JOURNAL OF THE AMERICAN WATER RESOURCES ASSOCIATION
FEBRUARY AMERICAN WATER RESOURCES ASSOCIATION 2004

USE AND EFFECTIVENESS OF MUNICIPAL WATER RESTRICTIONS DURING DROUGHT IN COLORADO[1]

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ABSTRACT: Drought conditions in the summer of 2002 prompted several cities along Colorado's Front Range to enact restrictions on outdoor water use, focusing primarily on limiting the frequency of lawn watering. The different approaches utilized by eight water providers were tracked to determine the level of water savings achieved, measured as a comparison of 2002 usage to 2000 to 2001 average usage, and also based on a statistical estimate of 2002 "expected use" that accounts for the impact of drought conditions on demand. Mandatory restrictions were shown to be an effective tool for drought coping. During periods of mandatory restrictions, savings measured in expected use per capita ranged from 18 to 56 percent, compared to just 4 to 12 percent savings during periods of voluntary restrictions. As anticipated, providers with the most stringent restrictions achieved the greatest savings.
(KEY TERMS: water conservation; drought; water restrictions; urban water management.)

Kenney, Douglas S., Roberta A. Klein, and Martyn P. Clark, 2004. Use and Effectiveness of Municipal Water Restrictions During Drought in Colorado. Journal of the American Water Resources Association (JAWRA) 40(1):77-87.

INTRODUCTION

There is a long tradition in municipal governments to base water plans and associated water development activities on high growth scenarios, extreme drought conditions, and only a modest level of water conservation savings (Baumann *et al.,* 1998). This worst case scenario planning greatly limits the risk of experiencing water shortages and thus the political fallout that can accompany such an event. For this reason, most municipal residents in the United States, even in arid and semi-arid regions, rarely if ever experience shortages at the tap. It takes something truly out of the ordinary to seriously test the resilience of most municipal water systems.

In the summer of 2002, residents in the Denver metro area experienced something out of the ordinary. A few relatively dry but otherwise uneventful years quickly developed into the most extreme drought on record, surpassing even the 1954 drought often used for planning purposes. Faced with rapidly declining water supplies and the prospects of real shortages, most municipalities in the region turned to outdoor lawn watering restrictions as an emergency coping mechanism. Restrictions, both voluntary and mandatory, were coupled with public education campaigns and sometimes included other elements such as price increases.

In this study the experiences of municipal water providers serving the following cities along Colorado's northern Front Range were tracked: Aurora, Boulder, Fort Collins, Lafayette, Louisville, Thornton, and Westminster. Denver Water also was tracked. In addition to serving Colorado's largest city, Denver Water provides full or partial supplies to approximately 90 surrounding communities and water districts (Hydrosphere Resource Consultants, Inc.; HRS Water Consultants, Inc.; Mulhern MRE, Inc.; and Spronk Water Engineers, Inc., 1999, unpublished report). As shown in Table 1, these eight providers collectively serve more than 1.85 million customers. Each of the eight municipal water providers studied operates with a different mix of supply sources and water rights portfolios, and each enacted a slightly different suite of

[1]Paper No. 03072 of the *Journal of the American Water Resources Association* (JAWRA) (Copyright © 2004). **Discussions are open until August 1, 2004.**
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policies to deal with the crisis. This paper documents the various approaches they used and evaluates if voluntary and/or mandatory restrictions were effective in reducing water consumption and if so, to what extent. This information is useful in a variety of ways: e.g., in evaluating the effectiveness of actions taken in 2002; for comparing (and presumably learning from) the different approaches across the eight regions; in evaluating and designing future strategies for drought coping; and perhaps in illuminating potential opportunities for achieving longer term conservation savings. This information is useful not only to water managers, but to city council members and other local officials called upon to design, enact, and enforce emergency measures.

TABLE 1. Population and Growth Rates of Study Regions.

Municipality	Estimated 2002 Population	Average Annual Change in Population 1999 to 2001 (percent)
Aurora	289,325	2.0
Boulder	94,621	-0.1
Denver Water	1,100,000	4.0
Fort Collins	125,953	2.8
Lafayette	24,309	3.2
Louisville	18,914	-0.2
Thornton	93,363	5.6
Westminster	104,642	1.7
Total	1,851,127	

DROUGHT CRISIS AND RESPONSE

The Drought Crisis of Summer 2002

Colorado is no stranger to drought, defined by the state as occurring when "a normal amount of moisture is not available to satisfy an area's usual water-consuming activities" (State of Colorado, 2002). Receiving an average of only 17 inches of precipitation a year, Colorado has experienced several droughts in the past 110 years of observed weather data, most notably in the 1930s, 1950s, mid-1970s, and 1980 to 1981 (McKee *et al.,* 2000). In addition, tree ring reconstructions indicate that persistent and severe droughts in the area were not uncommon in the 19th Century (Jain *et al.,* 2002).

Historically, municipalities along Colorado's northern Front Range – the north-south string of cities anchored by Denver in the rain shadow east of the Rocky Mountains – have been able to withstand these periods by using reservoir storage, replenished annually by snowmelt cascading down the mountains in the late spring and early summer. However, three forces have conspired in recent years to increase the region's vulnerability to water shortages (Nichols *et al.,* 2001). First, Colorado emerged as the nation's third fastest growing state, with an approximately 31 percent population increase during the 1990s (U.S. Census Bureau, 2001). Second, proposals to build new water storage projects, such as the locally infamous Two Forks Dam, were blocked by legal and political opposition, prompting cities to service growing populations with existing reservoir storage and newfound conservation savings, effectively reducing the regional drought cushion (Luecke, 1999). Third, the state enjoyed one of the longest periods of wet weather since 1929, thereby hiding the potential consequences of the inevitable next drought (McKee *et al.,* 1999).

The winter of 2001 to 2002 was abnormally warm and dry. Precipitation throughout the first four months of 2002 in the South Platte basin ranged from a high of 73 percent of average in February (NRCS, 2002c) to a low of 31 percent of average in April (NRCS, 2002d), a time of year usually characterized by heavy (water laden) snows. By May 31, snowpack in the two major basins serving the Front Range – the South Platte and Upper Colorado – were at 23 percent and 28 percent, respectively, of the long term average (NRCS, 2002b). Similarly, water storage in these basins had dropped to just over 80 percent of the long term average, a figure that could not be sustained very long given the low snowmelt and the coming summer months of municipal lawn watering (NRCS, 2002a). By summer, the entire state of Colorado was in an extreme drought (NOAA, 2002).

Demand Management

In response to low water storage and high demand, municipalities throughout the region scrambled to design and institute emergency demand management programs. A May 2002 report from the Colorado Water Conservation Board (CWCB) found that only 22 percent of the region's municipalities already had a drought response plan in place (CWCB, 2000, unpublished report). Efforts inevitably focused on restricting outdoor water use, particularly lawn watering, which accounts for well over half of annual residential water use and much more than half during the hot and dry Colorado summers (Mayer *et al.,* 1999). The exact nature of the programs and the intensity of their application, however, varied significantly from city to city, as each municipal water system had a different level of vulnerability, and was overseen by different water agencies and local governments. While each of the eight providers studied is physically located in the South Platte basin and has some access to local supplies, the level of access is far from uniform. The South Platte water rights of some cities, particularly Denver, are much more extensive and senior than those of the younger suburbs such as Aurora and Thornton. Additionally, access to other sources, particularly western slope (i.e., Upper Colorado River) resources, is far from uniform, based on water rights, engineering systems, and physical geography. Municipalities without extensive or diversified sources were particularly vulnerable. Lafayette, for example, is primarily dependent upon a single watershed that by May 31 held only 13 percent of normal snowpack (NRCS, 2002b).

Entering the summer of 2002, most cities along the northern Front Range had sufficient water in storage to satisfy normal levels of summer demand. With the notable exception of Lafayette, the real fear was not so much shortages in 2002, but rather the prospect of entering 2003 with depleted reservoirs combined with the possibility of another winter of low snowfall. For this reason, the water restrictions imposed in 2002 were largely precautionary, with the level of restrictions and the intensity of their enforcement reflecting the perceived risk of each municipality.

Overview of Water Restrictions

Our study period extended from May 1 to August 31, 2002, the four months with the highest evapotranspiration and highest lawn watering demand in Colorado (Swift, 1996). During this period, five of the eight municipal water providers studied implemented voluntary restrictions on outdoor water use, with four eventually shifting to mandatory outdoor water restrictions. The remaining three cities used mandatory programs exclusively. These programs were highly publicized by the local media, were prominently featured in city web pages, and in many cases were described in detail in mailings (sometimes included with monthly water bills) sent directly to the affected households. Public education was a part of all efforts. The key provisions of each program were the rules regarding lawn watering, although a mix of other conservation elements were typically bundled with the watering restrictions. Four of the eight providers limited lawn watering to once every three days, three cities limited watering to twice a week, while Lafayette restricted lawn watering to once a week. These restrictions often specified the time of day watering was to occur, the maximum length of the watering period, special rules for irrigating trees and perennials, and allowances for hand watering. Other common restrictions included prohibitions against using hoses to wash paved areas, limits on car washing and filling or refilling swimming pools, and restrictions on planting and/or watering new sod. New drought inspired pricing mechanisms were also implemented in two cities during the study period to discourage and penalize excessive use. This information is summarized in Table 2, with the cities listed in increasing order of water restriction stringency.

EFFECTIVENESS OF DROUGHT INSPIRED WATER RESTRICTIONS

Two general strategies are used to measure the effectiveness of drought restrictions. The first approach is to compare daily water use (i.e., deliveries) during periods of water restrictions to water use over the same time periods in previous years. The second approach is to compare daily water use during drought restrictions to an estimate of what use would have been, given the temperature and precipitation conditions (i.e., "expected use"), in the absence of restrictions. The first approach, used extensively by the water providers, has the advantage of requiring only information that is readily available to the utilities. Additionally, the results are unquestionably relevant: the amount of water actually demanded (and thus delivered) is ultimately the figure most relevant to system operators. Finally, this approach has the advantage of being the traditional standard familiar to water managers as well as the public and policy makers.

The second approach is considerably more complicated and therefore is used and publicized less frequently by the cities. Nonetheless, an approach accounting for expected use has the potential to offer a much more accurate assessment of drought restriction effectiveness. The reason is simple: in a year of extreme drought, it is a poor assumption that water use, in the absence of restrictions, will be similar to that seen in preceding years. To the contrary, drought conditions inevitably increase water demands, especially for landscaping purposes, and failure to consider this impact can result in an underestimation of the effectiveness of drought restrictions. Similarly, on the odd chance that a drought restriction is enacted during a sudden easing of drought conditions, failure to compare observed use to an expected value can overstate the effectiveness of restrictions. This phenomenon was documented by Anderson *et al.* (1980) in their study of the Fort Collins drought in 1977.

In this study, both approaches are used to assess the effectiveness of water restrictions.

TABLE 2. Restrictions on Outdoor Water Use (May through August, 2002).[1]

Municipal Water Provider	Lawn Watering Restrictions: Dates of Voluntary Limits	Dates of Mandatory Limits	Specified Watering Times[2]	Specified Watering Length[2]	Other Restrictions: Start Date of Drought Surcharges	Residential Car Washing	Planting New Sod
Providers Limiting Lawn Watering to Once Every Three Days (2-1/3 times/week)							
Thornton	May 8 to August 31	None				Voluntary Restriction	Voluntary Restriction
Aurora	None	May 15 to August 31	6 pm to 9 am		July 6		
Denver Water	May 8 to June 30	July 1 to August 31	6 pm to 9 am	3 hours per day		Restricted	Voluntary Restriction
Westminster	May 22 to July 31	August 1 to 31	6 pm to 9 am	3 hours per day		Restricted	Restricted
Cities Limiting Lawn Watering to Twice a Week							
Fort Collins	June 26 to July 21	July 22 to August 31	6 pm to 10 am[3]			Voluntary Restriction	
Boulder	May 8 to May 20	May 21[4] to August 31	6 pm to 9 am	15 min. per zone		Restricted	
Louisville	None	May 15 to August 31	7 pm to 7 am	10 min. per zone			
Cities Limiting Lawn Watering to Once a Week							
Lafayette	None	May 22 to August 31	5-7 am or 8-10 pm	2 hours per day	May 21	Banned Entirely	Banned Entirely

[1]Programs described are only for the study period May 1 to August 31, 2002. Several cities have further modified their water restriction programs since the end of this period.
[2]Values are for the period of most stringent restrictions.
[3]Unless using automatic (i.e., programmable) sprinkler systems, then midnight to 4 am.
[4]May 21, the date on which the City Manager adopted mandatory watering restrictions through emergency rule, is used as the starting date of Boulder's mandatory restriction period, although the Boulder City Council did not formally approve the restrictions until June 4 and enforcement did not begin until June 10.

Data and Methods

For each of the eight study regions, daily water use data from May 1 to August 31, 2002, were collected directly from the relevant municipal water agencies. For purposes of comparison, the same data were also collected for the two preceding years. Given the high rates of growth for some cities during this period, population data from the Colorado State Demographer's office, from the water utilities for 1999 to 2001, and from 2002 population estimates derived from those data were used to convert overall water delivery figures to per capita water consumption (see Table 1) – something the cities often do not do in their own calculations of water restriction effectiveness. Accounting for population growth is necessary to provide an accurate reflection of how well individuals conserved water; failure to account for population growth understates the effectiveness of restrictions. This information, combined with knowledge of when restrictions were initiated (shown in Table 2) is all that is necessary to provide rudimentary estimates of water restriction effectiveness.

Calculating "expected use" requires the use of statistical models that can explain the variability in observed daily per capita water use (the dependent variable) with respect to climatic factors, namely the drier conditions and warmer temperatures associated with drought. For each city, daily data on maximum temperature and precipitation were used as predictors in a multiple linear regression equation to predict what water use would have been each day in the absence of watering restrictions. A one-day lag variable also was included in the regression equations to account for temporal persistence in the time series of municipal water use. Similar approaches have been used in earlier drought studies, including those by Anderson *et al.* (1980), Lee and Warren (1981), Maidment *et al.* (1985), Maidment and Miaou (1986), Shaw and Maidment (1988), and Shaw *et al.* (1992).

The regression model has the form

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_k x_k + \varepsilon$$

where y is the response variable (i.e., per capita water use), β_0 is the regression constant, β_1 is the slope coefficient for the first explanatory variable (x_1), β_2 is the slope coefficient for the second explanatory variable (x_2), β_k is the slope coefficient for the kth explanatory variable (x_k), and ε is the remaining unexplained noise in the data (the error). This model uses three explanatory variables: daily data on maximum temperature (x_1), daily data on precipitation (x_2), and one-day lag variable of water use (x_3). The coefficients in the regression equations were estimated using data from the year 2000 and tested on the year 2001. Both summers of 2000 and 2001 had no watering restrictions. This cross-validation exercise demonstrated that these very simple equations had considerable accuracy in predicting water use (as shown in the right-hand column of Table 3); r-squared values ranged from 0.62 to 0.77. Undoubtedly, more sophisticated advanced regression techniques could lead to even greater accuracy. However, this level of accuracy is more than sufficient for our purpose of describing drought response in this case study. The regression equations were applied to data from the summer of 2002 to estimate expected use (i.e., what per capita use would have been absent restrictions and given climate conditions) during periods of watering restrictions. The difference between expected (calculated) water use and actual (measured) water use provides an estimate of the water savings that can be attributed to the drought inspired water restrictions. This is shown graphically in Figure 1 for the city of Westminster.

Presentation of Results

Tables 3 and 4 summarize the calculated effectiveness of water restrictions, both voluntary and mandatory, over the study period. Percent savings in Table 3 are based on the methods described above [i.e., "net

TABLE 3. Water Savings During Water Restrictions (May through August, 2002).

	Basis of Percent Savings Calculation[1]									
	Entire Study Period			**Voluntary Restrictions Period**			**Mandatory Restrictions Period**			
Municipal Water Provider	**Net Use** (%)	**Per Capita Use** (%)	**Expected Use Per Capita** (%)	**Net Use** (%)	**Per Capita Use** (%)	**Expected Use Per Capita** (%)	**Net Use** (%)	**Per Capita Use** (%)	**Expected Use Per Capita** (%)	**Model Skill (r2)**
Providers Limiting Lawn Watering to Once Every Three Days (2-1/3 times/week)										
Thornton	-8	1	9	-7	2	10	–	–	–	0.71
Aurora	9	12	16	–	–	–	13	15	18	0.72
Denver Water	7	10	13	2	5	7	14	16	21	0.67
Westminster	4	7	14	3	6	11	17	19	27	0.70
Average[2]	3	7	13	0	4	9	14	17	22	--
Cities Limiting Lawn Watering to Twice a Week										
Fort Collins	9	13	18	3	7	12	17	20	24	0.63
Boulder	24	24	27	-2	-2	4	29	28	31	0.62
Louisville	39	39	41	–	–	–	43	43	45	0.77
Average[2]	24	25	29	0	2	8	30	31	33	--
Cities Limiting Lawn Watering to Once a Week										
Lafayette	46	49	50	–	–	–	53	55	56	0.69

[1]"Net use" compares daily system wide water deliveries in 2002 to the 2000 to 2001 average for the same dates. "Per capita use" standardizes the net use calculation by accounting for population growth over the 2000 to 2002 period. "Expected use per capita" is a comparison of actual per capita use (deliveries) in 2002 with that level of use anticipated in 2002 had water restrictions not been in effect and given the adverse climatic conditions associated with drought. In all cases, negative numbers indicate an increase in water use.
[2]Averages are calculated from nonrounded values.

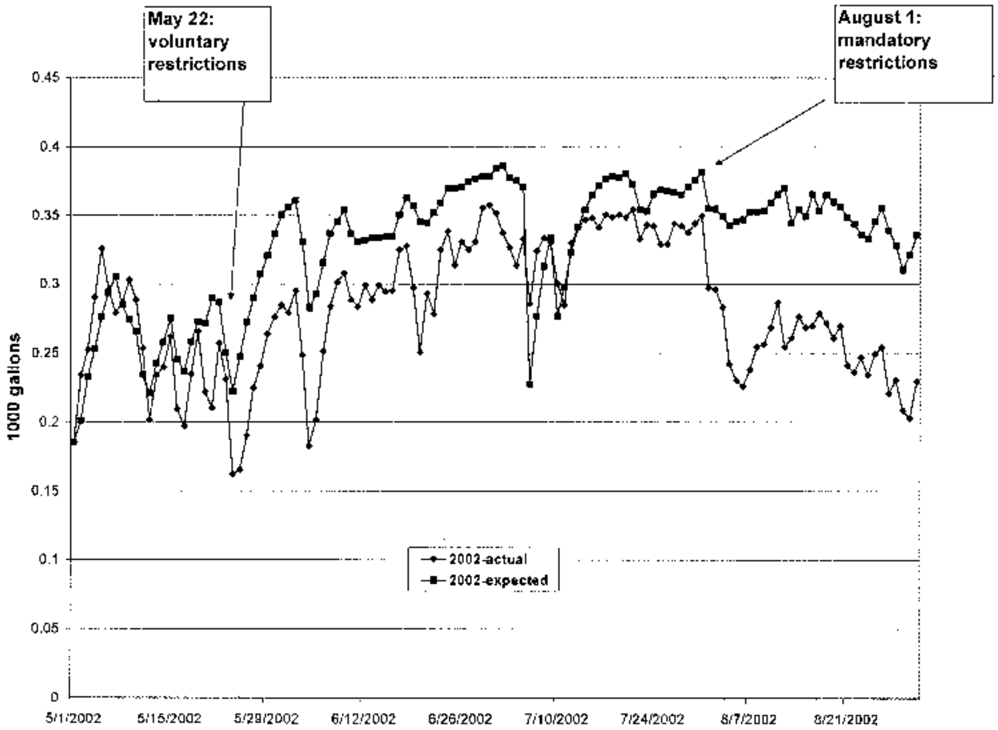

Figure 1. Comparison of Actual and Expected Per Capita Water Use for the City of Westminster From May 1 to August 31, 2002.

use" compares 2002 usage (deliveries) to the average of 2000 to 2001 usage; "per capita use" translates net use to a per person value in order to account for population growth; and "expected use per capita" is a comparison of actual per capita use in 2002 with that level of use anticipated in 2002 had water restrictions not been in effect and given the adverse climatic conditions associated with drought]. Essentially, the first metric evaluates water restriction effectiveness from the standpoint of the reservoir system, while the second and third reflect the standpoint of the individual water user. The comparisons are for the exact corresponding dates in one of three time spans: the entire study period (May 1 to August 31), the period of voluntary restrictions (case specific), and the mandatory restriction period (case specific). Thus, for example, the effectiveness of voluntary restrictions in Westminster is based on a comparison of usage from May 22 to July 31, 2002 (see Table 2), with the same periods in 2000 and 2001 and with the expected value during those same dates in 2002. These dates are different for each city and in some cases may comprise too brief of time periods to merit serious comparisons.

Table 4 provides estimated ranges of actual and potential water savings in volumetric terms, with the net use and expected use per capita methods as upper and lower boundaries. For the "Actual Savings" examples, the lower figure is calculated by subtracting 2002 use from 2000 to 2001 average use, while the higher number is calculated by subtracting 2002 use from the "expected" level of 2002 use. For the "Potential Savings" scenarios, the lower number is 2000 to 2001 average use multiplied by the average savings under the "net use" method for a given scenario (i.e., every three days, twice weekly, etc.), while the higher number is the product of the expected use in 2002 times the average savings under the "expected use" method associated with the given scenario. These savings percentage values are shown in Table 3. For the scenario assuming "Mandatory Restrictions Employed All Study Period" the percentage values used are city specific.

Although calculations for each city were conducted in a standardized manner, cross-city comparisons should be done cautiously. Each city has unique circumstances, including the blend of residential to other uses (industrial, commercial, agricultural), the size and age (and thus technology) of the water system, the preexisting level of conservation programs, the mix of single family homes to multifamily dwellings, average household size, and so on. Each of these factors can influence the effectiveness of water restrictions. For example, Narayanan *et al.'s* (1985) study of drought in Utah found that the effectiveness

TABLE 4. Volumetric Range of Actual and Potential Water Saved Based on Net Use and Expected Use Methods (May through August, 2002).[1]

Municipal Water Provider	Actual Savings (acre feet): Over the Entire Study Period	Actual Savings (acre feet): Mandatory Restrictions Period (city-specific)	Potential Savings (given the following hypothetical situations applied over the entire study period) (acre feet)[2]: Assuming Mandatory Restrictions Employed All Study Period	Assuming Savings Typical of the Every Third Day Watering Schedule	Assuming Savings Typical of the Twice Weekly Watering Schedule	Assuming Savings Typical of the Once a Week Watering Schedule
Aurora	2,842 to 5,522	3,617 to 5,614	3,914 to 6,170	4,371 to 7,459	9,367 to 11,188	16,548 to18,986
Boulder	2,805 to 3,287	2,956 to 3,268	3,355 to 3,750	1,646 to 2,693	3,528 to 4,040	6,233 to 6,855
Denver	9,528 to 18,768	10,066 to 15,938	18,365 to 28,774	18,266 to 30,737	39,142 to 46,105	69,151 to 78,239
Fort Collins	1,254 to 2,933	864 to 1,404	2,409 to 3,959	2,028 to 3,556	4,345 to 5,334	7,677 to 9,051
Lafayette	1,198 to 1,393	1,201 to 1,354	1,372 to 1,557	361 to 610	774 to 916	1,368 to 1,554
Louisville	1,031 to 1,141	1,069 to 1,138	1,156 to 1,247	372 to 609	798 to 914	1,409 to 1,551
Thornton	-855 to 1,112	N/A	N/A	1,426 to 2,673	3,055 to 4,010	5,397 to 6,804
Westminster	460 to 1,844	500 to 946	1,918 to 3,542	1,621 to 2,852	3,474 to 4,278	6,137 to 7,260
TOTALS	18,263 to 36,000	20,272 to 29,662	32,491 to 48,998	30,092 to 51,190	64,483 to 76,784	113,920 to 130,301

[1]In each cell, the lower number is the net use value, while the higher value uses the expected use calculation (see text for explanation).
[2]For these scenarios, the higher number is the product of the expected use in 2002 times the average savings percentage associated with the given scenario (from Table 3). For the scenario assuming "Mandatory Restrictions Employed All Study Period" the percentage values used are city-specific (e.g., 13 and 18 percent for Aurora). For the remaining three scenarios, the savings values are the multi-city averages: 14 and 22 percent, respectively, for the every third day programs, 30 and 33 percent for the twice weekly programs, and 53 and 56 for the once weekly program.

of outdoor watering restrictions declined as household size increased and for families with below average monthly use. Additionally, lumping all programs into "voluntary" or "mandatory" based primarily on the treatment of residential lawn watering restrictions is, as mentioned earlier, an inexact process, as enforcement of restrictions was inconsistent across the eight study regions and since other conservation elements were typically enacted simultaneously with the lawn watering restrictions. Cities can influence total deliveries in many ways other than restricting residential outdoor use, such as by curtailing their flushing and maintenance programs and by limiting water use in public landscapes. For these and related reasons, the primary use of Tables 3 and 4 should be to compare usage within cities under various water restriction conditions. By comparing cities to themselves, the unique character of each region is automatically controlled for, and the values calculated are therefore highly robust. Cross-city comparisons are useful for identifying more general trends.

Discussion

Percentage Water Savings. The primary results of the study are presented in Table 3. Regardless of whether the actual use calculations (i.e., net use and per capita use) or the predictive method (i.e., expected use per capita) is utilized, four major "findings" emerge from the data.

(1) *Mandatory Restrictions Were Effective in Reducing Water Use*. In every city or provider region, conservation programs featuring mandatory restrictions were associated with significant savings in water use. Net use savings ranged widely from 13 percent (in Aurora) to 53 percent (in Lafayette), equal to 15 to 55 percent when expressed in per capita terms. Expected use per capita for these same cities ranged from 18 to 56 percent, providing a clear and powerful confirmation of the effectiveness of mandatory water restrictions. The wide range of savings is likely related, in part, to the differences among the cities in terms of service populations and water systems but is also undoubtedly linked to the differing stringencies of the restrictions programs (as shown in Finding 3).

(2) *Voluntary Restrictions Were of Limited Value.* The performance of voluntary water restrictions was, with few exceptions, disappointing. In terms of net use, consumption in Thornton and Boulder actually went up during voluntary restrictions, a phenomenon that persisted in Boulder even after accounting for population growth. Note, however, that the Boulder

result is based on only 12 days of voluntary restrictions. Only when expected use per capita is used to measure effectiveness are voluntary restrictions shown to have significant value, yielding savings as high as 12 percent in one case (Fort Collins) and savings of at least 7 percent in seven of the eight providers utilizing voluntary restrictions.

(3) *The Greatest Savings (by percentage) Were Found in the Cities With the Most Aggressive and Stringent Mandatory Restrictions.* The results during mandatory restrictions indicate that the most stringent limits on the frequency of outdoor watering result in the greatest savings. Expected use per capita during mandatory restrictions resulted in the following reductions in water use: 22 percent for the four water providers using every third day watering, 33 percent in the three cities limiting watering to twice a week, and 56 percent in Lafayette, which limited watering to once a week. Measured in terms of actual (measured) per capita use, these values are 17, 31, and 55 percent, respectively.

(4) *Every City Studied Was Able to Reduce Per Capita Use Over the Study Period Through the Use of Water Restrictions*. Savings ranged from a low of 1 percent in Thornton, the only city in the study that did not use mandatory restrictions, to 49 percent in Lafayette, the city with the most aggressive program of water restrictions. Thornton enacted mandatory restrictions soon after the study period ended. Overall savings in Thornton are a much more robust 9 percent when the per capita values are measured in terms of expected use. While mandatory restrictions appear more effective than voluntary programs (Findings 1 and 2) and stringent restrictions appear more effective than less restrictive programs (Finding 3), all the conservation programs studied saved water. Doing something, therefore, appears better than inaction.

The trends presented in Table 3 and described above were expected and generally reinforce findings from similar investigations. For example, several studies have shown mandatory water restrictions to be effective when compared to expected use projections [e.g., Shaw *et al.* (1992) calculated summer savings in Los Angeles of 36 percent during the 1991 drought; Shaw and Maidment (1988) calculated savings of 31 percent in Corpus Christi during the 1984 drought; similarly, savings of 30 to 40 percent were calculated in the San Francisco Bay area during the 1976-1977 drought (CDWR, 1991)]. The literature regarding voluntary water restrictions is less clear. Shaw and Maidment's (1988) study of the Corpus Christi drought in 1984, just like their earlier study (Shaw and Maidment, 1987) of Austin, showed voluntary restrictions to have no effect. However, Shaw *et al.'s* (1992) study of the 1991 Southern California drought found San Diego's voluntary program to yield summer savings of 27 percent (compared to 36 percent from Los Angeles' mandatory program). Thus, while the track record of voluntary restrictions is somewhat spotty, it does seem safe to conclude that mandatory restrictions generally work better than voluntary restrictions, a central theme in the work of Lee (1981) and Lee and Warren (1981) regarding the Iowa drought in 1977. Whether the generally greater effectiveness of mandatory programs is worth the added political costs (compared to voluntary requests) is, of course, a larger issue transcending water management.

Utility of Expected Use Values. While the expected use formula employed in this study is, by modeling standards, relatively simple, it is nonetheless much more complicated and labor-intensive to apply than approaches based solely on actual use. Whether this regression based technique should be adopted by water managers is an individual decision. Certainly large water providers with extensive in-house expertise and recordkeeping systems would likely find this approach easier to apply than their smaller counterparts. But the more relevant question is whether the technique produces information that is valuable to water managers.

In this study, for most water providers and time periods studied, the expected use per capita savings was roughly about 2 to 6 percent greater than savings calculated from a traditional actual use per capita comparison with previous years. While this is not a large difference, it is nonetheless significant whenever there is a management need to consider the response of water users to climatic extremes, even in the absence of water shortages or water restrictions. It is easy to imagine many scenarios where this type of information would be useful. Indeed, water managers and planners spend a great deal of resources understanding how drought and long term climate changes can potentially influence supplies; a similar investment of effort seems warranted in understanding the impact of climate on water demands. Incorporating expected use calculations into the assessment of drought response programs is only one of several potential applications of this methodology, many of which are arguably more important than the specific application featured in this study.

Volumetric Savings. Another way to illustrate the value of water restrictions – particularly the mandatory restrictions – is in volumetric terms. This is a particularly relevant measure of water savings for reservoir management but is also useful to compare the efficacy of demand management strategies to other means of reducing drought vulnerability, such as through constructing new projects, purchasing new water rights (or options on rights), constructing wastewater reuse systems, and so on. For these types of comparisons, water volumes are much more relevant than percent reductions in customer demands. Only for this reason are volumetric savings presented in this study.

Table 4 provides estimated ranges of actual and potential water savings in acre feet (equal to 325,851 gallons) using the net use and expected use per capita methods as upper and lower boundaries. The volume of water saved is a function of total water deliveries (i.e., the size of the water system), the percent savings achieved through restrictions, and the type and duration of restrictions. Collectively, the eight providers studied saved approximately 18,263 to 36,000 acre feet of water during the four-month study period. To put these values into perspective, 20,000 acre feet is the typical annual water demand of a town of approximately 75,000 people (using the conservative assumption of 0.27 acre feet per person) and has a retail (end user) value of more than $13 million (assuming a typical rate of $2 per thousand gallons).

The potential savings could have been much greater. Rough extrapolations suggest that had our seven providers with mandatory restrictions utilized their programs for the entire four-month study period, total savings likely would have ranged from 32,491 to 48,998 acre feet. Furthermore, if all eight providers had used the twice a week watering schedule and achieved the 30 percent average level of savings seen for this approach in this study, water savings could have totaled 64,483 to 76,784 acre feet. Using the same logic, the more aggressive once a week schedule could have potentially translated into 113,920 to 130,301 acre feet of savings had this approach been used in mandatory programs over the four-month period.

Translating Drought Savings to Long Term Conservation Potential. These potential savings estimates provided above are admittedly very rough and should be used judiciously; nonetheless, they suggest a potential for demand management in the region that is perhaps not confined merely to drought emergencies. In the absence of drought, the cities of Colorado's Front Range may want to consider adopting outdoor watering restrictions on a permanent basis as part of a long term conservation program. This is already done in Castle Rock (just south of Denver), which has utilized the every third day watering schedule since 1996.

There are several reasons, however, to use caution in assuming that demand management savings during drought could be sustained during nondrought periods. Specifically, the savings experienced were largely the result of cooperation and "goodwill" on the part of citizens and represented a "belt tightening" that was publicly acceptable given the emergency conditions but perhaps unacceptable if adopted as a normal part of management. Additionally, to the extent that some water savings were, in part, due to management decisions to postpone system flushing and maintenance, to limit water applications on public parks, and other emergency drought coping measures, it would be dangerous to assume that these savings could be achieved on a permanent basis.

It should also be noted that any effort to reduce waste in the system could have the effect of reducing the "drought cushion" that allows cities the flexibility of drought year conservation savings – although that cushion could likely be provided in other ways, such as through an expanded use of dry year options with the agricultural sector (Nichols *et al.,* 2001; Luecke *et al.,* 2003). This threat becomes real if the water conserved goes to support new growth rather than being held in reserve for drought emergencies. The relationship between water management and growth is beyond the scope of this paper as well as beyond the control of water managers, but it is nonetheless part of the context that must be considered when describing the relationship between drought coping and long term conservation. In any case, further research is warranted regarding the ability to translate drought savings into permanent conservation savings.

SUMMARY AND RECOMMENDATIONS

This study indicates that outdoor watering restrictions, particularly mandatory programs, are an effective means of reducing water demand during drought periods among Colorado's Front Range municipalities. While this conclusion is evident regardless of the means used to calculate savings, the expected use per capita methodology yields the greatest savings and is a particularly useful approach for measuring the effectiveness of water restrictions from the standpoint of the end users (i.e., residents) dealing first-hand with the impacts of drought on residential landscaping.

As expected, the level of water savings increases as the frequency of permitted watering days declines and as time limits (per zone) are tightened. The dramatic jump in savings achieved by cities using the twice a week regime compared to the marginally more restrictive every third day (or 2-1/3 days per week) approach is notable, especially since twice weekly watering is often sufficient to maintain the health of landscaping. Actual water demand is very site specific and is influenced by factors such as soil type, wind and sunlight exposure, and precipitation events. Additionally, Kentucky bluegrass, even if allowed to turn brown and go dormant for months, will turn green when watered again (Wilson, 2002). While each provider needs to consider its own unique circumstances, our results generally suggest that conservation programs based on mandatory, twice weekly landscape watering restrictions provide an attractive balance between saving water and limiting the impact on customers, particularly for water providers with a goal of reducing demand by approximately 30 percent.

Using a conservation approach based on designated watering days is also consistent with the current administrative, technological, and enforcement capacities of the region's municipal water providers, although several managers expressed concern that some customers may feel obligated to water on their designated days even if rains had recently occurred or were forecast, thereby reducing the potential savings from this form of water restrictions. It may also be worthwhile to combine water restriction programs with pricing strategies such as drought surcharges. These programs are also relatively easy to implement – administratively, if not politically – although several studies show residential water use to be largely inelastic (Michelsen *et al.,* 1998). Reforms in technology and administrative capacity may be necessary to pursue more dynamic means of residential water conservation during drought, such as approaches featuring individual water budgets and supported by systems providing customers with real time water use data, climate and demand forecasts (such as evapotranspiration estimates), and price signals.

Epilogue

Following the experience in the summer of 2002, several regional water managers expressed the opinion that customers were confused by the diversity of water restriction programs across neighboring municipalities (Lawn Watering Work Group, 2003, unpublished report). This diversity of approaches made it difficult for the media to inform and remind customers of the watering restrictions specific to their area. Similarly, the diversity of approaches for measuring water savings made it difficult to track and communicate levels of success. For these reasons, a consortium of Front Range cities known as the Lawn Watering Work Group was established to devise a consistent metro wide program of restrictions should drought conditions persist into 2003 (Lawn Watering Work Group, 2003, unpublished report). Consistent with the results of this study, an approach allowing twice weekly watering was adopted.

This new coordinated approach to watering restrictions was largely stillborn, however, as one of the largest snowstorms in history hit the Front Range on March 18 and 19, 2003, dropping 31.5 inches of heavy, water laden snow in the metro area and in excess of seven feet of snow in some nearby mountain watersheds (NSIDC, 2003). Primarily due to this storm, snowpack by mid-April in the Upper Colorado and South Platte basins had rocketed to 108 and 115 percent, respectively, of normal (NRCS, 2003). As warmer spring temperatures initiated snowmelt, reservoir storage quickly recovered, and each city devised its own schedules for easing and ultimately ending water restrictions. By fall of 2003, all mandatory water restrictions in the metro area had been lifted or were scheduled to terminate soon.

ACKNOWLEDGMENTS

The authors wish to acknowledge the cooperation of the eight participating water agencies and research assistants Adam Morrison and Bethany Gravell in providing and compiling the relevant data. This work was supported by the Western Water Assessment, an interdisciplinary project funded by the National Oceanic and Atmospheric Administration and administered by the Cooperative Institute for Research in Environmental Sciences, University of Colorado.

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