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Evaluating Non-Price Water Demand Policies during Severe Droughts[1]

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The Issue

Western states and provinces live under constant drought threat. When and how to time restrictions on outdoor watering are crucial management issues. The effectiveness of various policies is assessed using experience from Colorado during a severe drought.

Implications and Conclusions

A time-series analysis of daily water demand for two medium-sized and geographically distinct Colorado cities indicates that daily water use restrictions instituted during the 2002 drought had the desired effect. Results also indicate that moderate restrictions adopted early in the outdoor watering season are more useful than stringent restrictions adopted later in the season. Depressing water use early in the growing season leads to a lower water use trajectory across the entire watering season. In contrast, more stringent restrictions adopted later in the season must depress water use from an already high use trajectory – a harder task given the cyclical nature of outdoor water demand.

Introduction

Drought, or the threat of it, is a constant problem in the western states and provinces. Chronic and inherent water scarcity is being further accentuated by demographic transitions as water use shifts from agricultural irrigation toward municipal and domestic use. Given the critical and vital nature of drinking water, finding the best ways to manage water use during droughts is critically important to the cities of western North America.

While modifications in prices are often used as a drought strategy, most strategies rely on limiting the time and frequency of outdoor watering through daily-use restrictions. Limits are employed primarily to cope with very low demand elasticities for municipal water and to discriminate between essential in-home uses of water and non-essential outside-the-home uses. Unfortunately, it is by no means clear how to time the adoption of restrictions: is it better to adopt weak restrictions at the beginning of the season or strong restrictions later on? This research addresses that question.

The question is evaluated within the context of two medium-sized communities located north of Denver, Colorado: Fort Collins and Greeley. Both cities experienced the worst droughts in their history in 2002 and 2003. While Denver and its adjoining suburbs make up the largest urban concentration in the state, the close proximity to each other of the different jurisdictions within this metropolitan area results in municipal water systems that cross political and service area boundaries. This makes analysis quite difficult and reduces the ability to isolate policy effects on a given city. In contrast, while Fort Collins accounts for almost 3 percent of the state's population and Greeley holds just under 2 percent, each city is over 40 miles away from Denver and they are 30 miles from each other, so they are geographically distinct entities whose drought management policies influence identifiable and unique regions.

The analysis begins by briefly explaining the drought policies adopted by each city. The effectiveness of these policies is then examined using auto-regressive/moving average regression functions. As will be seen, daily-use restrictions did affect per capita demand, and due to cyclical water demand during the irrigation season the most stringent policies were less effective than moderate restrictions adopted early in the season.

Basic Demand Management in Fort Collins

Roughly 60 miles due north of Denver lies the city of Fort Collins, which had a population of approximately 118,652 in the 2000 U.S. census and covers roughly 45 square miles. To meet its citizens' water needs, Fort Collins 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). During the drought summers of 2002 and 2003, Fort Collins' primary management tool was regulation of

Table 1 Summary of Restrictions in Fort Collins and Greeley during 2002 and 2003

	2002	**2003**
Fort Collins		
None	N/A	2 Sept. - 31 Dec.
Voluntary	16 May - 21 Jul.	N/A
3 days/week	N/A	N/A
2 days/week	22 Jul. - 26 Sept.	22 Apr. - 1 Sept.
1 day/week	27 Sept. - 31 Dec.	1 Jan. - 21 Apr.
Banned	N/A	N/A
Greeley		
None	N/A	N/A
*Voluntary**	16 Apr. - 3 Jul.	N/A
3 days/week	3 Jul. - 30 Sept.	15 Jul. - 31 Aug.
2 days/week	N/A	16 May - Jul. 15; 1 Sept. - 31 Oct.
1 day/week	N/A	16 Apr. - 15 May
Banned	1 Oct. - 31 Dec.	1 Jan. - 15 Apr.

* The voluntary restrictions in Greeley were neither as formal nor as large in scale as the requests to reduce use in Fort Collins.

daily water use. Timing and duration of the restrictions are summarized in table 1 (Dustin, 2003).

The basic effects of these restrictions are shown in table 2. This table shows average daily water use in gallons per capita per day for both 2002 and 2003. Winter demand is provided as a reference for water use during a non-irrigation season. This basic data summary raises both points of interest and points of concern. All measures of water use for Fort Collins, including both "winter demand" and "annual demand," fell from 2002 to 2003, suggesting that on a per capita basis residents responded to the drought. It is also interesting to note that water demand under "voluntary" restrictions is higher than "annual" water demand and all other forms of restrictions. This raises 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 a seasonal variation or a legitimate rise in water use under voluntary restrictions.

Table 2 Average Water Use in Gallons per Capita per Day under Different Types of Water Restrictions

	Base usage		Under restrictions		
Fort Collins					
	Winter demand	*Annual*	*Voluntary*	*1 day/week*	*2 days/week*
2002	115.945	232.709	292.21	131.796	249.126
2003	98.161	198.819	n/a	103.621	212.422
Greeley					
	Winter demand	*Annual*	*1 day/week*	*2 days/week*	*3 days/week*
2002	233.438	277.813	N/A	N/A	298.647
2003	228.033	234.933	126.394	248.062	337.028

Basic Water Management in Greeley

The City of Greeley is located roughly 30 miles southeast of the City of Fort Collins and is the largest city in Weld County. Its population in the 2000 U.S. census was 76,930, and the city covers an area of approximately 30 square miles. The City of Greeley has some of the most senior water rights in northern Colorado. During the drought of 2002, Greeley adopted "suggestive" outdoor watering restrictions on April 16 and ultimately, on July 3, restricted water users to three irrigations per week. As with Fort Collins, the types and durations of the restrictions imposed by Greeley are summarized in table 1 and their general effects are shown in table 2. These restrictions were enforced using a fine system. For residential users, fines ranged from $100/incident for first-time offenses to $500/incident, with a mandatory flow restrictor, for a fourth offense. For commercial users, the fines ranged from a $250 first-time fine to $1000, with a flow restrictor, for the fourth offense (Greeley, 2004).

As indicated, both Fort Collins' and Greeley's drought management programs relied heavily on limiting the number and frequency of outdoor irrigations. These restrictions were initially adopted in 2002, but generally carried over into the following water year. While examination of the raw data suggests water savings occurred, the outcomes of specific management tools are not clear and further analysis is necessary.

Statistical Modeling

Based on a superficial evaluation of raw statistics, it is not clear how the imposition of water use 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 correlate to higher water usage. However, raw statistics do not account for the seasonality and cyclical nature of water demand but instead show what water demand was at a given point in time. Further analysis is required.

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 markets. Ideally, panel/household level data should 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. Municipalities typically use increasing block rate prices that lead to correlation between higher prices and higher water usage. The former leads to statistically degenerate estimates of demand, while the latter leads to upward sloping demand curves.

Several alternatives have been proposed to deal with these issues. Nieswiadomy and Molina (1989) estimated both marginal water price and the difference between actual water expenditures and those priced at the margin. These estimates were then used as instrumental variables in a two-stage least squares process, a method that accounted for increasing block rate prices and eliminated biases related to endogenous prices. However, it also showed results suggesting the difference between actual expenditures and those priced at the margin is negative. This suggests consumers demand less water the larger the difference between the upper and lower tiers of prices, a counter-intuitive result given that the marginal price of water is unchanged.

Another alternative for handling water price is the method used by Pint (1999), whereby 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 (1989). However, this method can be utilized only when household water prices vary sufficiently over space and time; it cannot be employed when prices are degenerate (or nearly so).

A final approach is simply to accept that lack of variation in prices makes price uninformative. As a substitute, time-series analysis of daily per capita water use as a function of those variables that do change can be used, which is the method taken here. The concept of a time-series model is simple: water use on a given day is a function of water use on previous days and external forces such as weather and use restrictions. Kenney, Clark, and Klein (2004) have already used a variation of this approach to analyze drought management strategies in Colorado during the 2002 drought. However, a potential statistical problem exists with their model, as it does not account for autocorrelation. Use of ordinary least squares in this case leads to regression results that are statistically inefficient and whose variances may be biased (Judge et al., 1988).[2] As a result, this research instead employs an autoregressive/moving average model (ARMA).

To estimate an autoregressive/moving average time-series equation for water use in Fort Collins and Greeley, it is necessary to assume that daily per capita water demand is a stationary deterministic process conditioned on a variety of external factors. This requirement is necessary to ensure that correlation between errors over time gradually disappears, preventing an overestimate of water demand.

For the purpose of this analysis, exogenous factors include maximum daily temperature (*max daily temperature*), estimated daily rainfall (*precipitation*), a trend variable to indicate whether the day in question was at the beginning, middle, or end of the irrigation season (*trend*), a squared term on the trend variable to allow for rising/falling water cycles over time, and dummy variables to represent the year. For Fort Collins, the dummy variables for the years are 2000, 2002, and 2003, indicating a "base" water year of 2001. Greeley had additional data available, so 1999 was included. Including these dummy variables allows comparison across years to determine if there are annual trends in water demand and avoids evaluating demand outside available data.

For the purpose of policy analysis, it is most critical that the regressions include variables to evaluate specific water use restrictions. To achieve this, dummy variables identifying the watering restrictions in place were included. These are one day per week (*1 day/week*), two days per week (*2 days/week*), three days per week (*3 days/week*), or voluntary limitation (*voluntary*). It should be noted that these were included only where relevant to each city. Last, since Fort Collins also banned water use on Mondays during the 2002 drought, an additional dummy variable for this day was included (*Monday*). Data came from the respective cities' municipal water supply departments.

Water demand in each city is measured using gallons per capita per day figures covering the 2000 to 2003 irrigation seasons (roughly mid-April to October) for Fort Collins and 1999 to 2003 for Greeley. Using the exogenous variables previously mentioned and lagged observations on daily water use, an autoregressive/moving average model was estimated in LIMDEP for each city. Ultimately, an ARMA(1,7) model proved the most effective fit for both cities, indicating that water use on a given day is a function of cumulative water use over the previous week (7 days) and that the error terms are linked only across a single time period. The 7-day lag relationship between current and prior water use in both cities is not surprising, since water use restrictions were enforced on a weekly basis. However, it does suggest that longer trends matter more in daily water use than has been previously reported.[3] Additionally, the strong significance of the AR(1) coefficient (the correlation coefficient between error terms in the current time period and the time period immediately prior) in both demand models provides evidence of autocorrelation and suggests it is essential to account for this potential bias.

Econometric Analysis

The ARMA(1,7) demand function results for Fort Collins are reported in the upper half of table 3. Aside from the previously mentioned finding that a 7-day lag on water use and a 1-day lag on the error terms provides the best overall fit, the results show that water demand is highly cyclical, rising at the beginning of the irrigation season and falling later in the season. This is seen in the strong significance of both the *trend* and *trend-squared*

Table 3 ARMA Results for Fort Collins and Greeley Daily per Capita Water Use

Fort Collins

Variable	Coeff.	t-ratio
constant	-27.4295	-2.21064**
max daily temperature	1.4538	11.8771***
precipitation	-4.88079	-0.623387
trend variable	1.55268	5.81809***
trend-squared variable	-0.0074176	-6.01672***
Monday restriction	-11.4229	-4.94769***
7 day lagged usage	0.475459	17.0457***
voluntary restrictions	-7.93316	-0.600413
1 day/week restrictions	-19.923	-1.45926
2 days/week restrictions	-29.9154	-2.75647***
2000	11.6957	1.51401
2002	5.21242	0.488818
2003	-13.0759	-1.11145
AR(1) term	0.647904	24.3271***

Greeley

Variable	Coeff.	t-ratio
constant	0.446426	0.0286564
max daily temperature	1.73581	14.1026***
precipitation	-0.0305344	-0.0045499
trend variable	2.80029	8.90156***
trend-squared variable	-0.0129514	-9.33983***
7 day lagged usage	0.197844	7.01077***
1 day/week restrictions	-40.4182	-2.04322**
2 days/week restrictions	-30.2411	-1.92192*
3 days/week restrictions	-15.11	-1.07114
1999	-27.6654	-2.57373**
2000	19.3362	1.85033*
2002	-0.651567	-0.0420821
2003	-29.1951	-1.96558**
AR(1) term	-40.4182	-2.04322**

Significant at $\alpha =$ 0.1*
0.05**
0.01***

variables, with *trend* being positive and *trend-squared* being negative. This is consistent with a concave demand function that rises to a peak and falls in a seasonal cycle. While this result is somewhat intuitive, it suggests that the effectiveness of watering restrictions will depend heavily upon the trajectory of water demand. Adopting watering restrictions earlier in the season, when water use is naturally rising, may be more effective than adopting restrictions later in the season when water use is naturally falling. Consequently, water demand models must include cyclical trends.

Additionally, water use on a given day is strongly dependent upon peak temperature but not on daily precipitation. However, the latter result should not be overstated since precipitation was virtually non-existent during the drought and the utility of this variable is debatable. The dummy variables for each year were also not significant for Fort Collins, suggesting that there are no detectable multi-year trends in the data.

What was significant, however, was the dummy variable for *2 days/week* watering restrictions. Based on the coefficient for this variable, this watering restriction reduced daily per capita water use by nearly 30 gallons per capita per day (gpcpd) relative to unrestricted demand. More importantly, since this restriction was adopted early in the irrigation season, it reduced the overall trend of water use during the period and led to an overall lower trajectory for water use in Fort Collins in 2002 and 2003.

Conversely, neither the *voluntary* nor *1 day/week* restrictions exerted a statistically significant effect on daily per capita water use. Recall, however, that these policies were adopted both very early and very late in the irrigation season during both 2002 and 2003. This raises the issue of cyclical water demand effects. These policies likely had limited effects because they either were adopted at points in the cycle where water demand was already low (at the beginning of the irrigation season in the case of voluntary restrictions) or when water use was already trending downward (at the end of the season in the case of the 1 day/week restrictions). This does not mean these policies were ineffective, only that natural demand cycles play a stronger role in per capita water demand. For example, it is likely that 1 day/week restrictions in late September met the consumptive requirements of lawns at that time.

Results for Greeley, shown in the lower half of table 3, are similar to those found in Fort Collins. Yet again, strong significance of both the *trend* and *trend-squared* variables suggests per capita water demand is highly cyclical in Greeley. It rises from the beginning of the irrigation season to a peak in the middle of the summer, from which point it progressively falls. As with Fort Collins, this rather intuitive result suggests that when a water demand policy is adopted matters greatly.

Climatic responses in water demand are also similar in Greeley: temperature matters, but rainfall does not. Again, this latter result may be due to the unusually dry summer weather of 2002. There is however, one notable difference between Greeley and Fort Collins. In Greeley's demand equation, the dummy variables representing year are significant for *1999*, *2000*, and *2003*. More specifically, *1999* and *2003* are negative, while *2000* is positive. Recalling that the data assume a 2001 base year, this implies that water demand in both *1999* and *2003* is statistically lower than it is in *2001* on a per capita basis, while water demand in *2000* is statistically higher. This suggests that the trend in per capita water demand in Greeley was rising prior to the drought, and following the drought (in 2003) per capita water use declined. Given available data, it is impossible to attribute this result to a specific event, but water use education efforts in Greeley during the drought may be a possible explanation for the drop in per capita water use in 2003.

Additionally, the significance of the year dummy variables means that it may not be valid to estimate "representative" water demand models for a city using a single year of data and then use out-of-sample time projections to anticipate demand in other years. Such an approach was a key feature of Kenney, Clark, and Klein's analysis of drought management policies in Colorado. Given the results in Greeley, it appears that trends across years are as critical in determining water demand as in-season cycles.

Among the policy variables for Greeley, both *1 day/week* and *2 days/week* watering restrictions were statistically significant and negative. Based on the parameter estimates, the 1 day/week restrictions reduced per capita water demand by approximately 40 gpcpd, while the less stringent 2 days/week restrictions reduced overall water demand by slightly over 30 gpcpd. That 1 day/week restrictions were significant in Greeley but not Fort Collins may be due to when the policies were enacted. Recall that Greeley began the water year in 2003 with water restrictions in place, while Fort Collins ended 2002 still restricted. The Greeley restriction was imposed when water use was naturally rising, while Fort Collins used this restriction when water use was cyclically falling. The difference in effectiveness of the water policies may be due to the natural trends in water demand. It is also interesting to note that the effects of the 2 days/week restrictions were relatively similar between the two cities. Why this occurred is not clear, but given that water demand is typically inelastic it could be that the effects across cities are roughly proximate. As with Fort Collins, the least stringent form of restrictions used in Greeley (limiting watering to 3 days/week) was statistically insignificant in reducing water use.

The main result worth noting is that the primary effect of the outdoor watering restrictions was to reduce the overall water-use trajectory in Greeley. What ultimately results from the demand models estimated here is that the effects of even modest restrictions are amplified with the passage of time given the recursive and cyclical nature of water demand. This is shown more specifically in figure 1, where cumulative water savings attributable to watering restrictions in both cities in 2002 and 2003 are shown. In each year and for both cities the differences between demand with and without restrictions are small, so resulting water savings are initially small on a per capita basis. However, the reduced water demand trajectory caused by early-season watering restrictions leads to progressively larger water savings as the irrigation season continues. The end result is that timing watering restrictions to match the rising cycle of water demand leads to fairly large overall water savings on a per capita basis by the end of the watering season even though savings on a daily basis are relatively modest.

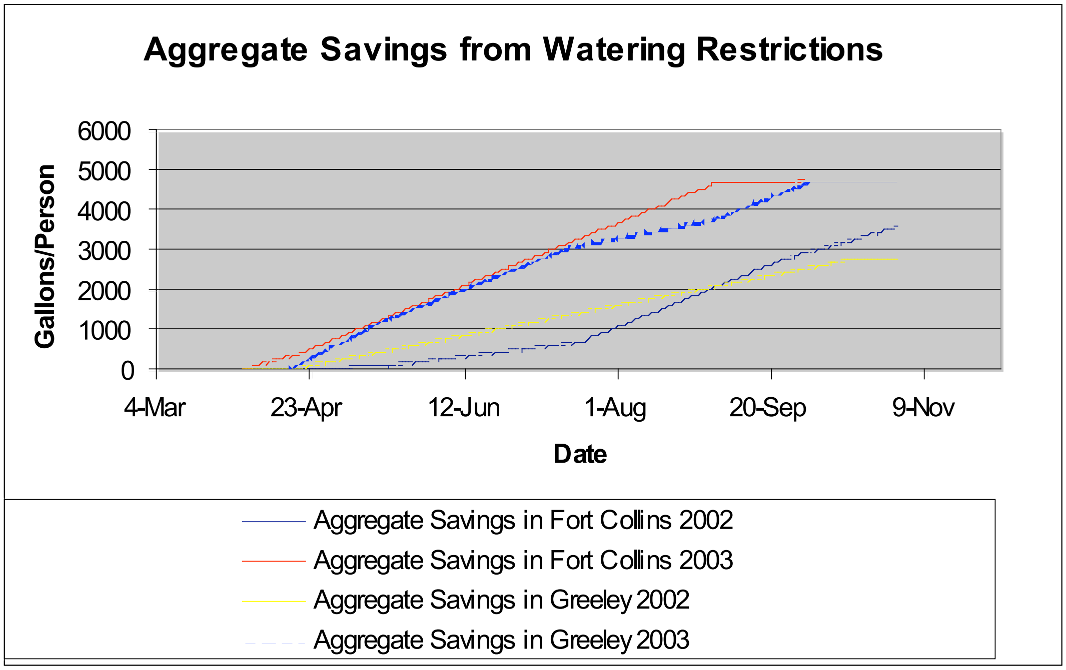

Figure 1 Aggregate per capita water savings for Fort Collins and Greely in 2002 and 2003.

Summary and Conclusion

Through time-series modeling of water demand for two of the major cities in northern Colorado, Fort Collins and Greeley, this study examines the relative effectiveness of water demand limits adopted in response to the worst drought in the state's recorded history. One of the key observations from these demand models is that water demand follows a natural cycle during the outdoor watering season, and the effectiveness of different drought management tools hinges on this cycle. Policies adopted early in the season were more effective than policies adopted late in the season, even if later policies were more stringent. Earlier restrictions had the effect of lowering the trajectory of water demand across the irrigation season while policies adopted later in the season occurred when demand was already tapering off due to cyclical forces. Simply put, *when* a policy is adopted is just as critical as *what* policy is adopted, and, based on the results here, less stringent policies adopted early in the season are more useful than stringent policies adopted late in the season.

Two other useful pieces of information resulted from this study, and both relate to the structure of the regressions used to estimate per capita water demand. To start, the demand models ultimately relied on a 7-day lag for current demand. This indicates that demand on a given day is a function of the water demand over the previous week. Given that watering restrictions in both cities were on a weekly basis, this outcome is not unexpected but is in sharp contrast with many existing demand models that rely on single-day lags. Additionally, this study recognizes that the use of lagged water demand as an explanatory variable raises certain statistical issues regarding the estimation of daily water demand. Specifically, there is a potential for serial correlation across error terms between observations of daily water use. Earlier attempts to assess the effects of the 2002 drought on municipal water demand in Colorado by Kenney, Clark, and Klein were useful in providing aggregate assessments of water savings across Colorado cities. But their model did not correct for serial correlation, which raises issues about the precision of their results. This model specifically recognizes this problem.

What this study does not do, however, is examine how the decisions were made to adopt specific restrictions. Given the critical importance of water demand cycles, further research is necessary to identify optimal timing of water use restrictions. Developing tools to ensure the decision to adopt specific restrictions occurs at the right point in the water demand cycle is vitally important to all western states and provinces.

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Endnotes

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[2] When the authors used their data to estimate functions similar to those reported by Kenney, Klein, and Clark, the Durbin's H statistic indicated first-order autocorrelation for both Fort Collins and Greeley across the full range of data.

[3] It is important to note that only the 7th day lagged water demand is included. While it is possible to include all days prior to the 7th day, this creates the potential for "overfit" where the effects of the highest order lagged variable are masked as simply the sum of the previous variables.