car less frequently	47.8%	43.5%	0.0%	8.7%	23
Fix leaky fixtures	67.9%	14.3%	3.6%	14.3%	28
Save and use cold water while waiting for hot water arrive at the tap	55.6%	37.0%	5.6%	1.9%	54

Notes: All Q15 questions were screened for "no" on the corresponding Q7 pick list measure. All landscape questions were screened for a "no" response on Q8. Q15_1 & Q15_3 are screened for "none" for amount of lawn or turf grass in Q13. The rainwater capture measure (Q15_14) was not offered in Boulder due to water rights restrictions in Colorado.

Q15: You already told us about steps to save water in a past drought. But if a more severe drought occurred, would your household consider doing the following steps to save water?

Irvine Ranch

	Yes	No	Need more info to decide	Already do it	n=
Stop or cut way back on watering the lawn	75.0%	12.5%	12.5%	0.0%	8
Less watering for all landscaping	100.0%	0.0%	0.0%	0.0%	5
Replace lawn and high-water-use plants with drought tolerant plants	51.9%	35.2%	9.3%	3.7%	54
Shorter showers	70.0%	23.3%	0.0%	6.7%	30
Turn off water in the shower while soaping up	63.2%	35.3%	0.0%	1.5%	68
Wash fewer loads of clothes	44.4%	41.7%	5.6%	8.3%	36
Replace clothes washer with a more efficient front loader or ENERGY STAR® model	40.5%	24.3%	8.1%	27.0%	37
Flush the toilet less often	46.6%	51.7%	0.0%	1.7%	58
Replace toilets with more efficient models	59.6%	9.6%	7.7%	23.1%	52
Careful to use less water washing dishes	89.5%	5.3%	0.0%	5.3%	19
Install a high-efficiency or ENERGY STAR dishwasher	50.0%	25.0%	0.0%	25.0%	40
Careful to not let faucet run while washing, shaving, and brushing teeth	87.5%	0.0%	0.0%	12.5%	8
Save and use graywater (shower and laundry water) for landscaping	N/A	N/A	N/A	N/A	N/A
Capture rainwater and use it for landscaping	46.1%	42.7%	11.2%	0.0%	89
Wash the car less frequently	48.0%	28.0%	0.0%	24.0%	25
Fix leaky fixtures	93.8%	0.0%	0.0%	6.3%	16
Save and use cold water while waiting for hot water arrive at the tap	54.1%	37.7%	6.6%	1.6%	61

Notes: All Q15 questions screened for "no" on corresponding Q7 pick list. All landscape questions were screened for a "no" response on Q8. Q15_1 & Q15_3 are screened for “none” for amount of lawn or turf grass in Q13. The graywater measure (Q15_13) was not offered for Irvine.

Q15: You already told us about steps to save water in a past drought. But if a more severe drought occurred, would your household consider doing the following steps to save water?

Monte Vista

	Yes	No	Need more info to decide	Already do it	n=
Stop or cut way back on watering the lawn	66.7%	33.3%	0.0%	0.0%	3
Less watering for all landscaping	80.0%	10.0%	10.0%	0.0%	10
Replace lawn and high-water-use plants with drought tolerant plants	32.0%	40.0%	20.0%	8.0%	50
Shorter showers	50.0%	40.9%	4.6%	4.6%	22
Turn off water in the shower while soaping up	55.0%	40.0%	3.3%	1.7%	60
Wash fewer loads of clothes	45.5%	40.9%	0.0%	13.6%	22
Replace clothes washer with a more efficient front loader or ENERGY STAR® model	39.0%	39.0%	17.1%	4.9%	41
Flush the toilet less often	46.0%	46.0%	5.4%	2.7%	37
Replace toilets with more efficient models	46.3%	41.5%	4.9%	7.3%	41
Careful to use less water washing dishes	64.3%	14.3%	0.0%	21.4%	14
Install a high-efficiency or ENERGY STAR dishwasher	18.2%	65.2%	12.1%	4.6%	66
Careful to not let faucet run while washing, shaving, and brushing teeth	87.5%	0.0%	0.0%	12.5%	8
Save and use graywater (shower and laundry water) for landscaping	37.2%	47.4%	14.1%	1.3%	78
Capture rainwater and use it for landscaping	49.3%	39.7%	8.2%	2.7%	73
Wash the car less frequently	33.3%	40.0%	6.7%	20.0%	15
Fix leaky fixtures	75.0%	8.3%	0.0%	16.7%	12
Save and use cold water while waiting for hot water arrive at the tap	56.9%	36.2%	5.2%	1.7%	58

Notes: All Q15 questions screened for "no" on corresponding Q7 pick list. All landscape questions were screened for a "no" response on Q8. Q15_1 & Q15_3 are screened for “none” for amount of lawn or turf grass in Q13.

Q15: You already told us about steps to save water in a past drought. But if a more severe drought occurred, would your household consider doing the following steps to save water?

Petaluma

	Yes	No	Need more info to decide	Already do it	n=
Stop or cut way back on watering the lawn	66.7%	33.3%	0.0%	0.0%	6
Less watering for all landscaping	100.0%	0.0%	0.0%	0.0%	9
Replace lawn and high-water-use plants with drought tolerant plants	51.2%	37.2%	4.7%	7.0%	43
Shorter showers	56.0%	32.0%	0.0%	12.0%	25
Turn off water in the shower while soaping up	50.8%	45.9%	1.6%	1.6%	61
Wash fewer loads of clothes	47.4%	36.8%	2.6%	13.2%	38
Replace clothes washer with a more efficient front loader or ENERGY STAR® model	42.9%	40.5%	0.0%	16.7%	42
Flush the toilet less often	48.0%	44.0%	0.0%	8.0%	25
Replace toilets with more efficient models	54.2%	27.1%	6.3%	12.5%	48
Careful to use less water washing dishes	76.9%	7.7%	0.0%	15.4%	13
Install a high-efficiency or ENERGY STAR dishwasher	35.4%	39.6%	2.1%	22.9%	48
Careful to not let faucet run while washing, shaving, and brushing teeth	50.0%	50.0%	0.0%	0.0%	2
Save and use graywater (shower and laundry water) for landscaping	45.6%	38.0%	15.2%	1.3%	79
Capture rainwater and use it for landscaping	54.2%	34.9%	8.4%	2.4%	83
Wash the car less frequently	43.8%	37.5%	0.0%	18.8%	16
Fix leaky fixtures	68.4%	21.1%	0.0%	10.5%	19
Save and use cold water while waiting for hot water arrive at the tap	63.2%	26.3%	7.0%	3.5%	57

Notes: All Q15 questions screened for "no" on corresponding Q7 pick list. All landscape questions were screened for a "no" response on Q8. Q15_1 & Q15_3 are screened for “none” for amount of lawn or turf grass in Q13.

Q15: You already told us about steps to save water in a past drought. But if a more severe drought occurred, would your household consider doing the following steps to save water?

San Antonio

	Yes	No	Need more info to decide	Already do it	n=
Stop or cut way back on watering the lawn	80.0%	20.0%	0.0%	0.0%	5
Less watering for all landscaping	78.6%	14.3%	0.0%	7.1%	14
Replace lawn and high-water-use plants with drought tolerant plants	47.5%	35.0%	15.0%	2.5%	40
Shorter showers	61.9%	28.6%	0.0%	9.5%	42
Turn off water in the shower while soaping up	52.4%	47.6%	0.0%	0.0%	63
Wash fewer loads of clothes	34.5%	55.2%	0.0%	10.3%	29
Replace clothes washer with a more efficient front loader or ENERGY STAR® model	33.3%	55.6%	7.9%	3.2%	63
Flush the toilet less often	39.0%	56.1%	0.0%	4.9%	41
Replace toilets with more efficient models	51.2%	39.5%	4.7%	4.7%	43
Careful to use less water washing dishes	57.9%	36.8%	0.0%	5.3%	19
Install a high-efficiency or ENERGY STAR dishwasher	22.2%	66.7%	6.4%	4.8%	63
Careful to not let faucet run while washing, shaving, and brushing teeth	76.5%	23.5%	0.0%	0.0%	17
Save and use graywater (shower and laundry water) for landscaping	39.0%	50.0%	8.5%	2.4%	82
Capture rainwater and use it for landscaping	47.1%	41.2%	10.3%	1.5%	68
Wash the car less frequently	44.0%	36.0%	8.0%	12.0%	25
Fix leaky fixtures	76.2%	19.1%	0.0%	4.8%	21
Save and use cold water while waiting for hot water arrive at the tap	45.3%	47.2%	3.8%	3.8%	53

Notes: All Q15 questions screened for "no" on corresponding Q7 pick list. All landscape questions were screened for a "no" response on Q8. Q15_1 & Q15_3 are screened for “none” for amount of lawn or turf grass in Q13.

Q15: You already told us about steps to save water in a past drought. But if a more severe drought occurred, would your household consider doing the following steps to save water?

Santa Fe

	Yes	No	Need more info to decide	Already do it	n=
Stop or cut way back on watering the lawn	100.0%	0.0%	0.0%	0.0%	2
Less watering for all landscaping	37.5%	37.5%	25.0%	0.0%	8
Replace lawn and high-water-use plants with drought tolerant plants	53.3%	33.3%	0.0%	13.3%	15
Shorter showers	45.8%	45.8%	0.0%	8.3%	24
Turn off water in the shower while soaping up	68.7%	28.4%	0.0%	3.0%	67
Wash fewer loads of clothes	68.0%	16.0%	0.0%	16.0%	25
Replace clothes washer with a more efficient front loader or ENERGY STAR® model	35.6%	49.2%	5.1%	10.2%	59
Flush the toilet less often	41.7%	54.2%	0.0%	4.2%	24
Replace toilets with more efficient models	40.6%	37.5%	6.3%	15.6%	32
Careful to use less water washing dishes	61.5%	30.8%	0.0%	7.7%	13
Install a high-efficiency or ENERGY STAR dishwasher	24.1%	59.3%	5.6%	11.1%	54
Careful to not let faucet run while washing, shaving, and brushing teeth	61.5%	30.8%	0.0%	7.7%	13
Save and use graywater (shower and laundry water) for landscaping	32.3%	43.6%	17.7%	6.5%	62
Capture rainwater and use it for landscaping	47.2%	44.4%	8.3%	0.0%	36
Wash the car less frequently	20.0%	44.0%	0.0%	36.0%	25
Fix leaky fixtures	53.3%	13.3%	0.0%	33.3%	15
Save and use cold water while waiting for hot water arrive at the tap	46.3%	41.5%	2.4%	9.8%	41

Notes: All Q15 questions screened for "no" on corresponding Q7 pick list. All landscape questions were screened for a "no" response on Q8. Q15_1 & Q15_3 are screened for “none” for amount of lawn or turf grass in Q13.

Q15: You already told us about steps to save water in a past drought. But if a more severe drought occurred, would your household consider doing the following steps to save water?

Santa Rosa

	Yes	No	Need more info to decide	Already do it	n=
Stop or cut way back on watering the lawn	33.3%	33.3%	0.0%	33.3%	3
Less watering for all landscaping	66.7%	0.0%	33.3%	0.0%	6
Replace lawn and high-water-use plants with drought tolerant plants	46.9%	31.3%	12.5%	9.4%	32
Shorter showers	56.5%	39.1%	0.0%	4.4%	23
Turn off water in the shower while soaping up	68.6%	29.4%	2.0%	0.0%	51
Wash fewer loads of clothes	23.8%	61.9%	0.0%	14.3%	21
Replace clothes washer with a more efficient front loader or ENERGY STAR® model	36.4%	39.4%	3.0%	21.2%	33
Flush the toilet less often	52.4%	42.9%	0.0%	4.8%	21
Replace toilets with more efficient models	37.9%	27.6%	10.3%	24.1%	29
Careful to use less water washing dishes	75.0%	12.5%	0.0%	12.5%	8
Install a high-efficiency or ENERGY STAR dishwasher	42.9%	48.6%	2.9%	5.7%	35
Careful to not let faucet run while washing, shaving, and brushing teeth	60.0%	20.0%	0.0%	20.0%	5
Save and use graywater (shower and laundry water) for landscaping	35.1%	45.6%	19.3%	0.0%	57
Capture rainwater and use it for landscaping	37.5%	55.4%	7.1%	0.0%	56
Wash the car less frequently	61.9%	14.3%	4.8%	19.1%	21
Fix leaky fixtures	70.0%	5.0%	0.0%	25.0%	20
Save and use cold water while waiting for hot water arrive at the tap	59.0%	28.2%	10.3%	2.6%	39

Notes: All Q15 questions screened for "no" on corresponding Q7 pick list. All landscape questions were screened for a "no" response on Q8. Q15_1 & Q15_3 are screened for “none” for amount of lawn or turf grass in Q13.

Q16: If a more severe drought occurred in the future, how much of your normal water use do you estimate you could save?

	None	5-10%	11-20%	21-30%	31-40%	41-50%	>50%	Don't know/Unable to estimate	n=
Boulder	3.0%	32.7%	23.8%	16.8%	7.9%	2.0%	1.0%	12.9%	101
Irvine Ranch	1.0%	40.8%	29.1%	11.7%	2.9%	2.9%	0.0%	11.7%	103
Monte Vista	6.0%	43.0%	16.0%	10.0%	3.0%	2.0%	0.0%	20.0%	100
Petaluma	4.0%	50.5%	15.2%	15.2%	1.0%	1.0%	1.0%	12.1%	99
San Antonio	4.0%	40.0%	22.0%	8.0%	5.0%	2.0%	0.0%	19.0%	100
Santa Fe	10.9%	27.7%	22.8%	13.9%	0.0%	1.0%	1.0%	22.8%	101
Santa Rosa	4.0%	40.0%	25.3%	16.0%	1.3%	1.3%	0.0%	12.0%	75
Aggregate	4.7%	39.2%	21.9%	13.0%	3.1%	1.8%	0.4%	15.9%	679
n=	32	266	149	88	21	12	3	108	

Notes: Q16 responses were recoded into categories to capture the open ended responses and represent them with the pick list responses.

Q17: The recession may have affected water use for some customers. On a scale of 1 to 5, with 5 as the most important, how important was the recent recession for your water use in recent years?

	The recession did not affect my water use	1 = Not very important for my water use	2	3	4	5 = Most important for my water use	Don't know/ unsure	n =
Boulder	31.7%	42.6%	7.9%	8.9%	5.0%	4.0%	0.0%	101
Irvine Ranch	45.6%	16.5%	5.8%	8.7%	7.8%	14.6%	1.0%	103
Monte Vista	15.0%	19.0%	5.0%	15.0%	12.0%	26.0%	8.0%	100
Petaluma	28.3%	15.2%	7.1%	22.2%	8.1%	17.2%	2.0%	99
San Antonio	32.0%	22.0%	9.0%	12.0%	4.0%	18.0%	3.0%	100
Santa Fe	25.7%	25.7%	5.0%	8.9%	11.9%	17.8%	5.0%	101
Santa Rosa	18.7%	42.7%	5.3%	16.0%	8.0%	9.3%	0.0%	75
Aggregate	28.6%	25.6%	6.5%	13.0%	8.1%	15.5%	2.8%	679
n=	194	174	44	88	55	105	19	

Q18: Would you prefer to use less water in a drought, or have the utility spend more money on a new water supply project that may only be needed in drought years, but would increase the cost of water bills every year and may have environmental impacts?

	Prefer to use less water during a drought	Prefer to be charged for more expensive supplies	Don't know/ unsure	n =
Boulder	76.2%	9.9%	13.9%	101
Monte Vista	87.0%	10.0%	3.0%	100
Petaluma	83.8%	7.1%	9.1%	99
San Antonio	71.0%	14.0%	15.0%	100
Santa Fe	69.3%	11.9%	18.8%	101
Santa Rosa	86.7%	2.7%	10.7%	75
Aggregate	78.6%	9.5%	11.8%	576
n=	453	55	68	

Notes: For Monte Vista, the question was rephrased to *"If a shortage of imported water occurs during a severe drought, Monte Vista Water District would have to curtail use, or provide more expensive water supplies. Would you prefer to use less water, or be charged for more expensive water supplies if a shortage occurs due to drought?"* Q18 was not asked in Irvine Ranch.

Q19: Do you agree or disagree with the following statement? "Your household would be willing to conserve more water in wet years if the water utility would hold it as a reserve for future drought years."

	Strongly disagree	Somewhat disagree	Somewhat agree	Strongly agree	Don't know/ unsure	n =
Boulder	7.9%	7.9%	33.7%	45.5%	5.0%	101
Irvine Ranch	0.0%	6.8%	39.8%	45.6%	7.8%	103
Monte Vista	4.0%	5.0%	24.0%	58.0%	9.0%	100
Petaluma	0.0%	5.1%	37.4%	50.5%	7.1%	99
San Antonio	2.0%	2.0%	30.0%	58.0%	8.0%	100
Santa Fe	7.9%	5.0%	33.7%	38.6%	14.9%	101
Santa Rosa	5.3%	4.0%	24.0%	61.3%	5.3%	75
Aggregate	3.8%	5.2%	32.1%	50.7%	8.3%	679
n=	26	35	218	344	56	

Q-PPH: How many persons, including yourself, live in your household?

	1	2	3	4	5	6	7	8	10	Declined	n=
Boulder	16.8%	54.5%	16.8%	8.9%	3.0%	0.0%	0.0%	0.0%	0.0%	0.0%	101
Irvine Ranch	3.9%	35.9%	13.6%	30.1%	11.7%	3.9%	0.0%	0.0%	1.0%	0.0%	103
Monte Vista	14.0%	33.0%	16.0%	17.0%	7.0%	6.0%	4.0%	3.0%	0.0%	0.0%	100
Petaluma	17.2%	45.5%	20.2%	13.1%	2.0%	1.0%	1.0%	0.0%	0.0%	0.0%	99
San Antonio	16.0%	44.0%	19.0%	10.0%	7.0%	3.0%	1.0%	0.0%	0.0%	0.0%	100
Santa Fe	29.7%	46.5%	16.8%	5.9%	0.0%	0.0%	0.0%	0.0%	0.0%	1.0%	101
Santa Rosa	25.3%	54.7%	6.7%	8.0%	4.0%	1.3%	0.0%	0.0%	0.0%	0.0%	75
Aggregate	17.2%	44.5%	15.9%	13.6%	5.0%	2.2%	0.9%	0.4%	0.2%	0.2%	679
n=	117	302	108	92	34	15	6	3	1	1	

Q-PPH2: How many persons, including yourself, live in your household during the drought years ___ (most recent drought years)?

	1	2	3	4	5	6	7	8	9	10	22	Declined	n=
Boulder	7.9%	36.6%	26.7%	22.8%	4.0%	1.0%	0.0%	0.0%	1.0%	0.0%	0.0%	0.0%	101
Irvine Ranch	2.9%	22.3%	13.6%	39.8%	16.5%	2.9%	0.0%	0.0%	0.0%	1.0%	1.0%	0.0%	103
Monte Vista	11.0%	36.0%	15.0%	17.0%	8.0%	7.0%	3.0%	2.0%	1.0%	0.0%	0.0%	0.0%	100
Petaluma	14.1%	40.4%	20.2%	18.2%	5.1%	1.0%	1.0%	0.0%	0.0%	0.0%	0.0%	0.0%	99
San Antonio	13.0%	46.0%	14.0%	14.0%	11.0%	2.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	100
Santa Fe	22.8%	37.6%	20.8%	10.9%	3.0%	1.0%	1.0%	1.0%	0.0%	0.0%	0.0%	2.0%	101
Santa Rosa	18.7%	48.0%	17.3%	9.3%	5.3%	1.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	75
Aggregate	12.7%	37.7%	18.3%	19.3%	7.7%	2.4%	0.7%	0.4%	0.3%	0.2%	0.2%	0.3%	679
n=	86	256	124	131	52	16	5	3	2	1	1	2	

Q-TEN: Is your residence owned by someone in your household, or rented?

	Owned	Rented	Declined	n=
Boulder	99.0%	1.0%	0.0%	101
Irvine Ranch	96.1%	2.9%	1.0%	103
Monte Vista	96.0%	3.0%	1.0%	100
Petaluma	96.0%	4.0%	0.0%	99
San Antonio	99.0%	1.0%	0.0%	100
Santa Fe	99.0%	0.0%	1.0%	101
Santa Rosa	93.3%	5.3%	1.3%	101
Aggregate	97.1%	2.4%	0.6%	75
n=	659	16	4	

Q-EDU: What is the highest level of education a member of your household has completed?

	High school or less	At least one year of college, trade or vocational school	Bachelor's degree	Master's or PhD	Declined	n=
Boulder	2.0%	8.9%	26.7%	62.4%	0.0%	101
Irvine Ranch	1.0%	12.6%	41.8%	42.7%	1.9%	103
Monte Vista	27.0%	39.0%	21.0%	12.0%	1.0%	100
Petaluma	11.1%	22.2%	35.4%	28.3%	3.0%	99
San Antonio	29.0%	19.0%	25.0%	26.0%	1.0%	100
Santa Fe	9.9%	13.9%	26.7%	48.5%	1.0%	101
Santa Rosa	9.3%	16.0%	42.7%	30.7%	1.3%	75
Aggregate	12.8%	18.9%	30.9%	36.1%	1.3%	679
n=	87	125	210	245	9	

Q-AGE

	27 to 34	35 to 44	45 to 54	55 to 64	65 or over	Declined	n=
Boulder	0.0%	3.0%	13.9%	37.6%	42.6%	3.0%	101
Irvine Ranch	1.9%	16.5%	37.9%	23.3%	18.5%	1.9%	103
Monte Vista	2.0%	11.0%	17.0%	29.0%	40.0%	1.0%	100
Petaluma	2.0%	7.1%	22.2%	22.2%	42.4%	4.0%	99
San Antonio	0.0%	11.0%	19.0%	24.0%	44.0%	2.0%	100
Santa Fe	1.0%	5.0%	7.9%	24.8%	58.4%	3.0%	101
Santa Rosa	0.0%	1.3%	25.3%	18.7%	53.3%	1.3%	75
Aggregate	1.0%	8.1%	20.3%	25.9%	42.3%	2.4%	679
n=	7	55	138	176	287	16	

Q-ETH: Ethnic background

	White	Black	Hispanic	Asian or Pacific Islander	Native American	Middle Eastern	Other	Declined	n=
Boulder	89.1%	0.0%	1.0%	2.0%	0.0%	1.0%	0.0%	5.9%	101
Irvine Ranch	59.2%	1.0%	5.8%	25.2%	0.0%	0.0%	1.0%	7.8%	103
Monte Vista	49.0%	2.0%	38.0%	5.0%	2.0%	0.0%	1.0%	3.0%	100
Petaluma	88.9%	3.0%	2.0%	1.0%	0.0%	1.0%	1.0%	3.0%	99
San Antonio	51.0%	6.0%	35.0%	2.0%	1.0%	0.0%	2.0%	3.0%	100
Santa Fe	51.5%	0.0%	36.6%	1.0%	1.0%	1.0%	0.0%	8.9%	101
Santa Rosa	85.3%	0.0%	0.0%	5.3%	1.3%	0.0%	1.3%	6.7%	75
Aggregate	67.0%	1.8%	17.5%	6.0%	0.7%	0.4%	90.0%	5.6%	679
n=	455	12	119	41	5	3	6	38	

Q-INC: Household income

	Under $25,000	$26,000 to $50,000	$51,000 to $75,000	$76,000 to $100,000	$101,000 to $150,000	Over $150,000	Declined	n=
Boulder	5.9%	10.9%	10.9%	16.8%	22.8%	12.9%	19.8%	101
Irvine Ranch	0.0%	4.9%	8.7%	12.6%	21.4%	29.1%	23.3%	103
Monte Vista	20.0%	32.0%	14.0%	7.0%	6.0%	7.0%	14.0%	100
Petaluma	5.1%	18.2%	24.2%	13.1%	13.1%	5.1%	21.2%	99
San Antonio	19.0%	16.0%	20.0%	20.0%	6.0%	3.0%	16.0%	100
Santa Fe	8.9%	30.7%	16.8%	5.9%	8.9%	5.9%	21.8%	101
Santa Rosa	5.3%	28.0%	16.0%	12.0%	16.0%	10.7%	12.0%	75
Aggregate	9.3%	19.7%	15.8%	12.5%	13.4%	10.6%	18.6%	679
n=	63	134	107	85	91	72	127	

APPENDIX B: DEVICE TURNOVER MODELS

In the absence of saturation surveys, water planners use turnover models to estimate saturation of efficient plumbing fixtures and appliances, usually with the aim of estimating remaining conservation potential in a specific end use, such as toilet flushing, clothes washing, showering, etc. These turnover models rest partially on real data (e.g., number and type of fixtures and appliances installed per year via incentive or possibly direct-install programs, housing and demographic data) and partially on assumptions (e.g., the natural replacement rate, program free-ridership rate).

Natural replacement plus plumbing codes restrict purchases to water-efficient devices making natural replacement a powerful force that causes the stock of plumbing fixtures and appliances to become more efficient over time even in the absence of active retrofit programs. Since federal efficiency standards went into effect in 1992, only ultra-low-flush toilets (ULFT) and low-flow showerheads have been available for replacement in old homes or installation in new homes built after that year. Water suppliers also have been promoting high-efficiency toilet (HET) retrofits in recent years. Similarly, the federal clothes washer efficiency standards of 2007 and the ENERGY STAR® labeling program has caused many customers to opt for these water and energy efficient clothes washers. We assume that the natural turnover rate of toilets is 4% per year; of clothes washers, 7.1% per year. These assumptions in turn imply that the average life of a toilet is 25 years; of clothes washers, 14 years. These assumptions have been commonly used in California for evaluating the impact of water conservation programs.[36] Another set of assumptions involve program free ridership. Free ridership refers to some percentage of customers taking advantage of rebate programs when one is available to replace a broken fixture or appliance. Such fixtures and appliances would have been replaced anyway, thus are counted under the natural replacement category. To also count them under replacements caused by active retrofit programs amounts to double counting. We have assumed that free ridership in toilet retrofit programs is 25%; in clothes washer programs, 10%. These assumptions were also taken from the report cited earlier.

Detailed data were collected from each case study about the number of toilets and clothes washers rebated by year. Some case studies were able to separate residential toilet rebates issued to single-family customers from those issued to multi-family customers. For those that could not, we have assumed that rebates went to single-family customers roughly in line with their proportion of total population. Clothes washer rebates, however, were all assumed to have gone to single-family customers. Water Factors (WF) of the new rebated washers were unavailable. We assumed rebated washers had a WF between 6.0 and 8.5, and that naturally replaced washers or washers installed in new homes were distributed about 85% with a WF of 11.7 (the estimated norm in 1999), with three-fourths of the remainder having a WF between 8.5 and 9.5 and one-fourth a WF between 6.0 and 8.5. As long as these assumptions are made uniformly across all case studies it is possible to test whether saturation differences observed in the telephone survey tracks differences predicted by these turnover models.

Figure 14 and 15 compare results of the turnover models with those of the telephone survey. With respect to the saturation of efficient toilets (ULFTs and HETs taken together), the turnover models track

[36] CALFED Bay-Delta Program Water Use Efficiency Element, *Water Use Efficiency Comprehensive Evaluation*, August 2006.

the survey results quite well. Where the telephone survey indicates a higher level of efficiency, so does the turnover model. In general, the turnover models over-predict saturation of efficient toilets, but this does not matter for the purpose at hand. Minor exceptions to the general rule are Santa Fe with telephone surveys suggesting a somewhat higher saturation rate compared to their toilet turnover model and Monte Vista where the gap between the two metrics is the greatest. Monte Vista has participated in a regional toilet rebate program run by the Metropolitan Water District of Southern California for many years. It is possible that the regional data allocates more rebated toilets to Monte Vista than it should. Boulder has the lowest saturation of efficient toilets, consistent with the city having grown the slowest compared to the other six case studies. Slow growth cities rely more on natural turnover and active programs to boost the saturation of efficient plumbing fixtures, whereas high growth cities have a third factor working in their favor, namely, newer homes outfitted with the latest code-compliant fixtures being added to the housing stock year after year.

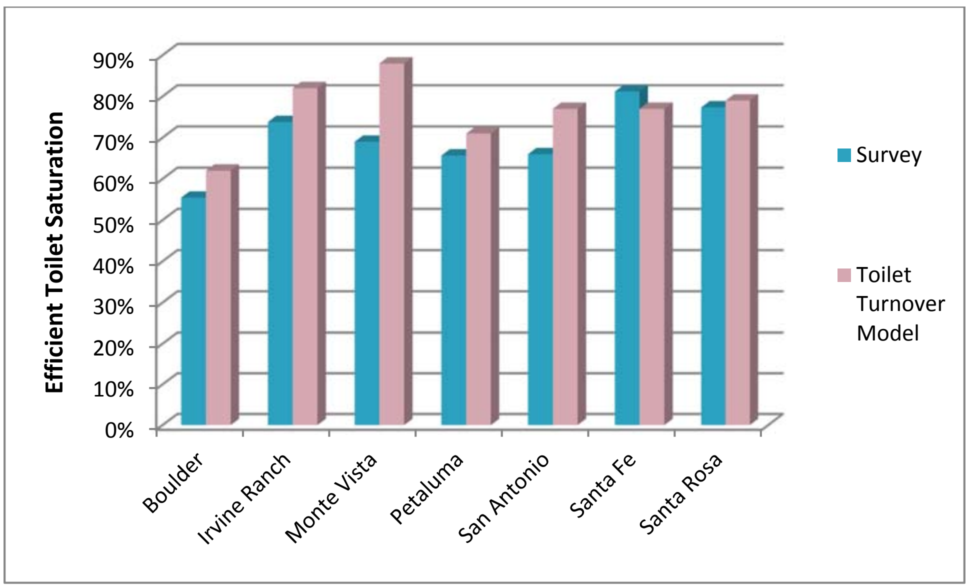

Figure 14. Efficient Toilet Saturation: Survey versus Turnover Model

Figure 15 compares saturation of efficient clothes washers obtained from the telephone survey with predicted average WF from the washer turnover model. The telephone survey directly asks whether the respondent replaced their old washer with either a front loader or an ENERGY STAR model, so it is possible to estimate a saturation of efficient clothes washers. With the turnover model, there is no clear definition available of an efficient washer since washer WFs span a large spectrum. Thus, derivation of the percentage of all washers that can be considered efficient is difficult to do through a turnover model. The best one can do is to derive an average WF for the entire single-family sector. Once again, it is the pattern of variation in WFs across case studies that is more important, not the exact magnitude of the average WF. These patterns once again indicate a fairly tight correspondence between the two metrics in Figure 15. Where the telephone survey suggests a higher saturation of efficient washers, the turnover models predict a lower average WF for the single-family sector as a whole, and vice versa.

Figures 14 and 15 taken together suggest that the inter-case study differences that can be observed in many of the survey responses reflect meaningful differences. They are not simply artifacts of the respondent samples themselves.

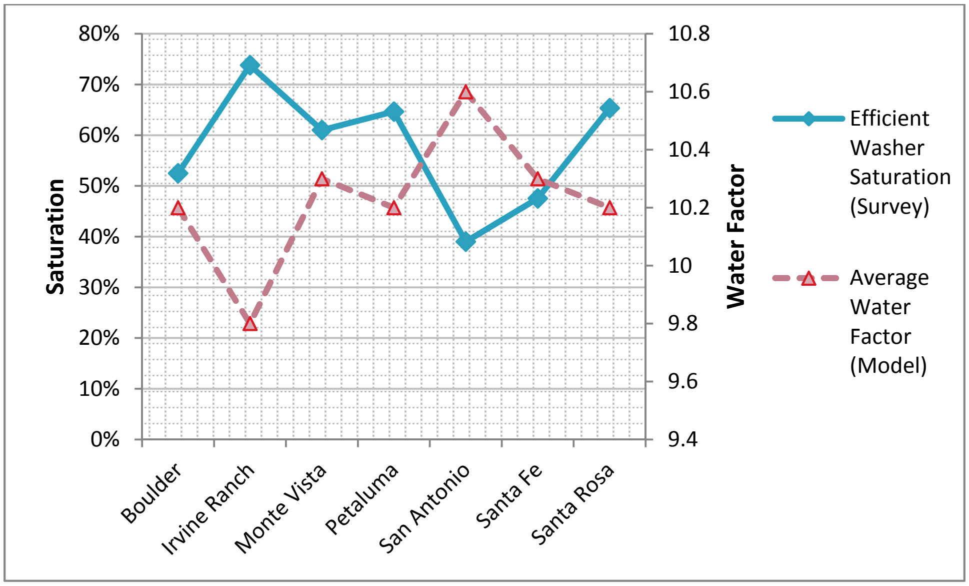

Figure 15. Efficient Clothes Washer Saturation: Survey versus Turnover Model

APPENDIX C: WATER SHORTAGE CONTINGENCY PLANS

Boulder
https://www-static.bouldercolorado.gov/docs/drought-rules-and-regulations-1-201304021224.pdf

Irvine Ranch *(included in 2010 Urban Water Management Plan)*
http://www.irwd.com/images/pdf/doing-business/engineering/Final_2010UWMP-061311.pdf

Monte Vista
http://www.mvwd.org/download.cfm?ID=19

Petaluma *(included in 2010 Urban Water Management Plan)*
http://cityofpetaluma.net/wrcd/pdf/2010_uwmp_final.pdf

San Antonio
http://www.saws.org/conservation/droughtrestrictions/

Santa Fe
http://www.santafenm.gov/water_use_restrictions

Santa Rosa
http://ci.santa-rosa.ca.us/departments/utilities/conserve/water_policies/Pages/WaterShortageContingencyPlan.aspx