Perceptions of water use

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In a national online survey, 1,020 participants reported their perceptions of water use for household activities. When asked for the most effective strategy they could implement to conserve water in their lives, or what other Americans could do, most participants mentioned curtailment (e.g., taking shorter showers, turning off the water while brushing teeth) rather than efficiency improvements (e.g., replacing toilets, retrofitting washers). This contrasts with expert recommendations. Additionally, some participants are more likely to list curtailment actions for themselves, but list efficiency actions for other Americans. For a sample of 17 activities, participants underestimated water use by a factor of 2 on average, with large underestimates for high water-use activities. An additional ranking task showed poor discrimination of low vs. high embodied water content in food products. High numeracy scores, older age, and male sex were associated with more accurate perceptions of water use. Overall, perception of water use is more accurate than the perception of energy consumption and savings previously reported. Well-designed efforts to improve public understanding of household water use could pay large dividends for behavioral adaptation to temporary or long-term decreases in availability of fresh water.

water conservation | decision making | judgment | anchoring

Fresh water is used increasingly beyond sustainable levels (1). Do people know how much water is used by a variety of daily activities? If people were asked to conserve water, would they know which behaviors are more effective than others? Gleick (2) estimated that 13.2 gallons of clean water are required per person per day for human needs (drinking, sanitation, hygiene, and food preparation). In 2005, the average American used about 98 gallons of water per day (3), of which ∼70% was used indoors (4). Thus, the average American uses more than seven times the water estimated by Gleick as needed. To understand how water use is distributed among daily activities in American households, Mayer et al. (5) surveyed 12 study sites during 1996 through 1998 to disaggregate residential end-use water consumption. Fig. 1 shows the average distribution for six categories. They also found that indoor water use was fairly homogenous across the 12 sites, except for the category "leaks"; whereas outdoor water use varies substantially depending on local climate (5).

Most Americans assume that water supply is both reliable and plentiful. However, research has shown that with climate change, water supply will become more variable due to salinization of ground water and increased variability in precipitation (6, 7). Some have argued that rather than focusing on increasing freshwater supply alone, we need also to reduce water demand (8). Demand-side policy responses to future freshwater variability will benefit from a deeper understanding of public perceptions of water use, which is the focus of this study.

Similar to Attari et al. (9), a study that explored public perceptions of energy use, here actual water use is compared with perceived water use for a variety of indoor and outdoor activities. Perceived energy consumption is a fairly flat function of actual consumption. Such a compression bias (9, 10) could result from participants' lack of knowledge about energy in its different manifestations. The flatness is also partly due to the judgment heuristic of anchoring and insufficient adjustment (11, 12), which arises when a person generates a numerical estimate by first adopting a salient reference as a starting point and then adjusts this estimate in the desired direction, but insufficiently. Attari et al. (9) also showed that participants overestimate energy consumption for activities that use small amounts of energy, and underestimate consumption for activities that use large amounts.

Do similar over- and underestimations exist for judgments of water use? Given the consistent tangible physical quality that exists for water but is somewhat obscure for energy as well as the familiarity of the unit of measurement, one could expect more accurate estimates for water. Additionally, Attari et al. (9) found that both numeracy and proenvironmental attitudes are associated with more accurate perceptions of energy use. Similar predictions for individual difference variables are tested here for judgments of water use.

Results

Perception of the "Most Effective Thing." The study began with two open-ended survey questions that asked participants to indicate the most effective thing they could personally do to conserve water in their lives, and to indicate the most effective thing Americans can do to conserve water in their lives. These two questions were shown in randomized order, where 515 participants completed the order self/Americans and 505 participants completed the opposite order Americans/self. Two judges identified 25 mutually exclusive categories in a set of initial 50 surveys and then independently coded the remaining surveys (Table 1). Interrater agreement was "almost perfect," $\kappa = 0.86$ (13).

Each of the 25 categories was then classified as a curtailment action (e.g., taking shorter showers) or efficiency action (e.g., switching to water-efficient fixtures). Some responses were difficult to categorize as curtailment or efficiency (e.g., checking for leaks and repairing them). Similar to the findings for energy use (9), where most participants mentioned curtailment over efficiency, here, 75.8% of participants mention curtailment actions for themselves and 67.4% for other Americans, and only 9.7% of participants mention efficiency actions for themselves and 12.5% for other Americans. By contrast, the Environmental Protection Agency (EPA) recommends that retrofitting toilets results in the

Significance

Public perceptions of water use are explored using an online survey (N = 1,020). Results show that participants underestimated water use by a factor of 2 on average, with large underestimates for high water-use activities. High numeracy scores, older age, and male sex were associated with more accurate perceptions of water use. Overall, perception of water use is more accurate than the perception of energy consumption and savings previously reported, however perceptions of both resources show significant underestimation.

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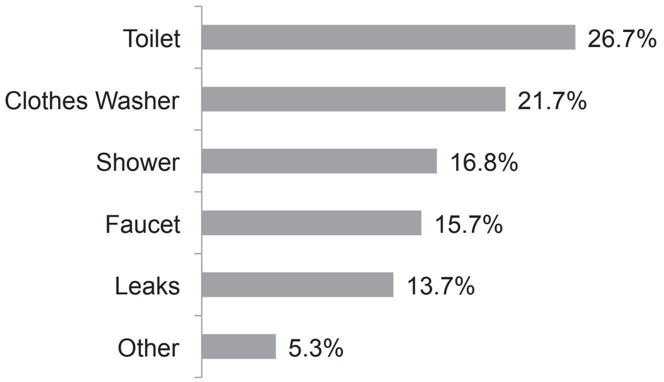

Fig. 1. Disaggregated residential indoor water use based on 12 study sites in the United States published in 1999, adapted from Mayer et al. (5).

greatest savings (71%) in indoor household water use (14), followed by retrofitting clothes washers (19%), showerheads (5%), and faucet aerators (5%). (Even though toilets use less water volumetrically than washers and showers per use, the frequency of use results in higher water use overall.) Note that a more subtle classification of the categories would be to code them as "intent-oriented" or "impact-oriented" behaviors (15). In intent-oriented behaviors, the intention to help the environment shapes the behavior without taking the actual environmental impact or effectiveness into account, such as turning off the water while brushing teeth. Alternatively, impact-oriented behaviors are focused on making a large difference, such as retrofitting toilets. The gap between intent- and impact-oriented actions may be explained by the lack of information (people do not know what is effective) or the lack of motivation (people are not motivated to act out effective behaviors). However, further research is needed to clearly classify the elicited behaviors in this manner.

Table 1 shows a major shift between endorsing fewer/shorter showers for oneself vs. endorsing watering the lawn less for others. Even though both these activities are classified as curtailment (restrictions on consumption), the shift could indicate that participants know that watering the lawn less is an effective action.

Fig. 2 shows the relative joint percentage distribution of responses for self and for other Americans using three categories: curtailment, efficiency, and other. Fig. 2 also displays a significant asymmetry as highlighted by the arrow, indicating that participants are more likely to recommend curtailment actions for themselves and efficiency actions for others than vice versa [$\log(7.6/4.0) = 0.64 \pm 0.26$, $P \approx 0.001$]. One reason for this asymmetry may be the upfront capital costs involved with efficiency actions (i.e., "I cannot afford the retrofits, but perhaps others can"). Further investigation to tease out why this asymmetry exists will be needed to more fully understand the self/other bias.

To explore order effects, Fig. 2 can be divided into two 3×3 tables (self/American vs. American/self), with the three categories (see Fig. S1 in *SI Text*). Note that the two tables are fairly similar and the hypothesis of identical joint distributions cannot quite be rejected: $\chi^2 = 13.63$ (likelihood-ratio test, 8 df). Given the absence of appreciable order effects, the data from the two orders of presentation are combined here and later.

Perceptions of Water Use. Before conducting the current study, a survey designed to elicit preferred units of measuring water quantity was conducted. Specifically, participants from a university community were asked the following question:

> Water quantity can be measured in several possible units: milliliters, customary (US) ounces, cups, quarts, liters, gallons, cubic feet, cubic meters, tons, etc. When thinking about water use, what units of measurement are you most comfortable with?

Of the 225 participants who completed this open-ended question, 73.3% stated gallons, 16.9% stated liters, 5.8% stated

Table 1. Categorized responses to the two open-ended questions about the single most effective thing participants could do to conserve water in their lives, and the single most effective thing Americans could do to conserve water in their lives

Activity	Curtailment (C) or efficiency (E)	Self, %	Americans, %
Shorter or fewer showers	C	42.6	28.0
Turn off water while doing other activities (not including brushing teeth)	C	9.9	10.0
Turn off water while brushing teeth	C	6.9	6.7
Conserve water or use water efficiently	—	4.5	6.6
Do less laundry or full loads of laundry	C	4.3	2.2
Pay more attention to water use	—	4.2	6.4
Water lawn less	C	4.1	12.5
Reduce dishwasher use or hand wash dishes	C	3.6	1.0
Other reason (mentioned once)	—	3.2	3.6
Harvest water by using rain barrels	E	2.4	1.6
Check for leaks and repair them	—	2.1	2.9
Bathe less and shower instead	E	1.8	1.5
Switch to water-efficient fixtures/technologies	E	1.7	2.4
Water-efficient toilet	E	1.5	2.4
Flush less	C	1.2	1.4
Turn off shower while shampooing and soaping	C	1.0	1.3
Switch to low-flow showerheads	E	0.9	1.1
Eat less meat	C	0.8	1.0
Switch to low-flow faucets	E	0.7	1.1
Don't drink bottled water	C	0.6	1.9
Recycle	—	0.5	0.7
Wash car less	C	0.5	1.2
Get rid of lawns or switch to water-efficient plants	E	0.5	2.2
Switch to water-efficient clothes washing machines	E	0.4	0.4
Buy fewer products	C	0.3	0.4

		Americans		
		Curtailment	Efficiency	Other
Self	Curtailment	57.9	7.6	10.3
	Efficiency	4.0	3.4	2.3
	Other	5.4	1.5	7.7
	Diagonal asymmetry	$\log_e(7.6/4.0) = 0.64 \pm 0.26$		

Fig. 2. Joint distributions (percentages) of endorsement categories for self and for Americans from the first two open-ended questions ($N = 1{,}020$). Test of asymmetry in response shifts from self to Americans, indicated by the arrow, is given as estimated log odds with estimated SE.

cups, 3.6% stated ounces, 0.9% stated cubic meters, and 0.4% stated quarts. Therefore, in the current study participants were asked to estimate water use in gallons, as it was shown to be the preferred metric for water use judgments in the presurvey.

In the current study, after completing the open-ended questions, each participant estimated the water use in a variety of household end uses and other activities. The correlation between each participant's perceptions of water use with the actual volume of water used (as determined by the literature and estimation provided in *SI Text*) was assessed, after transforming both distributions logarithmically. The mean correlation between log*Perception* and log*Actual* was $r = 0.83$, indicating that participants do have significant knowledge about which activities used more water than others. Note that the reported mean correlation between log*Perception* and log*Actual* values of energy was $r = 0.51$ (9), far lower than the correlation for water. (The difference in Fisher *Z*-transformed correlations for water and energy is $+0.63 \pm 0.06$.)

The relationship between participants' perceptions of water use as a function of actual water use was examined in more detail by using a multilevel regression model in Eq. **1**.

$$\log 10\,Perception_{ij} = \beta_{0j} + \beta_{1j}\log 10\,Actual_i + \beta_{2j}(\log 10\,Actual_i)^2 + r_{ij} \quad [1]$$

In this equation, *i* indicates the use or activity and *j* indicates the participant. The variation among participants was modeled by letting β_{0j} and β_{1j} vary about their average values, thereby allowing each participant to have his or her own regression equation (i.e., participant *j*'s intercept and slope differed from the average intercept and slope). In contrast, the quadratic effect was treated as fixed, so β_{2j} was the same for all participants. Note that the values of log10*Perception* and log10*Actual* were centered relative to the original mean of log10*Actual*, so that the coefficients would be more interpretable. The intercept β_{0j} indicates over- or underestimation, the slope β_{1j} indicates the general relationship between perceptions and actual values, and the coefficient for the quadratic term β_{2j} indicates the curvature in that relationship. This specification allows for a detailed assessment of the accuracy of participants' perceptions. For perfectly accurate perceptions, $y = x$, the values of $\beta_{0j} = 0$ (intercept or elevation), $\beta_{1j} = 1$ (slope), and $\beta_{2j} = 0$ (curvature).

Results for the average parameter estimates are shown in Fig. 3, along with mean perceptions for the 17 uses and activities. The average intercept, which gives the average elevation of perceptions at the mean of log10*Actual*, was significantly negative, $M(\beta_{0j}) = -0.31 \pm 0.01$. On average, participants underestimated water use by a factor of $10^{0.31} = 2.0$. Reported underestimation for energy use was a factor of $10^{0.44} = 2.8$ (9). (Note that removing both pool activities, Olympic-sized pool and outdoor pool, from the analysis yielded an average underestimation of water use of a factor of 1.6.)

The average slope, evaluated at the mean of log10*Actual*, was significantly greater than zero, $M(\beta_{1j}) = 0.70 \pm 0.007$, but significantly less than 1. This slope reflects two features of the data. First, it reflects the imperfect correlation between perceived and

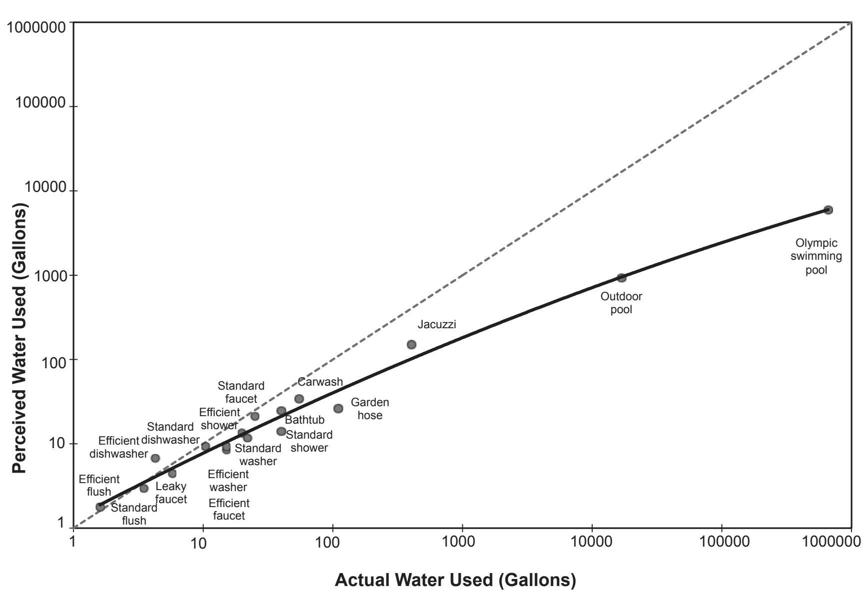

Fig. 3. Mean perceptions of water use as a function of actual water use for 17 different behaviors and activities. Error bars for 95% confidence intervals are omitted because they are typically no taller than the symbols themselves. The diagonal dashed line represents perfect accuracy.

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actual values. Second, participants' perceptions of water use were slightly less variable than actual water use: the mean SD of log10*Perception* was 1.03 and the SD for log10*Actual* was 1.35. This compression bias (10) is consistent with participants using gallons, which was found to be a natural familiar anchor from the presurvey, from which they insufficiently adjusted their estimates (12, 16).

On average, participants demonstrated sensitivity to the size of actual water-use differences, as evident by the slope, which is much closer to 1 than 0. In general, participants correctly reported that standard appliances and fixtures (faucets, flushes, showers, clothes washers, and dishwashers) consume more water than their efficient counterparts. For example, participants on average perceived that a standard clothes washer used about 14 gallons of water when they use about 34 gallons of water. Participants perceived that an efficient clothes washer used about 9 gallons of water when in fact they use about 15 gallons of water. On average, participants underestimated water use for all standard appliance and fixtures. However two water-efficient counterparts were overestimated: efficient flush (by a factor of 1.1) and efficient dishwasher (by a factor of 1.7), which lie above the diagonal line in Fig. 3.

The quadratic effect was significant, negative, and small [$M(\beta_{2j}) = -0.03 \pm 0.002$], yielding a function that starts to flatten when actual water use is high. Notably, participants underestimated activities of high water use: garden hose was underestimated by a factor of 4.2, hot tub ("Jacuzzi") by a factor of 2.7, outdoor pool by a factor of 18.1, and Olympic-sized swimming pool by a factor of 111.5, as can be seen in Fig. 3. Participants were relatively more accurate for behaviors in the middle and lower end of the range (e.g., flushes, showers, faucets, etc.). Overall, the combination of mean underestimation and a slope that is flatter for high water-use values reflect few overestimates when actual water use is low and large underestimates when actual use is high (Fig. 3).

Fig. 4 shows the comparative results for perceptions of energy use (results reported by Attari et al. in ref. 9) and perceptions of water use together. Fig. 4 clearly highlights that perceptions of water use are much more accurate than energy use. Additionally, the severe compression bias (relatively flat curve) seen in estimates for high energy-use activities is far less for high water-use activities, even though the water-use activities elicited span more orders of magnitude.

For embodied water judgments, mean ranks scarcely vary among the four different goods of sugar, rice, cheese, and coffee.

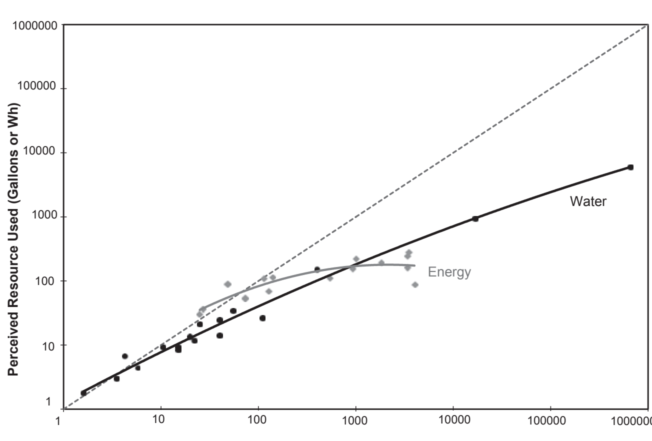

Fig. 4. Mean perceptions of water and energy used as a function of actual water and energy used shown together. Data for energy perceptions are from Attari et al. (9).

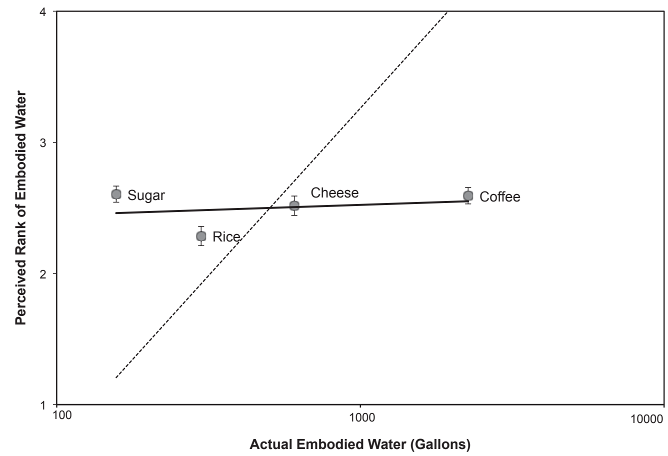

Fig. 5. Mean perceptions of embodied water as a function of actual water embodied in four different goods. Error bars indicate 95% confidence intervals for mean perceptions. Diagonal dashed line was derived by regressing the correct ranks onto actual embodied water content.

Average results for these analyses appear in Fig. 5. Embodied water was defined as analogous to water footprint (17) of a good, as

> the amount of water needed to produce a particular good. This water includes all sources (example: rainfall, surface water) and all stages of production (example: feed, irrigation).

The average slope was essentially flat [$M(\beta_{1j}) = 0.08 \pm 0.04$] and substantially less than the correct slope of 2.56 [for judged rank vs. log10(embodied water)].

Individual Differences in the Accuracy of Perceptions. To investigate individual differences in accuracy, 10 centered individual difference variables [e.g., numeracy, proenvironmental attitudes as measured by the New Ecological Paradigm (NEP) scale (18), age] were added as predictors in the multilevel regression model. The results of the extended model (using all 10 centered individual difference variables) appears in Table S1 in *SI Text*, with the results of the simple model (using only 3 centered individual difference variables) shown in Table 2. The results for water use are split over two columns to show the effects on elevation β_{0j} (main effects) and slope β_{1j} (interactions of the additional variables with log10*Actual*). Note that the extended model and the simple model are not appreciably different.

The average elevation in Fig. 3 was negative (indicating underestimation) and the average slope in Fig. 3 was less than the correct slope. As a result, positive coefficients for the individual difference variables imply more accurate perceptions of water use (less underestimation or steeper slopes) in both columns of Table 2.

The results for Fig. 3 show that the coefficient for age is positive and significant for elevation and slope, indicating that older participants had more accurate perceptions of water use. Surprisingly, age was not found to be a significant predictor for accurate perceptions of energy consumption (9). Male participants also had steeper and more accurate slopes, again a result not found for perceptions of energy consumption. Numeracy (19) is positive and significant for the slope alone, indicating that participants with a better understanding of numerical concepts had steeper and more accurate slopes, i.e., they were able to estimate the relative differences between the actions more accurately. These results are confirmed by looking at elevation effects alone with slope interactions removed from the model.

The coefficient for proenvironmental attitudes, as measured by the NEP score (19), was not significant, indicating that participants with more proenvironmental attitudes did not have

Table 2. Results of multilevel regressions for predicting individuals' perceptions of water use (± estimated SE)

Parameters	Elevation, slope, and main effects (effects on elevation)	Interactions (effects on slope)
Intercept (elevation)	−0.31 ± 0.01***	—
Within-participant (level 1) predictors		
Actual water use, log10*Actual*	0.70 ± 0.007***	—
Quadratic term, $(\log10 Actual)^2$	−0.031 ± 0.002***	—
Between-participant (level 2) predictors		
Numeracy (0–3, $\alpha = 0.42$)	0.02 ± 0.01	0.05 ± 0.007***
Male	−0.009 ± 0.02	0.04 ± 0.01**
Age, y	0.004 ± 0.001***	0.003 ± 0.0006***

Elevation and slope are reported at the relevant mean of log10*Actual*, the *x* axis variable in Fig. 3. In Fig. 3 elevation varied, and it was tested against the relevant mean of actual water use. The slope was tested against the correct slope of 1. $^{**}P < 0.01$; $^{***}P < 0.001$.

more accurate perceptions of water use. This result highlights yet another difference between water and energy perception, as participants who were more proenvironmental had more accurate perceptions of energy consumption (9) which is not the case for water use. Several variables that one might expect to be related to accuracy of water-use judgments (e.g., experience of drought, having efficient appliances in the home, education level) were not reliable predictors in these regressions.

The mean judged ranks for embodied water use scarcely vary among the four goods, as shown in Fig. 5. No combination of the 10 centered individual difference variables correlate appreciably with this slope [$r^2 = 0.017$, $F(10, 974) = 1.75$].

Discussion

When asked what is the most effective action they can take to decrease their water use, participants stated curtailment actions rather than efficiency actions, possibly because of the upfront monetary costs involved with efficiency actions. Results also show a significant asymmetry indicating that some participants are more likely to recommend curtailment actions for themselves and efficiency actions for others than vice versa.

As shown in Fig. 1, toilets use the most volume of water indoors and their suggested retrofits is the top recommendation made by the EPA (14). However, "buying water-efficient appliances and fixtures" along with "water-efficient toilet" and "flushing less" are among the least-mentioned actions as shown in Table 1. One reason why participants did not mention toilets or flushes may be due to ignoring the frequent but short duration daily exposures related to these behaviors in contrast to single but longer daily exposure related to showers, which topped the list.

Participants in this study did have some knowledge about water used by a variety of activities, as illustrated by the slope of the curve in Figs. 3 and 4, which is somewhat close to the diagonal line. The observed correlation between judged and actual water use is positive and large. However, as water use increases, participants tend to compress the actions together, underestimating the relative differences between different actions that use a lot of water. Older participants were more accurate, indicating that the experience that comes along with age may be leading to more accurate perceptions of water use. Being male and numerate also led to more accurate perceptions. Although proenvironmental attitudes were shown to be important predictors of accuracy for energy consumption (9), they do not seem to be as important for accurate judgments of water use.

Another challenge highlighted by this study is that participants systematically underestimate the water used by standard appliances and fixtures, however they tend to overestimate some efficient appliances (efficient dishwashers and flushes) while underestimating others. Given standard appliances and fixtures are always underestimated, the relative savings of switching to their water-efficient counterparts may go unrealized.

In general, participants were unable to correctly rank order the four goods based on their embodied water content. Although this may not be too surprising, these results show that there is much work to be done to educate people on how much water goes into growing the different foods that we consume daily (17, 20). Note that anchoring effects play no role in Fig. 5, because a referent was not provided in the ranking task.

In contrast to perceptions of energy consumption (9) which were not very encouraging, participants here had more accurate perceptions of water use and tended to underestimate water use less compared with results from the energy study (Fig. 4). One reason why perceptions of water use are more accurate may be due to the consistent physical characteristics of water as opposed to energy, which is transformed based on the end-use activity (e.g., heating, cooling, lighting, motion). Another reason for greater accuracy for water use is that most Americans make decisions about gallons of liquid nearly every day (e.g., buying gasoline or milk), therefore the unit of measurement may be much more familiar for water use than for energy use. Even though perceptions of water use are more accurate, there is still significant underestimation over the range of activities explored in this study. One reason for this underestimation is due to anchoring and insufficient adjustment (12). However, using gallons as a unit of measure may be a natural anchor that Americans use to think about water volumes in the United States. Of course using larger units of measure would lead to overestimation (21, 22), but based on the presurvey results, gallons was used as a unit of measure in the survey as it may be the preferred natural unit for these judgments. Thus, the observed underestimation should generalize beyond this survey.

This study, like that of Attari et al. (9), has many limitations. Monetary incentives were not offered for accuracy and an Internet sample was used, which was not completely representative of the US population. The actual water-use data have limitations due to availability of data, as they come from a variety of sources and snapshots in time, which is a documented problem in this field (23). It is important to note that the data in Fig. 1 is about 14 y old, even though it is the best available data and is currently being used by the EPA (4). It may be the case that with new regulations and technology, the distribution of water use in the home (as shown in Fig. 1) has shifted over time.

Price signals related to residential water use were a factor omitted from the study that could serve as an important predictor for accuracy. However, pay structures for residential water use vary widely in the United States (e.g., uniform cost per month independent of consumption, uniform rates, progressive or increasing block rates, and regressive or decreasing block rates) (24, 25). Gaudin (25) found that in a sample of 383 water utilities in the United States, only 17% of the utilities indicated marginal prices next to units of water consumed on the bill, whereas 78% gave no price information other than the total amount of money due. Thus, in many cases, people may not have access to the necessary monetary information on their water bill to make informed decisions about water conservation (25).

In conclusion, this study aims to advance our understanding of residential water use by testing ideas developed around energy to a very different vital resource. The results provide comparative insights into our basic understanding of the psychology of consumption, and also initiate a needed bridge between the energy and water literature. Given the results of this study, as with energy consumption, well-designed efforts to correct misperceptions are needed. Further research that investigates the relationship of these judgments to actual behaviors would also help the field understand how important judgments of resource use really are, or whether they can be side-stepped to facilitate long-lasting conserving behaviors.

Methods

Participants. Between April 21 and 25, 2013, 1,064 participants were recruited via Amazon's Mturk panel (www.mturk.com), of which 1,020 participants completed the full survey. On completion, participants received US $3 in their Amazon account. The survey was restricted to participants located in the United States. Based on 1,020 participants who completed the survey, the median age was 30 y, compared with 37.2 y in the United States (26), and 51.6% of participants were male (49.2% in the United States). The median family income was US$50,000–$80,000 (US$50,054 in the United States in 2011) and the median level of education was having a college degree (35.4% have an associate's degree or more in the United States) (27). Fifty-four percent self-identified as liberals (score = 1–3), 21% as moderates (score = 4), and 25% as conservatives (score = 5–7). These figures may indicate some selection bias.

Survey Materials. The complete survey and tables of actual water values are presented in Dataset S1 and *SI Text*, respectively.

At the beginning of the survey, participants answered two open-ended questions about the single most effective thing they could personally do to conserve water in their lives and the most effective thing that Americans could do to conserve water in their lives. The order of these two questions was randomized. Next, participants estimated the number of gallons of water used by 17 different activities (e.g., flushing a standard-flow toilet one time, filling one typical bathtub, washing one load of dishes with a standard home dishwasher, washing one load of dishes with a high-efficiency home dishwasher, etc.). Note that one task involved estimating the volume of water in an Olympic-sized swimming pool, which has a specified size and was used because it roughly represents the volume of water that could be stored in some water towers (which vary greatly in size and provide potable water for excess demand and for emergencies). The participants were asked to make these estimates in gallons (note that gallon was chosen after a presurvey suggested that this was the most preferred unit of measurement for water use).

Next, participants rank-ordered four goods (1 pound of rice, 1 pound of coffee, 1 pound of sugar, and 1 pound of cheese) in terms of most-embodied water to least-embodied water for production. Embodied water was defined as the amount of water needed to produce a particular good. Participants were then asked about how many gallons of water their household uses in a typical day and how many gallons of water they thought the average American household used in a typical day.

To make sure participants were paying attention to the survey, a test question was included at this point of the survey. Participants then completed the revised NEP scale (18), a 15-item instrument for assessing proenvironmental attitudes. The original responses (1 = "completely disagree," 7 = "completely agree") were coded in the proenvironmental direction and then averaged to yield an overall NEP score for each participant. In addition, participants completed Schwartz et al.'s (19) numeracy assessment, which consists of three open-ended questions. For example, "In the BIG BUCKS LOTTERY, the chance of winning a $10 prize is 1%. What is your best guess about how many people would win a $10 prize if 1,000 people each buy a single ticket to BIG BUCKS?"

Next, participants were asked what they paid attention to on their water bill (checking all that apply from: cost of bill, amount of water used, tips to decrease water use, "I do not pay attention to any information," "I do not receive a water bill," or other). Participants were then asked what kinds of appliances they had in their homes with response options of standard appliance; low-flow or high-efficiency appliance; and do not own and do not know for toilet, shower, bathroom faucet, dishwasher, and clothes washing machine. Participants then answered a few questions to elicit their perceptions of drought in their area in the past year, past month, and past week. Demographic questions concluded the survey. This research was approved by Indiana University's Internal Review Board at the Office of Research Administration and informed consent was received from all participants.

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Supporting Information

Attari 10.1073/pnas.1316402111

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Data Sources and Values of Actual Water Use

The estimation process and the data sources for actual water use for the 17 activities are detailed below. The data reflect the best available information at the time of analysis.

Estimation for actual water use for all of the end-uses and activities shown in Fig. 3:

i) Flushing a low-flow toilet one time: as per the Environmental Protection Agency (EPA) (1), the current federal standard for low-flow or efficient toilets is **1.6 gallons per flush or less**, even though there are models that currently exist that both provide superior performance and use less water that are rated as WaterSense toilets that operate at 1.28 gallons per flush (1).

ii) Flushing a standard-flow toilet one time: Mayer et al. (ref. 2, p. 96) found that for the majority of the 348,345 toilet flushes recorded in their 12 sites, the range for water use fell into 3–5 gallons per flush, with **3.5 gallons per flush** dominating. Another source from the EPA confirms that pre-retrofit, the average flush volume is 3.68 gallons per flush (3, p. 37), which is an average from three study sites. The Mayer et al. (2) estimate was used as the actual value because it covered 12 study sites.

iii) Washing one load of dishes with a high-efficiency home dishwasher: efficient dishwashers are rated at less than or equal to **4.25 gallons per load** by the Department of Energy (4).

iv) A leaking faucet (1 drip per 1 s) for 1 d (24 h): this was calculated and verified; 1 drip per s produces 60 drips per min. Multiplied by 1,440 min/d gives 86,400 drips total. One gallon has 15,140 drips as per the US Geological Survey (5), giving **5.7 gallons per d.**

v) Washing one load of dishes with a standard home dishwasher: in their water trivia facts, the EPA estimates that the average dishwasher uses between 9 and 12 gallons of water per load. The arithmetic average of **10.5 gallons per load** was used as the actual number.

vi) Running a high-efficiency bathroom faucet for 10 min at its maximum flow rate: The EPA WaterSense specification for low-flow/high-efficiency faucets is set at a maximum of 1.5 gallons per min (6). Therefore, 10 min at the maximum flow rate is **15 gallons** of water.

vii) Using a high-efficiency, front-loading home washer for one load of laundry: as per the Energy Star Department of Energy rating, "a full-sized Energy Star certified clothes washer uses **15 gallons of water per load**" (7).

viii) Taking a low-flow shower for 10 min at its maximum flow rate: EPA WaterSense standards for low-flow showerheads must use no more than 2 gallons per min (8), giving **20 gallons of water** for a 10-min shower.

ix) Running a standard bathroom faucet for 10 min at its maximum flow rate: the EPA specification for standard faucets is 2.2 gallons per min (6), giving **22 gallons of water** for 10 min.

x) Taking a standard-flow shower for 10 min at its maximum flow rate: EPA-regulated standard showerheads use 2.5 gallons per min (8), giving **25 gallons of water** for a 10-min shower.

xi) Filling one typical bathtub: as per the California Energy Commission, an average bath requires 30–50 gallons of water (9). An arithmetic mean on the range gives about **40 gallons of water.**

xii) Using a standard, top-loading home washer for one load of laundry: as per the California Energy Commission, older top-loading machines use about 40 gallons of water to wash a full load of clothes although newer standard models use about 27 gallons of water (10). An arithmetic mean on the range gives about **34 gallons of water per load.**

xiii) Washing a car at a drive-in, conveyor automatic car wash: a report prepared for the water utilities in El Paso, TX stated that in-bay automatic carwashes use about 50–60 gallons per vehicle (11). The arithmetic average of **55 gallons per vehicle** was used.

xiv) Watering a lawn with a garden hose at its maximum flow rate for 10 min: the volume of water used from a garden hose was determined based on hose size (5/8 inch), hose supply pressure (40 psi), and hose length (100 feet) will have a flow rate of 11 gallons per min, leading to **110 gallons of water** for 10 min (12).

xv) Filling one hot tub ("Jacuzzi") (six-person capacity): there is no standard hot tub dimension that fits six people. To estimate this activity's water use, many sources were found online via retail stores selling the product and water-use specifications were averaged providing an estimate of **405 gallons of water**. These estimates were from 260 gallons (13) to about 550 gallons (14).

xvi) Filling one typical backyard in-ground pool (5 × 15 × 30 feet): these dimensions give a volume of 2250 cubic feet or **16,831 gallons of water.**

xvii) Filling one Olympic-sized competition swimming pool: the dimensions of an Olympic-sized pool are 50 × 25 × 2 m (15), giving 2,500 m^3 or about **660,000 gallons of water.**

Data Sources and Values of Embodied Water Use

The data sources for embodied water content (alternatively "water footprint") were used from the Waterfootprint.org website. They state that the "Water Footprint of a product is the volume of freshwater appropriated to produce the product, taking into account the volumes of water consumed and polluted in the different steps of the supply chain."

i) One pound of sugar: it takes about 1,782 L of water to produce 1 kg of sugar from sugar cane and about 920 L of water to produce 1 kg of sugar from sugar beets (16). In the United States, which is the world's largest sugar producer, sugarcane accounts for about 45% of the total sugar produced domestically, and sugar beets for about 55% of production (17). Thus, the weighted average is (0.45 × 1782) + (0.55 × 920) = 1,308 L of water to produce 1 kg of sugar or about **157 gallons of water per pound of sugar.**

ii) One pound of rice: it takes about 2,497 L of water to produce 1 kg of rice (16, 18) or about **299 gallons of water per pound of rice.**

iii) One pound of cheese: it takes about 5,060 L of water to produce 1 kg of cheese (16, 19) or about **606 gallons of water per pound of cheese.**

iv) One pound of coffee: it takes about 18,900 L of water to produce 1 kg of roasted coffee (16) or about **2,264 gallons of water per pound of coffee.**

Order Effects of First Two Open-Ended Questions

To explore order effects, Fig. 2 can be divided into two 3 × 3 tables (self/American vs. American/self), with the following categories: curtailment, efficiency, and other. Fig. S1 shows the relative joint percentage distribution of responses for self and for Americans using these three categories. Fig. S1 also displays a marginally significant asymmetry as highlighted by the arrows, indicating that participants are somewhat more likely to recommend curtailment actions for themselves and efficiency actions for others than vice versa. Note that the two tables are fairly similar and the hypothesis of identical joint distributions cannot quite be rejected: $\chi^2 = 13.63$ (likelihood-ratio test, 8 df).

Multilevel Regression Results

To investigate individual differences in accuracy, 10 centered individual difference variables [e.g., numeracy, proenvironmental attitudes as measured by the New Ecological Paradigm (NEP) scale, age] were added as predictors in the multilevel regression model. The result of the extended model (using all 10 centered individual difference variables) appears in the Table S1, and is not appreciably different from the simple model presented in the current paper.

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		Americans					
		Order: Self/Americans (*N = 515*)			Order: Americans/Self (*N = 505*)		
		Curtailment	*Efficiency*	*Other*	*Curtailment*	*Efficiency*	*Other*
Self	*Curtailment*	55.2	8.4	11.5	60.8	6.7	9.1
	Efficiency	4.9	2.7	2.7	3.2	4.2	1.8
	Other	4.3	1.4	9.1	6.5	1.6	6.1
	Diagonal asymmetry	$\log_e(8.4/4.9) = 0.54 \pm 0.37$			$\log_e(6.7/3.2) = 0.74 \pm 0.38$		

Fig. S1. Joint distributions (percentages) of endorsement categories for self and for Americans from the first two open-ended questions by order. Tests of the asymmetry in response shifts from self to Americans, indicated by the arrows, are given as estimated log odds with estimated SEs.

Table S1. Results of multilevel regressions for predicting individuals' perceptions of water use including all 10 centered individual difference variables

Parameters	Elevation, slope, and main effects (effects on elevation)	Interactions (effects on slope)
Intercept (elevation)	−0.31***	—
Within-participant (level 1) predictors		
Actual water use, log10*Actual*	0.70***	—
Quadratic term, (log10*Actual*)^2	−0.031***	—
Between-participant (level 2) predictors		
Numeracy (0–3, $\alpha = 0.42$)	0.019	0.050***
NEP (0–6, $\alpha = 0.89$)	0.034	−0.0047
Drought past year (1–6)	−0.013	0.0048
Pay attention to cost	0.043	0.0075
Efficient appliances at home[a]	0.0077	0.011
Political views (1–7)	0.012	0.0036
Male	−0.0088	0.035**
Age, y	0.0042***	0.0028***
Income (1–8)	−0.0077	0.0024
Education (1–6)	0.0032	−0.0031

Elevation and slope are reported at the relevant mean of log10*Actual*, the *x* axis variable in Fig. 3. In Fig. 3 elevation varied, and it was tested against the relevant mean of actual water use. The slope was tested against the correct slope of 1. $*P < 0.05$; $**P < 0.01$; $***P < 0.001$.

[a]The components of "Efficient appliances at home" were the sum of having any of the following low-flow or high-efficiency appliances: toilet, shower, bathroom faucet, dishwasher, and clothes washing machine.

Other Supporting Information Files

Dataset S1 (PDF)

Dear Participant,

Please complete this online survey on water consumption. The survey is anonymous, and no one will know what answers you give. This brief survey should take no more than 15 minutes to complete.

Thank you for your time and help with this effort.

If you have any questions, please do not hesitate to send me an email at: survey.iub@gmail.com .

Sincerely,

Dr. Shahzeen Attari

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Water Survey

[Note: The following two questions are randomized]

What is the single most effective thing that you can personally do to conserve water in your life?
[open ended]

[Error message: "Sorry, you cannot continue until you correct the following: Your response must be at least 5 characters."]

<page break>

What is the single most effective thing that Americans can do to conserve water in their lives?
[open ended]

[Error message: "Sorry, you cannot continue until you correct the following: Your response must be at least 5 characters."]

<page break>

Think about typical circumstances of each water use behavior listed below.

How many ***gallons*** of water do you think each of the following behaviors require?
Your best estimates are fine. Please enter whole numbers with no other text (not decimals or ranges).

[Error message: "Please enter whole numbers with no other text (not decimals or ranges)." Note: Numeric validation. Randomize order of behaviors.]

	Gallons
Running a standard bathroom faucet for 10 minutes at its maximum flow rate	
Running a high-efficiency bathroom faucet for 10 minutes at its maximum flow rate	
Flushing a standard-flow toilet one time	

Flushing a low-flow toilet one time	
Taking a standard-flow shower for 10 minutes at its maximum flow rate	
Taking a low-flow shower for 10 minutes at its maximum flow rate	
Filling one typical bathtub	
Using a high-efficiency, front-loading home washer for one load of laundry	
Using a standard, top-loading home washer for one load of laundry	
Washing one load of dishes with a standard home dishwasher	
Washing one load of dishes with a high-efficiency home dishwasher	
Washing a car at a drive-in, conveyor automatic car wash	
Filling one jacuzzi (6 person capacity)	
Filling one Olympic sized competition swimming pool	
Filling one typical backyard in-ground pool (5'x15'x30')	
A leaking faucet (1 drip per 1 second) for one day (24 hours)	
Watering a lawn with a garden hose at its maximum flow rate for 10 minutes	

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Embodied water is the amount of water needed to produce a particular good. This water includes all sources (example: rainfall, surface water) and all stages of production (example: feed, irrigation).

In your opinion, which of the following activities embodies the most amount of water over the course of production? *Rank these products* in order from 1 (most embodied water) to 4 (least embodied water). Your best estimates are fine.

Recall that *1=Most embodied water and 4=Least embodied water*

	1	**2**	**3**	**4**
1 pound of rice	☐	☐	☐	☐
1 pound of coffee	☐	☐	☐	☐
1 pound of sugar	☐	☐	☐	☐
1 pound of cheese	☐	☐	☐	☐

[Error message: "*Please assign a value from 1 to 4 for each item. Values may not be repeated.*"
Note: "Must Rank all" validation. Randomize order of behaviors.]

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Think about your household.

How many gallons of water does *your household* use in a typical day?
Your best estimate is fine. Please enter whole numbers with no other text (not decimals or ranges).

[open ended; text box; numeric validation]

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Think about an average household in the United States.

How many gallons of water does *the average American household* use in a typical day?
Your best estimate is fine. Please enter whole numbers with no other text (not decimals or ranges).

[open ended; text box; numeric validation]

<page break>

This page is a test to confirm that you are reading the instructions carefully. For the question which follows this paragraph, please give the following answer: reader. Please just ignore the text of the question, and type the word reader as your answer for the item. Thank you for reading carefully.

On average, how many times a day do you think about things you need to do? Please give your best estimate:

[open ended; text box]

Attitudes

For each statement below, please indicate how strongly you agree or disagree with the statement:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
We are approaching the limit of the number of people the earth can support	☐	☐	☐	☐	☐
Humans have the right to modify the natural environment to suit their needs	☐	☐	☐	☐	☐
When humans interfere with nature, it often produces disastrous consequences	☐	☐	☐	☐	☐
Human ingenuity will ensure that we do NOT make the earth unlivable	☐	☐	☐	☐	☐
Humans are severely abusing the environment	☐	☐	☐	☐	☐
The earth has plenty of natural resources if we just learn how to develop them	☐	☐	☐	☐	☐
Plants and animals have as much right as humans to exist	☐	☐	☐	☐	☐
The balance of nature is strong enough to cope with the impacts of modern industrial nations	☐	☐	☐	☐	☐

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For each statement below, please indicate how strongly you agree or disagree with the statement:

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Despite our special abilities, humans are still subject to the laws of nature	☐	☐	☐	☐	☐
Human destruction of the natural environment has been greatly exaggerated	☐	☐	☐	☐	☐
The earth has only limited room and resources	☐	☐	☐	☐	☐
Humans were meant to rule over the rest of nature	☐	☐	☐	☐	☐
The balance of nature is very delicate and easily upset	☐	☐	☐	☐	☐
Humans will eventually learn enough about how nature works to be able to control it	☐	☐	☐	☐	☐
If things continue on their present course, we will soon experience a major ecological disaster	☐	☐	☐	☐	☐

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Math Questions

To answer the following questions, please enter whole numbers or decimals with no other text (not ranges or percent signs).

Imagine that we flip a fair coin 1,000 times. What is your best guess about how many times the coin would come up heads in 1,000 flips?

______

In the BIG BUCKS LOTTERY, the chance of winning a $10 prize is 1%. What is your best guess about how many people would win a $10 prize if 1000 people each buy a single ticket from BIG BUCKS?

______

In ACME PUBLISHING SWEEPSTAKES, the chance of winning a car is 1 in 1,000. What percent of tickets to ACME PUBLISHING SWEEPSTAKES win a car?

______

[open ended; text box; numeric validation]

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Which of the following items do you pay attention to on your water bill? *(please check all that apply)*

- ☐ Cost of bill
- ☐ Amount of water used
- ☐ Tips to decrease water use

☐ I do not pay attention to any information
☐ I do not receive a water bill
☐ Other______________________

[multiple answers allowed]

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Which of the following do you have in your home? Please mark all that apply.

	Standard Appliance	Low-Flow or High-Efficiency Appliance	Do not own	Do not know
Toilet	☐	☐	☐	☐
Shower	☐	☐	☐	☐
Bathroom faucet	☐	☐	☐	☐
Dishwasher	☐	☐	☐	☐
Clothes washing machine	☐	☐	☐	☐

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Drought Question

The U.S. National Drought Monitor classifies areas experiencing drought into one of five categories:

Category	Description
Abnormally Dry	• Going into drought: short-term dryness slowing planting, growth of crops or pastures. • Coming out of drought: some lingering water deficits; pastures or crops not fully recovered
Moderate Drought	• Some damage to crops, pastures • Streams, reservoirs, or wells low, some water shortages developing or imminent. • Voluntary water-use restrictions requested
Severe Drought	• Crop or pasture losses likely • Water shortages common • Water restrictions imposed
Extreme Drought	• Major crop/pasture losses • Widespread water shortages or restrictions
Exceptional Drought	• Exceptional and widespread crop/pasture losses • Shortages of water in reservoirs, streams, and wells creating water

	emergencies

Based on the information above, which of the following best describes conditions in your area in the *past 12 months*?

☐ Not Applicable: I have not lived in my area for 12 months
☐ No abnormal dryness or drought
☐ Abnormally Dry
☐ Moderate Drought
☐ Severe Drought
☐ Extreme Drought
☐ Exceptional Drought

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Extreme Drought	• Major crop/pasture losses • Widespread water shortages or restrictions
Exceptional Drought	• Exceptional and widespread crop/pasture losses • Shortages of water in reservoirs, streams, and wells creating water emergencies

Based on the information above, which of the following best describes conditions in your area in the *past month*?

☐ Not Applicable: I have not lived in my area for one month
☐ No abnormal dryness or drought
☐ Abnormally Dry
☐ Moderate Drought
☐ Severe Drought
☐ Extreme Drought
☐ Exceptional Drought

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Drought Question

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Extreme Drought	• Major crop/pasture losses • Widespread water shortages or restrictions
Exceptional Drought	• Exceptional and widespread crop/pasture losses • Shortages of water in reservoirs, streams, and wells creating water emergencies

Based on the information above, which of the following best describes conditions in your area in the *past week*?

☐ Not Applicable: I have not lived in my area for one week
☐ No abnormal dryness or drought
☐ Abnormally Dry
☐ Moderate Drought
☐ Severe Drought
☐ Extreme Drought
☐ Exceptional Drought

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Which of the following best describes future drought conditions in your area in the next year?

☐ Drought will increase
☐ Drought will stay the same
☐ Drought will decrease

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Demographics

How many people are there in your household (including yourself)?
_____

[numeric validation]

How would you describe your political beliefs?

☐ Very Liberal ☐ Liberal ☐ Slightly Liberal ☐ Moderate ☐ Slightly Conservative ☐ Conservative ☐ Very Conservative

(Answer text is horizontal on the same line)

What is your gender?
☐Male
☐ Female
☐ Other, please specify: ________

During 2012, what was your yearly household income before tax? Your best estimate is fine.

☐ Did not have an income
☐ < $20,000
☐ $20,000 - $49,999
☐ $50,000 - $79,999
☐ $80,000 - $109,999
☐ $110,000 - $139,999
☐ $140,000 - $169,999
☐ > $170,000

What is the highest level of education you have attained?

☐ Some schooling, but no diploma or degree
☐ High school diploma or GED
☐ Some college
☐ College degree
☐ Some graduate school
☐ Graduate degree

What is your age? ______

<page break>

Have you lived at your current address for one year or more?
☐Yes
☐ No

Please select the state and county in which you currently reside.
State: _______[drop down menu, including option ‘not applicable’ or ‘Not from United States’]
County: _______[drop down menu, including option ‘not applicable’ or ‘don’t know’]

What is your ZIP code?
______ [Zip code validation]

Do you have any additional thoughts about water use or water conservation, or any comments about the survey that you would like to share with us?

[open ended; not required]

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