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Maintaining the Common Pool: Voluntary Water Conservation in Response to Varying Scarcity

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Abstract Studies of voluntary conservation response to changing information about an environmental problem have traditionally been synonymous with studies of information campaign effectiveness. As such, they have not been able to capture the response to actual changes in the environment. This paper takes a novel approach to identifying voluntary conservation by studying the impact of changing storage levels on urban water usage in the context of a prolonged drought and a highly ’water aware’ community. Our results suggest that voluntary conservation increases substantially when water is scarce and the public value of the savings is greatest. We discuss the implications of these findings for our understanding of environmental information campaigns in general, and urban water demand management in particular.

Keywords Voluntary conservation · Information campaigns · Warm glow · Water use · Demand management

JEL Classification Q25 · Q21 · D64

1 Introduction

Long the stalwart of water utility managers during drought, voluntary programs are becoming increasingly popular with environmental managers in other areas. This policy interest has

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spurred the growth of an empirical literature examining the effect of information campaigns on a range of consumer behaviour including towel reuse in hotels, commuting choices, household energy use and water consumption.[1] Though often statistically significant, the magnitude of the behavioural change that these papers find is associated with informing consumers about environmental issues is rarely greater than 10 %. Furthermore, Ferraro et al. (2011) found that after one year there was no significant difference in household water consumption between the control group and the consumers who had been provided information on the environmental consequences of their water use.[2]

Should we, then, despair at our inability to react in a socially responsible manner to information about a common threat? Perhaps. But perhaps not quite so much as the findings of the literature on information campaigns would suggest. By design, studies of information campaigns only measure the impact of the new information provided by the campaign; they do not measure how consumers react to all available information on a given environmental problem. The purpose of the current paper is to provide an empirical example of the potential magnitude of the voluntary response which is "missing" from studies of campaigns designed to raise awareness of an environmental problem. In particular, we examine the extent to which residential water consumption for a utility in South-Eastern Australia responded to changing water storage levels around the end of a decade-long drought. In order to identify (as far as possible) the impact of the changing storage levels, we chose a population which was already highly "water aware" at the start of our sample period,[3] and we control for all relevant policy changes. Thus, while the previous literature on voluntary conservation seeks to identify the impact of changing information provision while controlling for any changes in the actual environmental problem; the current study seeks to identify the impact of varying environmental threat with constant information provision.

The policy context of our study is urban water demand management; an important area of study in its own right, and one whose importance is growing as the twin pressures of climate variability and growing demand see increased occurrences of "drought" and introduction of mandatory water-use restrictions even in historically water-abundant places. Although there is a long and extensive literature on the economics of urban water management (Arbués et al. 2003) there are only a few studies examining the effectiveness of information campaigns (Halich and Stephenson 2009). This relative dearth appears surprising in light of the ubiquitous use of information campaigns as a policy response during drought, but it may be explained partly by information campaigns' unpopularity with water economists (who almost universally favour increased emphasis on price as a means of rationing scarce water) and partly by the fact that most studies find their impact is economically small, even if statistically significant.[4] Given that information campaigns for water demand management have traditionally focused on the provision of absolute information about water scarcity, the finding that they are not particularly effective is consistent with the literature on the impact of information campaigns for other environmental issues. The current paper highlights the

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[1] See for example Dulleck and Kaufmann (2004), Goldstein et al. (2008), Cutter and Neidell (2009) and Ferraro et al. (2011).

[2] Ferraro et al. (2011) did, however, find lasting behavioural change among consumers provided with information about how their consumption compared to that of their neighbours.

[3] 98 % of survey respondance were aware of the current conservation campaign, see Yardley (2009) and further discussion in Sect. 3.

[4] See for example Renwick and Green (2000) and Coleman (2009). A notable recent exception to the conclusion that information produces generally modest effects is Halich and Stephenson (2009), who find that information campaigns combined with mandatory restrictions had substantially greater demand reductions than programs relying on mandatory restrictions alone.

fact that the measured response to an information campaign substantially underestimates the full extent of voluntary conservation.

The remainder of this paper is organized as follows. Section 2 outlines our theoretical model and derives empirical predictions for the key variables of interest in our empirical study. Section 3 provides background to our case study and an overview of the data. Section 4 describes and motivates our empirical approach. Section 5 presents and discusses the empirical results, and Sect. 6 concludes.

2 Theory

Voluntary environmental programs such as information campaigns are often used in conjunction with other policies. In the case of urban water demand management during times of scarcity, information campaigns are typically combined with mandatory outdoor-use restrictions and sometimes price increases. Given the combination of policy tools employed, it seems appropriate to clarify what theoretically constitutes "voluntary conservation" in this context, and which aspects of it we are able to identify empirically. Broadly, we believe that it is appropriate to view as voluntary any conservation which is not a response to price changes or to the threat of formal enforcement of mandatory restrictions. Thus, using the terminology of Andreoni (1995), voluntary conservation is motivated either by the attainment of a "warm glow", or the avoidance of a "cold prickle".

Empirically, the current study identifies voluntary conservation as the decrease in demand which is attributable to decreases in dam storage levels, once we remove the level effects of other policy changes such as price and mandatory restriction intensity (referred to hereon as "restriction level"). This empirical strategy will capture some, but not all, of the water conservation which our theoretical discussion below suggests should be considered voluntary.

We adapt the model of Brekke et al. (2003) to our case study and extend it to allow for pricing and utility obtained from private, rival consumption of water.[5] We also borrow from Benabou and Tirole (2011) for some points of interpretation.

2.1 The Model

Assume that the society consists of N identical individuals. Each individual obtains utility from: the consumption of a fully private good, x_i; the consumption of water from public supplies, w_i; leisure time, l_i; the amount of water left in public storages, G; and a measure of the individual's image as a socially (or morally) responsible person, I. Specifically[6]

$$U_i = u(x_i, w_i, l_i) + v(G) + I_i \tag{2.1}$$

Following Benabou and Tirole we allow the value of the image, I, to arise from both pure self-image and external reputation. That is, individuals care if they see themselves as a morally responsible person, as well as whether others see them as such. The marginal utility of I is normalized to 1 and both u and v are increasing and concave.

Individuals may value the water in public storages, $v(G)$, for a variety of reasons, including reduced short-term risk of need to truck in expensive water from elsewhere, reduced medium-term likelihood of construction of alternative water storage or production facilities

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[5] We choose Brekke et al. (2003) from the available theoretical models since it expressly deals with the impact of changing information about the value of a social action (e.g. changing storage levels) as well as changing economic incentives (e.g. price)—both of which we investigate empirically.

[6] Equation 2.1 follows equation 9 in Brekke et al. (2003) except for the addition of individual subscripts and the water consumption term.

(for example reverse osmosis plants) which are economically and environmentally costly, or reduced diversion of water being from environmental uses.

For simplicity labour supply and wages are endogenously fixed. Thus agents choose how to distribute their time between leisure, l_i, and effort spent on water conservation, e_i, subject to the time constraint

$$l_i + e_i = T \tag{2.2}$$

where T is each individual's exogenous total time constraint minus the individual's exogenous labor supply, which is assumed to be equal for all.[7]

Similarly the budget constraint for each individual is given by

$$x_i + pw_i = B \tag{2.3}$$

where p is the (exogenous) price of water and B is each individual's exogenous budget, which is assumed to be equal for all. The private consumption good, x_i, is the numeraire.

The total amount of the water in storage is the sum of an exogenous component, G_p , and private conservation $\sum_i g_i$:

$$G = G_p + \sum_i g_i \tag{2.4}$$

where

$$g_i \equiv \bar{w} - w_i \tag{2.5}$$

with $\bar{w}$ the exogenous baseline consumption. The production function for water conservation is

$$g_i = \gamma(e_i) \tag{2.6}$$

We assume that $\gamma(0) = 0$ and that γ is increasing and concave.

The value of the individuals image as a morally (socially) responsible person is a function their actual effort, e_i, relative to the morally ideal effort, e_i^*. We follow all of Brekke et al.'s assumptions about the functional form and properties of I_i, most importantly that

$$I_i = -a\left(e_i - e_i^*\right)^2, \tag{2.7}$$

where a is a positive constant.

Furthermore, the morally ideal effort is that which would maximize a utilitarian social welfare function, conditional on all others doing the same. With N identical individuals we can omit the individual subscripts and write the social welfare as $N\left(u(x, w, l) + v(G_p + Ng)\right)$. Maximizing social welfare subject to 2.1–2.7, gives the first order condition for the morally ideal effort

$$u_l + u_w\gamma_e = \gamma_e p u_x + \gamma_e N v_G \tag{2.8}$$

where subscripts indicate derivatives. Thus at the moral ideal, the marginal costs of extra effort in terms of lost leisure and reduced water consumption, equal the marginal private and public benefits in terms of extra consumption of good x, and more water in storage.

After solving the social welfare maximization problem, the individual maximizes utility (Eq. 2.1) subject to her time constraint, the public good functions, and the identity function

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[7] Again to simplify, we disregard monetary expenditures on water conservation such as the purchase of more efficient household durables.

(Eqs. 2.2–2.7), taking the effort of all other individuals as given. This determines her actual behavior. In this latter problem, $e*$ is regarded as exogenous. The outcome gives a Nash equilibrium characterized by the first-order condition

$$u_l + u_w \gamma_e = \gamma_e p u_x - 2a\left(e - e^*\right) \tag{2.9}$$

where subscripts indicate derivatives. Thus at the Nash equilibrium actual effort, the marginal costs of extra effort in terms of lost leisure and reduced water consumption, equal the marginal private benefits in terms of extra consumption of good x and improved image.

2.2 Increased Water Price

To see the impact of increased water price, we first differentiate the first order condition for ideal effort (Eq. 2.8) with respect to p. Substituting where appropriate with the help of Eqs. 2.2–2.6 we get

$$e_p^* = \frac{-\gamma_e u_x}{u_{ll} + \gamma_e^2\left(u_{ww} + p^2 u_{xx} + N^2 v_{GG}\right) + \gamma_{ee}\left(p u_x - u_w + N v_G\right)} \tag{2.10}$$

The term $(p u_x - u_w + N v_G)$ makes the impact of price changes on ideal effort ambiguous—thus it is possible for price increases to lead to “crowding out” of conservation effort. A sufficient condition to guarantee that an increase in water price causes an increase in conservation effort is that $p u_x - u_w \geq 0$. In words this condition means that the marginal private consumptive benefits of water consumption do not exceed the cost in terms of forgone consumption of other goods. This condition is most likely to be violated—and thus crowding out effects are most likely to be present—when the marginal utility of water consumption is very high. Notably, the marginal utility of water consumption is highest when water consumption is lowest, and when precipitation is lowest. This has implications for the limits to using price to reduce water demand during drought. For the sake of clear empirical predictions, however, we assume that this condition holds in our case and thus that increased price will lead to increased morally ideal conservation effort.

To see the impact of price increase on *actual* conservation effort, we differentiate the first order condition given by Eq. 2.9 with respect to p. Once again, using Eqs. 2.2–2.7, we have

$$e_p = \frac{-\gamma_e u_x - 2a e_p^*}{u_{ll} + \gamma_e^2\left(u_{ww} + p^2 u_{xx}\right) + \gamma_{ee}\left(p u_x - u_w\right) - 2a} \tag{2.11}$$

The same sufficient condition used above—$p u_x - u_w \geq 0$—guarantees that that actual conservation effort will also rise in response to increased water price. Substituting into Eqs. 2.5 and 2.6 it follows that actual water use will fall.

2.3 Higher Storage Levels

We next consider the impact of an increase in the exogenous component of water storage levels (G_p), for example due to a high rainfall event. Following an analogous procedure to that for price changes, we find the marginal effect of G_p on ideal effort

$$e_{G_P}^* = \frac{-N\gamma_e v_{GG}}{u_{ll} + \gamma_e^2\left(u_{ww} + p^2 u_{xx} + N^2 v_{GG}\right) + \gamma_{ee}\left(p u_x - u_w + N v_G\right)} \tag{2.12}$$

Thus the morally ideal effort is decreasing in the exogenous component of storage levels whenever the denominator of Eq. 2.12 is negative. Once again, the condition $p u_x - u_w \geq 0$ is sufficient.

Similarly, the marginal effect of increased water storage on actual effort is

$$e_{G_P} = \frac{-2ae^*_{G_P}}{u_{ll} + \gamma_e^2 \left(u_{ww} + p^2 u_{xx}\right) + \gamma_{ee}\left(pu_x - u_w\right) - 2a} \tag{2.13}$$

which also is guaranteed to be negative if $pu_x - u_w \geq 0$.

Substituting into Eqs. 2.5 and 2.6 it follows that an exogenous increase in water storage levels will cause an increase in actual water use.[8]

2.4 Outdoor Use Restrictions

The mandatory outdoor use restrictions applied in our study area are described in greater detail in Sect. 3. For current purposes we simply note that certain types of outdoor water use—for example the watering of lawns—were prohibited. One impact of the mandatory restrictions was to increase the perceived cost of deviating from the morally ideal effort.[9] In terms of our model, this means an exogenous increase in the parameter a in Eq. 2.7. Intuitively we expect this to cause effort to increase towards the morally ideal level. To formally examine the impact of increasing a, we first note that image cost has no effect on the morally ideal effort. The marginal effect on *actual* effort is

$$e_a = \frac{2a(e - e^*)}{u_{ll} + \gamma_e^2 \left(u_{ww} + p^2 u_{xx}\right) + \gamma_{ee}\left(pu_x - u_w\right) - 2a} \tag{2.14}$$

which is positive.[10] Thus, insofar as mandatory restrictions increase either social or formal costs of deviating from the moral ideal, we expect them to cause increased conservation effort and decreased water use.

The second way in which mandatory restrictions may lead decreased water use is by communicating that the marginal value of water in storage, v_G, has gone up. Evidence for this mechanism is provided by a recent study from a neighboring municipality to our study area, which found that approximately half of the residential water savings during the restrictions was from (unrestricted) indoor usage reductions Beatty (2011).

Differentiating the first order condition for the moral ideal again, gives

$$e^*_{v_G} = \frac{-N\gamma_e}{u_{ll} + \gamma_e^2 \left(u_{ww} + p^2 u_{xx}\right) + \gamma_{ee}\left(pu_x - u_w + Nv_G\right)} \tag{2.15}$$

thus the morally ideal effort will increase when the marginal social value of water in storage is perceived to be higher. This in turn leads to an increase in the actual conservation effort and consequent reduction in water use.[11]

It is worth noting that to the extent that formal restrictions encourage conservation via changing perceptions about the marginal value of water in storage, they arguably act by increasing "voluntary" conservation. This component of voluntary conservation will not, however, be captured by our empirical approach.

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[8] Empirically this prediction needs to be made conditional on controlling for the cause of the rise in storage levels (e.g. high rainfall) which may have a direct effect of decreasing water use due to lower garden watering requirements.

[9] The expected cost of violating the mandatory restrictions was likely primarily driven by perceived social cost of being seen to violate. While the utility had the right to issue fines of $AU200–$AU1,000 for violations, formal enforcement of this type was very rare (pers. comms. from ACTEW Water officer).

[10] This prediction is unambiguous provided our sufficient condition, $pu_x - u_w \geq 0$, holds.

[11] The marginal effect on actual effort has the same form as that for exogenous dam-level changes (Eq. 2.13).

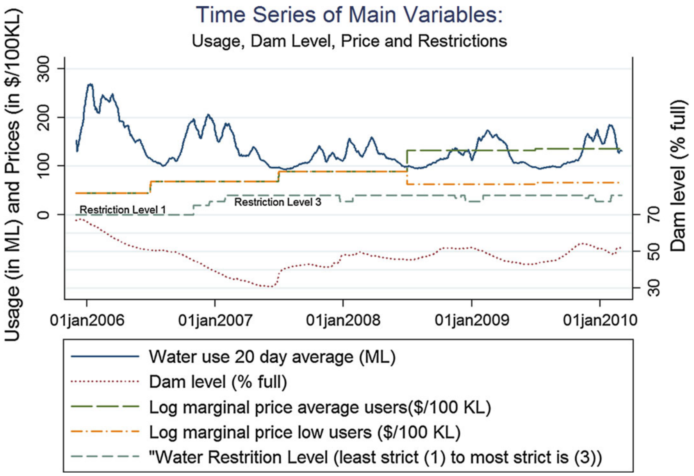

Fig. 1 Water usage, dam level, price and restrictions. *Notes* Water usage is represented as a 20-day moving average of daily consumption, low water users are household consuming less than 200 kL/year while the average water use is 232 kL/year, water use restrictions are presented in levels where the most stringent level (level 5) are stage 3 restrictions introduced on the 29th of January 2007 and continue with a few exemptions to the end of the sample. (Color figure online)

3 Data and Background

Our water usage data from the Australian National Capital region provides an exceptional opportunity to study how voluntary, uncoordinated actions respond to changes in the objective need for action, on an issue whose importance was widely recognized in the community. The sample period—from 1st of December 2005 to 3rd of March 2010—covers the end of a decade-long drought in South-Eastern Australia. The prolonged drought and consequent shortages in water reservoirs were frequently in the news, and a number of smaller towns had completely run out of water and been forced to import it. The Managing Director of the water-supply utility for our study area described the 2006 water storage levels as “dangerously low”,[12] and there was serious debate at the time about whether to use recycled waste water as drinking water (a practice which is unprecedented in Australia).[13] The evolution of storage levels over our sample period is plotted in Fig. 1 as a red dotted line.

A key component of the utility’s demand management response was an information campaign focusing on raising awareness of the water shortages and emphasizing that every consumer has responsibility for maintaining storage levels. Water storage levels (percent full) were reported weekly in the leading newspaper and on the television news during our sample and for more than two years prior.[14] The only documented change in the information campaign during our sample period was the introduction in 2007 of electronic roadside signs. The signs were positioned along all major arterial roads in Canberra and displayed current storage level, daily consumption, and target consumption. Given the prolonged and broad-based information campaign prior to their introduction, it seems likely that the population

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[12] http://www.canberratimes.com.au/news/local/news/general/climate-blamed-for-high-water-use/1815827.aspx.

[13] http://www.abc.net.au/water/stories/s1922096.htm.

[14] Actew’s information campaign also included television advertisement, specific publications, mail drops, advertising on posters and in newspapers such as in The Canberra Times.

was already saturated with water scarcity information prior to the introduction of the roadside signs. A survey by the water utility a few months prior to our sample period (and thus over a year prior to the introduction of the signs) found that 98 % of participants said they were aware of the current conservation campaign and, of these, 77 % said the campaign had at least some impact on their consumption behaviors [Results from ActewAGL surveys, reported in Yardley (2009)]. Nonetheless, we test the robustness of our findings to controlling for the introduction of the roadside signs.

As is common demand management practice in times of severe water shortage, the information campaign was accompanied by mandatory restrictions on outdoor water use. There were five restriction levels, all of which we observe in our sample. Stage 1—which began prior to the start of our sample—consists of relatively minor water restrictions. The somewhat stricter Stage 2 was only briefly in place before Stage 3 was introduced at the beginning of 2007. Stage 3 are the toughest restrictions and forbid the use of sprinklers, watering lawns and topping up pools, and only allow watering plants with a trigger nozzle hose at restricted times. Stage 3 lasted to the end of our sample and is only interrupted by short summer and spring clean exemption periods which briefly allow for more water uses. A detailed explanation of the water restriction categories can be found in the "Appendix". The timing of the changes in restriction levels are plotted as dashed line in Fig. 1.[15]

ActewAGL employs increasing block pricing, meaning that the relevant marginal price depends on consumption.[16] Marginal price increased for all users each year in our sample, except for low users consuming 100–200 kiloliters per year (kL/year) who saw a decrease in marginal prices in July 2008 due to the elimination of one of the block-pricing levels. The marginal price for low users is plotted as dashed-dotted line in Fig. 1. Marginal price for the average household, consuming 232 kL a year as of 2004[17], is plotted as long dashed line in Fig. 1. Note that price changes are permitted annually in July and this is helpful for our identification of the role of the different policy variables. In particular, the major change in restriction levels (from Stage 1 to Stage 3) occurred in January 2007, separating it from price changes by over 150 daily observations.

The solid line in Fig. 1 plots a 20-day moving average of the daily aggregate water usage.[18] We observe a cyclical variation of water consumption over the year with peak consumption taking place from December through February each year during the hotter summer month. Aside from the seasonal variation, a steep decline in consumption from the start of our sample through to mid-2007 is evident, followed by stabilization or slight gradual increase in the subsequent years. It is interesting to note that this gradual increase in usage from the 2007 low occurred despite the maintenance of the toughest Stage 3 restrictions and increases in average price in subsequent years. We will try to show later on in the paper that the reason for this gradual increase in consumption is the gradual recovery of water storage levels, leading consumers to lower their water conservation efforts.

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[15] For clarity in Fig. 1 we have coded the restriction levels according to their severity. Thus Stage 1 = Level 1, Stage 2 = Level 2, Summer Exemption = Level 2.3, Spring Exemption = Level 2.7, Stage 3 = Level 3.

[16] As with many water supply utilities around the world, price changes are regulated to ensure monopoly profits are not reaped by the supplier.

[17] See Troy et al. (2006) who produce statistics for average annual household consumption by type of dwelling. With separate houses using 319 kL (kL/year), semi-detached dwellings using 193 kL/year and flats 138 kL/year.

[18] Although we plot 20-day moving average consumption in Fig. 1, actual daily usage is used in our regression analysis. Daily data has two advantages compared to the monthly data used in previous studies of non-price demand management measures. Firstly, the higher frequency significantly reduces the extent of colinearity of the multiple policy changes that were made, an issue which has plagued most studies (Syme et al. 2000). Secondly, it allows for the inclusion of detailed weather controls as discussed below.

A key danger of such casual empiricism is, of course, the omission of other important variables. In particular, we may be concerned that higher rainfall in 2007—which led to the initial increase in dam levels—also suppressed consumption in that year. Controlling for local weather conditions is particularly important in Australian samples, for which weather typically explains a large part of the consumption variation.[19] In our study region over 90 % of households live in detached and semi-detached dwellings,[20] and within this group outdoor water use accounts for 43 % of water consumption.[21] We obtained weather data from the Bureau of Meteorology's Canberra airport weather station.[22] The observations include daily weather variables such as sun-hours, precipitation, temperature, evaporation and many more.[23] Including these we take considerably more care to control for weather influences than previous water-demand studies. We use daily (c.f. monthly) usage and weather data, and we control for contemporaneous and multiple days of lagged weather variables and also including moving averages as well as month dummies. The aim is to control for outdoor water use needs, given the past and current weather, as best we can.

Finally we control for population using quarterly estimates for the region from the Australian Bureau of Statistics.[24] The dependent variable used in the regression analysis is water usage in per capita term to account for the population growth in the region.

Summary statistics for key variables in our data by year from winter to winter season are provided in Table 1.[25] The average daily usage dropped by 36 % from 2005/2006 to 2007/2008. Consumption increases slightly in the subsequent years despite the increased precipitation. Dam levels reached their lowest point in June 2007. Marginal water prices for the average household have more than doubled over the observation period from under two dollars to almost four Australian dollars. In 2010 dollar terms prices increased by 150 % from $1.56 per kiloliter at the start of our observation period to $3.9 per kiloliter in 2010. The marginal price for low users, using less than 200 kL/year, has only increased by 25 % over the 5 years due to the change in block-price structure. The strictest stage 3 restrictions are in place form the 29th of January 2007 and stay in place through the end of our sample with only short exceptions for spring cleaning and summer exemptions. The table shows the percent of days in the given year that stage 3 restrictions have been in place. Roadside signs come into effect on 5th of December 2007 and stay in place throughout the rest of our sample period. Target-use levels are set jointly by government and utility company at the start of the year according to an estimated feasible water usage level taking the dam levels into account. A set of target-usages are set in advance conditional on each restriction stage. Table 1 reports the summer high and winter low usage targets in place. The seasonal target levels went down

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[19] We use a large number of weather variables in our final specification. All of these are highly significant and together explain 41 % of the water usage variation in the data.

[20] In the Australian Capital Territory 81.5 % are separate houses, 10.7 % semi-detached dwellings and 7.6 % flats (see ABS's Australian Social Trends—Housing Table 2.8 available at: http://www.abs.gov.au/ausstats/abs@.nsf/mf/4102.0).

[21] See ACT Goverment (2004, p. 22).

[22] This is the main weather station in Canberra with the most detailed and uninterrupted weather data from the region since 1939.

[23] The weather station records a total of 57 daily measures and statistics. For a complete list see: http://reg.bom.gov.au/climate/dwo/IDCJDW2801.latest.shtml.

[24] From the ABS's Australian Demographic Statistics publication. The estimates are based on the ABS's last 2006 Census and can be found here: http://www.abs.gov.au/ausstats/abs@.nsf/mf/3101.0.

[25] Statistics for additional variables such as population and other weather variables available on request from the authors.

Table 1 Summary statistics for key variables

	2005/2006	2006/2007	2007/2008	2008/2009	2009/2010
Mean daily usage (ML)	194	140	119	123	130
Mean dam level (%)	58.5	40.5	44.8	47.9	49.5
Minimum dam level (%)	50.8	30.8	37.9	43.1	43.2
Maximum dam level (%)	67.8	50.8	49.7	52.1	54.5
Average rain per day (mm)	1.26	1.17	1.25	1.4	1.6
Percent rain days (%)	17.5	26.3	29.0	30.7	31.3
Marginal price average user in $/KL	1.56	1.99	2.45	3.76	3.90
Marginal price low user in $/KL	1.56	1.99	2.45	1.88	1.95
Stage 3 restrictions in place (% of days)	0	42	90	79	88
Roadside signs in place (% of days)	0	0	57	100	100
Water-use target (summer/winter) (ML)	228/121	139/97	139/97	139/97	150/105

ML stands for megaliters. $/KL stands for 2009 AU$ per kiloliter. mm for millimeter of rain

at the start of our sample but stayed largely constant throughout the stage 3 restrictions and only rise slightly again in year 2009/10.

4 Empirical Approach

To identify the impact of water scarcity on consumption we regress (log) usage on dam storage levels, controlling for all other known determinants of aggregate demand changes over time. The other controls fall into three categories: policy, weather, and timing. Of these three categories, weather (e.g. rainfall) and timing (e.g. month and day of week) are clearly exogenous. The policy variables, in contrast, are clearly endogenous. The utility sets its demand-management policy (in consultation with the government and regulator) in view of current and predicted storage levels. Thus storage levels may affect consumption both directly—through impacts on voluntary conservation—and indirectly—through impacts on demand management policies. If then, we wish to estimate the direct impact of storage levels, it is important that we control for indirect impacts via demand management policies. As described in the previous section, the key residential demand management policies of the utility in our case study were the information campaign aimed at inducing voluntary conservation, mandatory outdoor use restrictions, and price changes.

Thus our base specification has the form:

$$\ln(y_t) = \alpha_0 + \alpha_1 Damlevel_{t-1} + Z_t'\beta + X_t'\delta + \varepsilon_t \tag{4.1}$$

where $\ln(y_t)$ is the log of per capita water usage in megaliters at time t. α_0 is the coefficient on a constant term. $Damlevel_{t-1}$ is the previous day's combined storage reservoir level (% full). *Damlevel* is lagged one day to avoid reverse causality from usage to storage levels. As argued above, dam levels have an indirect effect through demand management policies. Since we control for induced policy changes, we interpret α_1 as the magnitude of the direct effect of dam levels on consumption due to voluntary conservation. α_1 is thus our main parameter of interest.

Z_t represents a vector of water demand management policies. It includes the log of the marginal price (per kiloliter, in 2009 AU$) that would be relevant for both "average users" and "low-end users".[26] Including price for both types of user was important since the price changes did not always move in the same direction. Z_t also includes a dummy variable for each restriction level equal to 1 if the respective outdoor water use restriction is in place. Stage 3, the toughest restrictions, are the excluded restriction level in the regressions. The coefficients on the other restriction levels, therefore, represent their relative effect on consumption compared to Stage 3.

X_t includes all other control variables. These include an extensive set of variables from the Bureau of Meteorology to control as far as possible for the variation in consumption due to changes in weather. Weather controls included are rainfall, 5 days of lagged rainfall, 20-day moving-average rainfall, sun-hours, evaporation, 3 days of lagged evaporation, 20-day moving-average evaporation, the maximum temperature and yesterday's maximum temperature. As discussed in Sect. 3, this extensive set of weather controls is important in light of the significant outdoor component in water usage in our sample and the direct impact of weather on storage levels. In addition to weather controls, X_t also includes day-of-week dummies due to systematic variation in consumption patterns across the week. We find that people generally use less water during the week relative to the weekend. Average water use is highest on Sundays and lowest on Fridays. Finally X_t also includes month dummies to control for possible seasonal variations in water usage not captured by the weather controls. ε_t is a normally distributed error term which tests revealed as serially correlated and heteroskedastistic. Thus we employ the Newey and West (1987) estimation of our covariance matrix to get corrected standard errors.[27]

The serial correlation present in the error term from our base regression as per Eq. 4.1 suggests that the inclusion of an additional lag may be warranted. Table 4 reports the short and long-run effects from an estimation of our main specification with a lagged dependent variable as a regressor and as a partial adjustment model. The estimated long-run coefficients of the lagged specification are virtually unchanged from our main regression results at the same levels of significance. Thus for ease of exposition we retain the simpler Eq. (4.1) as our base specification. Additional checks of the robustness of our findings to specification changes are discussed along with their results in Sect. 5.

5 Results

The main results of the paper are presented in Table 2. The first column in Table 2 represents the correlation of (lagged) dam level with consumption, controlling for all weather and other exogenous controls, but no policy variables. The coefficient of 0.011 suggests that the combined policy-induced and voluntary response to a 10 % decrease in dam level would result in a demand decrease of around 11 %. Moving across the columns we progressively add policy controls. As we expect, the coefficient on dam level decreases, but even with a comprehensive set of policy controls remains statistically and economically significant. Our base (and preferred) specification is in column 3. The dam level coefficient of 0.0055 in our base specification indicates that a 10 % decrease in dam level will induce voluntary conservation reductions of around 5.5 %. Thus the dam level change from 60 to 30 % in our sample is estimated to have resulted in demand reduction of around 17 %.

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[26] To avoid endogeneity problems "average" and "low-end" users are defined according to the 2004 data reported in Troy et al. (2006).

[27] Following a common practice as a simple rule suggested by Greene and Zhang (2003, p. 267) Newey–West is implemented with a bandwidth of $B = (N)^{1/4}$ rounded up to the next integer. The bandwidth in our case with $N = 1548$ is $B = 7$.

Table 2 Main regression results

	Dam-only Per capita use (ln)	Dam + Price-only Per capita use (ln)	Base Per capita use (ln)	+Signs Per capita use (ln)	+Targets Per capita use (ln)
Dam level in %	0.0114***	0.00692***	0.00553***	0.00646***	0.00451***
	(8.85)	(8.42)	(4.45)	(4.00)	(2.8)
Marginal price avg. user (ln)		−0.274***	−0.200***	−0.162***	−0.150***
		(−18.80)	(−5.72)	(−3.99)	(−3.80)
Marginal price low user (ln)		−0.346***	−0.272***	−0.250***	−0.191***
		(−11.02)	(−5.32)	(−4.83)	(−3.69)
Stage 1 restrictions			0.0710*	0.0664	−0.0194
			(1.73)	(1.54)	(−0.47)
Stage 2 restrictions			0.114***	0.120***	0.0923***
			(4.60)	(4.81)	(3.42)
Summer exemption			−0.0383	−0.0359	−0.0122
			(−1.52)	(−1.42)	(−0.48)
Spring clean			−0.0367	−0.0317	−0.0207
			(−1.20)	(−1.06)	(−0.75)
Roadside signs				−0.0301	−0.0217
				(−1.33)	(−1.01)
Water use target (ln)					0.404***
					−4.13
Observations	1539	1539	1539	1539	1539
Adjusted R2	0.77	0.882	0.886	0.887	0.89

Standard errors are heteroskedasticity and autocorrelation consistent (Newey–West). (ln) indicates a variable that enters in logarithmic specification. ML stands for megaliters. The dependent variable is log per capita water usage. Dam level is lagged by a day. Each regression contains month and day of the week dummies and the complete set of weather controls described in Sect. 3

t Statistics in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Columns 4 and 5 of Table 2 are the first of our robustness checks. In column 4 we control in addition for roadside signs which were part of the ongoing awareness campaign. The Data on roadside signs was provided as part of the utilities data set and is a quick easy way to check if the extra information provision had an effect on the population. The negative but insignificant coefficient on roadside signs is an indication that the signs had little effect as the population was already saturated with water conservation awareness messages at the time the signs were introduced.

Column 5 controls for the aggregate water-use target the utility company issued as part of their awareness campaign. This seasonally-varying target was primarily a management tool, set jointly by the utility and government at the start of each year in accordance with the dam levels and an estimate of what was considered feasible in light of the water price and outdoor use restrictions. The time-series evolution of the target use is graphed alongside dam level and actual consumption in Fig. 2 in the "Appendix". The potential for the target to have a direct impact on consumption was limited. The only direct channel was that the target was advertized (for example on roadside signs) alongside the actual water use for the previous day. In terms of our model in Sect. 2, the aggregate water use target could be thought of as the government and utility's estimate of the collective/aggregate "morally ideal consumption".

Thus by advertizing the target along with the actual consumption, the utility was signaling how far collectively consumers were deviating from the moral ideal. An argument could also be made that including the target use in the regressions helps to capture any otherwise unobservable aspects of the utilities demand management efforts—most notably those aimed at the few non-residential customers.

Target level was not included in our base (preferred) regression, however, because it was set on the basis of predicted feasible consumption—based on the storage levels, weather predictions and other chosen policy variables. The extent of the colinearity and endogeneity problem this causes is illustrated by the fact that a simple regression of the target consumption on dam level, price, restriction level and month[28] produces an R-squared of 0.93. Thus, it is possible for target-level to be highly correlated with actual consumption without having any real causal effect. Indeed, in a related paper we use an event study show there is no evidence that target level has any causal effect on usage.[29]

The inclusion of target use in column 5 therefore represents a very conservative robustness check. Not surprisingly in light of the colinearity issues, column 5 shows that the inclusion of the water-use target decreases the explanatory power of the other policy variables and of the dam level. The coefficient on the dam level, however, remains significant at the 1 % level and continues to suggest a non-trivial magnitude of water-use response.

The magnitude of the coefficients on price also decrease as expected when we control for additional policy variables across the columns of Table 2, though the estimates all lie comfortably within the range reported in the literature.[30]

Perhaps surprisingly, the effect of less strict restrictions on outdoor uses (compared to the excluded Stage 3 restrictions) was appears to be relatively small. The ‘summer exemption’ and ‘spring clean’ appear to have no discernible effect on consumption. Stage 2 restrictions are associated with up to 12 % more consumption, but Stage 1—which should be the least restrictive—is only associated with up to 7 % more.[31] It is difficult to place these results relative to the literature since a dummy variable is generally included for ‘any restriction’ (see for example Grafton and Ward 2008; Kenney et al. 2004; Renwick and Green 2000). However, according to Ward (pers. comms.), although Grafton and Ward (2008) found the introduction of mandatory restrictions had a large effect of around 14 %, they did not differentiate *different* restriction levels in their reported regressions as they found no significant difference in their impacts. One possible explanation for both our results and those of Grafton and Ward is that restrictions largely work by indicating a need for conservation and raising people’s expectations that other consumers are making an effort to conserve. This explanation is supported by recent research by the Sydney Water Corporation which concluded that approximately half of the residential water savings during the restrictions was from (unrestricted) indoor

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[28] January, February, etc.

[29] See Aisbett and Steinhauser (2011).

[30] Dalhuisen et al. (2003) find a mean of −0.41 and a median of −0.35 in a meta-sample of 314 price elasticities from 64 studies. In our base specification the elasticity estimate for the low-user and average-user marginal prices are around −0.27 and −0.20 respectively. To compare these figures to the literature (which generally has disaggregated data and therefore a single relevant marginal price) we need to add the coefficients together. The intuition of adding the two elasticity estimates can be obtained from the thought experiment of calculating the effect of a uniform price increase which increased both marginal prices by, say, 10 %. Thus our equivalent total price elasticity estimate is −0.47. This lies between recently estimated Australian short-run marginal price elasticities of −0.35 by Grafton and Kompas (2007) for Sydney and the −0.51 estimated by Hoffmann et al. (2006) for Brisbane, but is higher than the −0.17 estimated for Sydney by Grafton and Ward (2008).

[31] This latter result, however, is not particularly robust as is demonstrated in Tables 3 and 4 and is discussed below.

Table 3 Robustness to price measure

	Base Per capita use (ln)	MC average user Per capita use (ln)	AC average user Per capita use (ln)	Average MC Per capita use (ln)
Dam level in %	0.00553***	0.00500***	0.00550***	0.00674***
	(4.45)	(4.34)	(4.64)	(4.99)
Marginal price (ln)	−0.200***	−0.121***		
	(−5.72)	(−4.62)		
Marginal price low users(ln)	−0.272***			
	(−5.32)			
Average price (ln)			−0.507***	
			(−5.98)	
Average marginal price (ln)				−0.336***
				(−5.54)
Stage 1 restrictions	0.0710*	0.169***	0.0781**	0.0783*
	(1.73)	(5.82)	(2.00)	(1.90)
Stage 2 restrictions	0.114***	0.151***	0.121***	0.116***
	(4.60)	(6.55)	(5.04)	(4.64)
Summer exemption	−0.0383	−0.0497*	−0.036	−0.0391
	(−1.52)	(−1.79)	(−1.40)	(−1.52)
Spring clean	−0.0367	−0.0261	−0.0294	−0.0328
	(−1.20)	(−0.92)	(−0.98)	(−1.13)
Observations	1539	1539	1539	1539
Adjusted R2	0.886	0.879	0.886	0.884

Standard errors are heteroskedasticity and autocorrelation consistent (Newey–West). (ln) indicates a variable that enters in logarithmic specification. ML stands for megaliters. The dependent variable is log per capita water usage. Each regression contains month and day of the week dummies and the complete set of weather controls described in Sect. 3

t Statistics in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

usage reductions Beatty (2011). It is also consistent with studies which find low estimates of willingness to pay for the removal of mandatory restrictions (Hensher et al. 2006; Gordon et al. 2001).

In light of the amount of attention that the economic literature on demand management has paid to the estimation of price elasticities, our first robustness Table is dedicated to this issue. There is ongoing debate in the literature as to whether consumers actually respond to average or marginal price of utilities (Shin 1985; Nieswiadomy and Molina 1991; Arbués et al. 2003; Olmstead et al. 2007). Additionally, since we are using aggregate data, arguments could be made for the use of either 'average marginal price or 'marginal price faced by the average user'.

The first column in Table 3 reproduces our base results. Column 2 is based on a regression with only marginal price for the average user included. While the results show a much smaller price elasticity, the coefficient on dam level remains robust. In columns 3 and 4 we include average marginal price and marginal price faced by the average user respectively as price measures. The results of these two columns similarly show that although the estimated price elasticities themselves vary according to the specification of price in the regression, the coefficient on dam level is robust. Interestingly, and somewhat reassuringly, the average price elasticity of −0.50 (in column 3) is very close to the implied total price elasticity of −0.47 from our base regression.

Table 4 Robustness checks

	Base	Time trend	Lagged dependent variable		Split sample
			Short-run effects	Long-run effects	
Dam level in %	0.00553***	0.00536***	0.00255***	0.00550***	0.00513***
	(4.45)	(4.27)	(3.91)	(4.55)	(2.80)
Marginal price (ln)	−0.200***	−0.282***	−0.0899***	−0.201***	−0.176***
	(−5.72)	(−4.50)	(−4.92)	(−5.92)	(−3.05)
Marginal price low users(ln)	−0.272***	−0.296***	−0.128***	−0.268***	−0.217***
	(−5.32)	(−5.61)	(−4.76)	(−5.33)	(−2.65)
Stage 1 restrictions	0.0710*	0.0723*	0.0323	0.0711*	
	(1.73)	(1.77)	(1.54)	(1.78)	
Stage 2 restrictions	0.114***	0.116***	0.0494***	0.117***	
	(4.60)	(4.73)	(2.73)	(5.47)	
Summer exemption	−0.0383	−0.0387	−0.0212	−0.0345	−0.0355
	(−1.52)	(−1.53)	(−1.33)	(−1.50)	(−1.18)
Spring clean	−0.0367	−0.038	−0.0225	−0.0301	−0.032
	(−1.20)	(−1.34)	(−1.07)	(−1.22)	(−0.94)
Time trend		0.0000626			
		(1.50)			
Lagged dependent variable			0.545***		
			(20.16)		
Observations	1539	1539	1539	1539	1163
Adjusted R2	0.886	0.887	0.917	0.919	0.825

The dependent variable is log per capita water usage. Standard errors are heteroskedasticity and autocorrelation consistent (Newey–West). (ln) indicates a variable that enters in logarithmic specification. ML stands for megaliters. Each regression contains month and day of the week dummies and the complete set of weather controls described in Sect. 3. By estimating the lagged dependent variable model as a partial adjustment model we get the long-run effects with their standard errors, for more details on the methods see Wickens and Breusch (1988)

t Statistics in parentheses: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table 4 displays the results of our non-price related robustness checks. Column 1 reproduces our base regression for ease of comparison. Column 2 tests robustness to the inclusion of a time trend to account for any underlying, exogenous technical or behavior trends toward lower consumption. The time trend is statistically insignificant and there is negligible change in any of the coefficients except for an increase in price elasticity. Column 3 adds a lagged dependent variable directly addressing the observed serial correlation evident in the errors. Though the coefficients change, the implied long-run effects of all coefficients reported in Column 4 are consistent with our base results and virtually unchanged.[32] In order to get standard errors along with the long-run effects of the lagged dependent variable model we can run the specification as a partial adjustment model to get all reported results for Column 4.[33] In Column 5 we restrict the sample to the Stage 3 restriction period, thereby exclud-

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[32] The variable coefficients in the regression of Column 3 represent the short-run same period effect. To get the comparable long-run effect of the variables we can divide the coefficient by (1 − lagged dependent variable coefficient). So the long-run effect of dam levels in the lagged model of Column 3 could be calculated as $0.00255/(1 - 0.545) = 0.0056$.

[33] For a more detailed discussion see Wickens and Breusch (1988).

ing the initial rapid decrease in both dam level and consumption at the start of our sample. Once again the coefficients are robust suggesting that our result is not driven by the strong correlation between consumption and dam level in the first half of the sample.

6 Conclusion

The results in this paper suggest that voluntary conservation increases when water is scarce and the public value of the savings is greatest. Furthermore, the size of the voluntary conservation response identified here is larger than is often found in studies of campaigns informing consumers of the value of conservation, particularly those targeted at urban water conservation. One reason we find a larger response may be that previous studies—in focusing on the impact of a single campaign—have not captured consumers' responses to environmental information from other sources.

An additional driver for the relatively large effects we identify may be that we observed the response to information changes by a population who were also subject to mandatory conservation measures. Unambiguous predictions about the impact of mandatory restrictions on voluntary the sensitivity of conservation effort to storage levels did not arise in our model, however, it seems intuitively likely that voluntary/information-based and mandatory conservation measures might be mutually re-enforcing. This potential interaction is an area worthy of further theoretical and empirical investigation. Better understanding interactions between voluntary and mandatory policy approaches will assist both in policy design, and in the proper assessment of efficiency comparisons.

Our empirical setting also has features which make a non-trivial voluntary response more likely. Firstly, water storage-level information is particularly useful for eliciting public response since it is undisputed, comprises a single, objective measure, and has an obvious link to the relevant social problem. Secondly, the residents in our study area have characteristics which make them particularly amenable to water-conservation information campaigns: on average they are highly educated, high income, and high water users (Freimuth and Mettger 1990; Aitken et al. 1994).

Understanding the economic importance of voluntary conservation and how it responds to the public value of maintaining resources is of obvious import for policy-makers who are considering the expansion or re-design of information campaigns. However, it is also important in areas—such as urban water demand management—where there is a push toward an increasing emphasis on price for the allocation of scarce resources. Both the efficiency and efficacy of such a shift depend on the magnitude of the voluntary conservation which it is likely to crowd out.

Our findings may also have implications for the extensive and highly sophisticated literature on the estimation of the price elasticity of urban water demand. In cases such as ours—where voluntary conservation appears to be both substantial and responsive to storage levels—the omission of storage levels from empirical demand specifications may lead to bias if prices are also raised in response to water scarcity. This suggests storage levels should be included in price-elasticity regressions.

Finally, our results may suggest a novel explanation for the recent empirical findings that the behavioural response to the provision of norm-referenced information (about the behaviour of comparable consumers) is larger and more persistent than the response to information about the environmental problem (Goldstein et al. 2008; Ferraro et al. 2011). The obvious explanation for these findings is that people are simply more responsive to norm-referenced appeals. Our results suggest a possible additional explanation, namely, that information about the consumption patterns of peers is less readily available in the absence of an information campaign than information about the environmental problem itself. Thus, consumers may show relatively little response to the provision of information about an environmental problem because they are already aware of the problem from other sources. Similarly, the impact of environmental information may appear less persistent than the impact of norm-referenced information because, over time, both treatment and control groups learn about the issue from alternative sources. Our results suggest that differences in alternative availability of norm-referenced and absolute environmental information may be responsible for some of the observed differences in the effectiveness of providing the two to consumers. We leave for future research the question of how *much of* this difference it explains.

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7 Appendix

See Table 5 and Fig. 2.

Table 5 Details of water restrictions

	Stage 1	Stage 2	Stage 3	Summer exemption	Spring clean
Lawns	Restricted times[a], sprinkler allowed	Restricted times, no sprinklers	No	Weekends; sprinklers 7–10 p.m.	No
Gardens	Sprinkler: restricted times, trigger nozzle hose, can or bucket: any time	Restricted times; no sprinklers, only trigger nozzle hose, can or bucket	Restricted times, no sprinklers, only trigger nozzle hose, can or bucket	Restricted times, no sprinklers, only trigger nozzle hose, can or bucket	Restricted times, no sprinklers, only trigger nozzle hose, can or bucket
Vehicles	Wash on lawn once a week, only trigger nozzle hose, can or bucket	Wash on lawn once a month, only trigger nozzle hose, can or bucket	No washing except at commercial car wash with recycled water	No washing except at commercial car wash with recycled water	Wash on lawn, only trigger nozzle hose, can or bucket
Fountains	Only if uses recirculated water, refill only with trigger nozzle hose, can or bucket	Must be switched off	Must be switched off	Must be switched off	Must be switched off
Ponds	May only be topped up with trigger nozzle hose, can or bucket	May only be topped up with trigger nozzle hose, can or bucket	May only be topped up if support fish	May only be topped up if support fish	May only be topped up if support fish

Table 5 continued

	Stage 1	Stage 2	Stage 3	Summer exemption	Spring clean
Pools	Filled: no, emptied: no, topped up: yes	Filled: no, emptied: no, topped up: yes	Must not be emptied, filled or topped up	Must not be emptied, filled or topped up	Must not be emptied, filled or topped up
Windows/ buildings	May be washed but not with a hose	No washing unless health hazard	No washing unless health hazard	No washing unless health hazard	May be washed but not with a hose
Paved areas	No washing	No washing	No washing	No washing	Washing permitted

For clarity in Fig. 1 we have coded the restriction levels according to their severity. Thus Stage 1 = Level 1, Stage 2 = Level 2, Summer Exemption = Level 2.3, Spring Exemption = Level 2.7, Stage 3 = Level 3. However in the regressions they enter as individual dummyvariables in the least restrictive form

[a] 'Restricted' times refers to 7–10 a.m. and 7–10 p.m. on alternate days according to the 'odds and evens' system

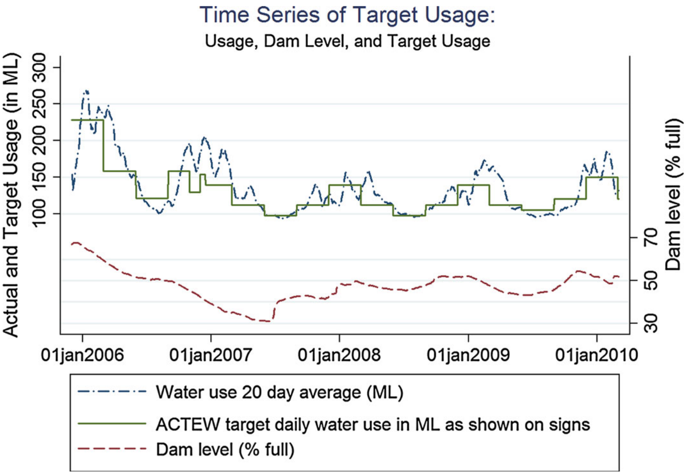

Fig. 2 Water usage, dam level and utility's consumption target. *Note* Water usage is represented as a 20-day moving average of daily consumption

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