

Evaluating Non-Price Water Demand Policies During Severe Droughts

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SHORT PAPER

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Introduction

Colorado experienced one of the most extreme droughts on record in the summer of 2002. The depth, breadth, and severity of this drought were unprecedented and led to the adoption of numerous policies limiting municipal water use across Colorado. Given pre-existing water prices and a limited ability to change these prices, the majority of water restrictions took the form of daily-use restrictions rather than the imposition of higher water prices. These daily use restrictions varied both across municipalities and through the summer irrigation season, but largely took the form of limits on the frequency with which lawns could be watered. Since these policies varied widely over space and time, their general effectiveness is by no means clear.

This research addresses a very fundamental aspect of these daily water use restrictions: what effect, if any, did these daily water use restrictions have on municipal water use across the Front Range. This effort has two key elements: cataloging the different types of water use restrictions adopted by Front Range municipalities, including changes in water rate structures and evaluation of the effects of these programs on daily per capita water use; and assessing the effects of these policy changes. The present analysis focuses specifically on the city of Fort Collins, and begins by briefly explaining the drought policies adopted by each city. After the policies used in the city have been discussed, the effectiveness of these policies is examined through the use of autoregressive/moving average regression functions. As will be seen, daily water use restrictions did affect per-capita demand. However, the cyclical and seasonal nature of water demand means these effects may not be superficially obvious.

Basic Demand Management in Fort Collins

Fort Collins uses a variety of water sources including Colorado-Big Thompson Project (C-BT), Cache la Poudre River Basin, and trans-mountain water from the Michigan River basin via the Michigan Ditch and Joe Wright Reservoir system. Much of the water from the C-BT project and the Windy Gap Project are stored and delivered from the Horsetooth Reservoir. The city owns water rights to about 70,000 acre-feet per year. It delivers an average of 32,100 acre-feet of treated water per year, uses 3,000 to 4,000 acre-feet of raw water to irrigate the City's parks, golf courses, cemetery, green belt areas and school grounds, and delivers about 4,000 acre-feet of other raw water obligations (Fort Collins, 1996-2003; Fort Collins, 2003). The city has strived to maintain a supply of water that would meet or exceed the demands during the most severe drought likely to occur on average once every 50 years.

In the past, Fort Collins has separated water supply and water demand programs, each reflecting the City's goals for future water use. However, in September of 2003, a combined water supply and demand management policy was adopted by the City Council. The water supply policy maintains that the City will be sensitive to the effects acquisition policies have on the agricultural community, they will maintain enough supply to meet at least the 1 in 50 drought event with accurate timing, and they will evaluate opportunities that arise to obtain the most desirable sources of water. Raw water requirements for new development will be set such that no other water acquisitions are harmed. The city also seeks to maintain regional cooperation to ensure adequate water supplies across the Northern Front Range. Lastly, the City seeks to continue public

water conservation education projects so long run water demands are more effectively met.

Fort Collins basic water demand management portion includes projecting water conservation as an “ethic”, educating the public on the necessity of conservation, and improving water efficiency so as to comply with anticipated federal and state permitting requirements. The initial demand management portion was implemented in 1992. It also included goals of reducing per capita water intake from 235 gallons per capita day (gpcd) to 195 in 2010. However, the drought of 2002 and resulting difficult year of 2003, the city re-evaluated their reduction goals. The resulting demand management tools established in 2003 includes the following:

- Water use goals – average use reduced to 185 gpcd and per capita peak daily demand reduced to 502 gpcd by 2010
- Educational Programs – schools, xeriscape landscaping, evapo-transpiration, and sprinkler system controllers
- Rate Structures – economic incentive to use water efficiently through methods including tiered rate structures, seasonal blocks, appropriate targets, and flat rates.
- Incentive programs – including replacing outdated plumbing structures, water conserving shower heads/toilets, etc.
- On-going Leak Detection Testing
- Regulatory Measures – city adopts regulations that promote water efficiency (i.e. – limit bluegrass turf) while still maintaining an attractive and pleasant environment

(Fort Collins Council, 1988; Fort Collins Council, 1992; Fort Collins Council, 2003; Fort Collins Utilities, 2003a; Fort Collins Utilities, 2003b)

During the drought-plagued summers of 2002 and 2003, Fort Collins’ primary water management tool was regulation in the form of daily water use restrictions. In 2002, these restrictions were initially voluntary, but were later change to 2-days/week limits on lawn watering and ultimately to 1-day/week watering restrictions. Voluntary restrictions were adopted on May 16, 2003 and continued until July 22, 2003. At this point in time, voluntary restrictions were replaced by 2-days/week limits. These limits remained in force until replaced by 1-day/week limits on September 27, 2002, limitations that remained in force for the rest of the year.

Fort Collins followed a similar path in 2003, although during 2003 no voluntary restrictions were imposed. Rather, 1-day/week limits were imposed on January 1, 2003 and kept in place until April 21, 2003, at which point in time 2-days/week limits were imposed. These 2-days/week limits were maintained until September 2, 2003. No restrictions were imposed after September 2, 2003 (Dustin, 2003).

The basic effects of these restrictions are shown in Table 1. This table shows average daily water usage in gallons per capita per day for both 2002 and 2003. Winter demand is provided as a reference for non-irrigation season water use.

Table 1: Average Water Use in Fort Collins in Gallons Per Capita Per Day Under Different Types of Water Restrictions

	Base Usage:		Under Restrictions:		
	<i>Winter Demand</i>	<i>Annual</i>	<i>Voluntary</i>	<i>1Day/Week</i>	<i>2 Days/Week</i>
2002	115.945	232.709	292.21	131.796	249.126
2003	98.161	198.819	n/a	103.621	212.422

This basic data summary raises both points of interest and points of concern. To start, all measures of water use, including both “Winter Demand” and “Annual” demand, fell from 2002 to 2003, suggesting that on a per-capita basis water users in Fort Collins were responding to drought conditions. However, it is interesting to note that water demand under “Voluntary” restrictions is markedly higher than both “Annual” water demand and under all other forms of water restrictions. This raises serious concerns about the effectiveness of voluntary water restriction programs. However since the “Voluntary” restrictions were adopted at the beginning of the irrigation season – typically a higher water use period – it is not clear if this difference is simply a statistical artifact related to seasonal variations, or if it is in fact a legitimate rise in the use of water under voluntary restrictions. Unfortunately, nothing in Table 1 can draw this distinction.

Statistical Evaluation and Preliminary Conclusions

Based on a purely superficial evaluation of raw water demand statistics, it is not clear how the imposition of watering restrictions influenced water demand in these two cities. As the results from the City of Fort Collins show, there is potentially evidence that voluntary restrictions actually promote water usage. However, raw statistics do not account for the seasonality and cyclical nature of water demand. Simply put, they show what water demand was at a given point in time, not why.

Evaluating municipal water demand is not a simple task, largely due to the fact most water prices are set by municipalities rather than revealed through market forces. Ideally, some form of a panel data set with household level data would be employed (see Billings and Agthe, 1980 or Billings, 1982). However, since water prices are administratively determined they generally do not vary across space or time and/or they

use increasing block rates that lead to correlation between higher prices and higher water usage. The former problem leads to statistically degenerate estimates of demand while the latter leads apparently upward sloping demand curves.

Several alternatives have been proposed for dealing with these issues.

Nieswiadomy and Molina (1989) estimated both marginal water price and the difference between actual water expenditures and water expenditures priced at the margin and used these estimates as instrumental variables in a two-stage least squares process. This method accounted for the use of increasing block rate prices and eliminated biases related to endogenous prices. However, it also generated results on the expenditure differential variable that suggested the difference between actual expenditures and expenditures priced at the marginal price of water is negative. This suggests consumers demand less water the larger the difference between the upper and lower tiers of prices. Given that the marginal price of water has not changed, this result is counter-intuitive.

Another alternative for handling water price is the method used by Pint (1999) in which the demand for water in a given tier of prices is weighted by the probability that a consumer will be in that price tier. This approach, estimated using maximum likelihood, solves the problems encountered by Nieswiadomy and Molina but can be utilized only when household water prices vary sufficiently over space and time. When water prices are degenerate (or nearly so), Pint's method cannot be employed.

Another approach is to simply accept that lack of variation in prices makes this variable uninformative. As a substitute, time-series analysis of daily per-capita water usage as a function of those variables that do change can be used. That is the method taken here. The concept of a time-series model is relatively simple: water use on a given

day is a function of water use on previous days and external forces such as weather and water use restrictions. If water use on a given day is W_t and exogenous forces are represented by the matrix X_t , then water demand on a given day is simply:

$$W_t = \mu + \phi_1 W_{t-1} + \phi_2 W_{t-2} \dots + \phi_k W_{t-k} + \beta X_t + e_t + \tau_{t-1} e_{t-1} \dots + \tau_{t-k} e_{t-k}$$

where μ is average water usage, ϕ_{t-k} coefficient on the daily water use k days prior to the current day, β is the vector of regression coefficients on exogenous data, and τ_{t-k} is the coefficient on the residual error term from estimated water demand k days prior to the current day of water demand.

To estimate a time-series equation for water use in Fort Collins, it is necessary to assume that daily per capita water demand in the city is a stationary deterministic process conditioned on a variety of external factors. This requirement is necessary to ensure that the τ_{t-k} terms gradually disappear and do not “blow up” estimated water demand. For the purpose of this analysis, exogenous factors include maximum daily temperature, estimated rain fall on a given day (*City Gauge*), average precipitation over a 3-day period (*Avg.3-day Precip*), estimated evapo-transpirative requirements based on the Penman equation (*Penman*), and a trend variable to indicate whether the day in question was at the beginning or end of the irrigation season (*Trend*). Lastly, since water use was strictly prohibited on a specific day of the week (*Monday*), a variable representing this limit is also included. This data was provided the municipal water supply department for Fort Collins. To account for different daily water use restrictions, dummy variables indicating that a particular water-use day fell into either a one-day per week, two-day per week, three-day per week or voluntary watering restriction period were also included. From this data, an autoregressive moving average models was estimated in LIMDEP for Fort

Collins during the irrigation demand season of 2002. An ARMA(7,1) model proved the most effective fit for Fort Collins, and the results of this regression are reported in Table 2.¹

Table 2: ARMA Results for Fort Collins Water Use in 2002

	Coeff.	t-ratio	P-value
<i>Phi(1)</i>	-0.100766	-0.683695	0.494168
<i>Phi(2)</i>	0.158455	1.37049	0.170535
<i>Phi(3)</i>	0.0411537	0.416246	0.67723
<i>Phi(4)</i>	0.209201	2.1072 **	0.0351004
<i>Phi(5)</i>	-0.0895868	-0.90687	0.364475
<i>Phi(6)</i>	-0.0896544	-0.885737	0.375759
<i>Phi(7)</i>	0.491512	6.10041 ***	1.06E-09
<i>Mu</i>	-29.1384	-4.55732 ***	5.18E-06
<i>Max Daily Temperature</i>	0.380066	1.59669 ***	1.10E-01
<i>City Gauge</i>	11.2682	1.04821	0.294541
<i>Avg. 3 Day Precip.</i>	1.1387	3.40713 ***	0.0006565
<i>Penman</i>	115.914	5.32153 ***	1.03E-07
<i>Voluntary Restrictions</i>	-25.1734	-7.39495 ***	1.41E-13
<i>1-day/week Restrictions</i>	-80.2912	-9.94601 ***	2.89E-15
<i>2-day/week Restrictions</i>	-72.1192	-10.0477 ***	2.89E-15
<i>Trend Variable</i>	0.295058	8.46719 ***	2.89E-15
<i>Monday Restriction</i>	-7.60378	-1.37629 ***	1.69E-01
<i>Tau(1)</i>	0.835845	5.10537 ***	3.30E-07

Significant at $\alpha =$

-
- 0.1 *
 - 0.05 **
 - 0.01 ***

Preliminary econometric results indicate that water use on a given day is largely a function of climate variables such as daily temperature and average precipitation over the preceding three days. It is interesting to note that among the lagged measures of daily water use, only water use four-days prior and one-week prior to the current day exert a

¹ This means that daily water use is a function of daily water demand over the previous seven days and the residual error from the previous day. A recent study of municipal water use during the 2002 drought in Colorado by Kenney et al. (2004) used similar data to evaluate drought responses but employed conventional OLS with lagged data rather than an autoregressive process. Based on Durbin's H test, the authors found that there is no evidence of first-order correlation using this approach, but as the results above indicate there is evidence of higher-order levels of autocorrelation.

significant influence on water demand. Since water use restrictions are generally tied to a weekly time-step, these results are most likely explained by the water restriction cycle.

All three of the dummy variables representing water use restrictions exerted a significant influence on daily water use, but voluntary restrictions were only about 1/3 as effective (approximately 25 gpcd reduction relative to demand without restrictions) in comparison to either 2-day/week (about 72 gpcd reduction compared to no restrictions) or 1-day/week restrictions (nearly 80 gpcd reduction from the restriction). Additionally, the ban on watering on Mondays appears to have reduced water use by about 7 gpcd relative to the water use on an equivalent day without restrictions. However, it is important to note that while from Table 1 average water demand under voluntary restrictions appears to be higher than basic average water use, the time-series model indicates that these restrictions do have the desired negative effect on water usage compared to what the demand would be at the same time of the year without restrictions. Consequently, while voluntary restrictions do not appear to be as effective as other types of restrictions, they do appear to be achieving the desired effect relative to what demand would have been without the watering limits and given the stage of the irrigation season during which these restrictions occurred. Without accounting for the trend in the watering season, the effectiveness of voluntary restrictions would have been questionable.

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