Landscape Irrigation and Water Conservation in Urban Areas: An Analysis of Information-based Strategies

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SUMMARY. Outdoor water use, especially for lawn and landscaping irrigation, accounts for a substantial proportion of residential water use and often peaks during summer months. Understanding how to reduce outdoor water use can play a critical role in balancing the increasing demand for and subsequent protection of water resources. This study aims to find out if information-based strategies can be effective in reducing homeowners' water use as well as identifying the key determinants that can enhance water conservation campaigns. Using online survey data from 2077 randomly selected urban homeowners with home lawns in a relatively water-rich state, we found that social norm-based information is generally more effective to promote household water conservation behavior than education information. Moreover, the results showed that the households' water-saving actions, lawn watering knowledge, awareness for local water scarcity, attitudes toward water conservation, socio-demographics, and landscape characteristics all play a role in determining household water conservation intention.

Increased population and public demand for water resources has raised public concerns about water scarcity (Brookshire et al., 2004; Buurman et al., 2017; Dieter et al., 2018). In the United States, 40 states are expected to have water shortages that are not related to drought by 2024 (U.S. Government Accountability Office, 2014). In response to these concerns, a variety of water conservation initiatives have been performed in the United States, such as installing WaterSense-labeled and other water-efficient appliances and minimizing or eliminating landscape irrigation in terms of domestic water use; subsequently, residential per capita water

use has declined significantly (Brelford and Abbott, 2017; DeOreo et al., 2016; Dieter et al., 2018; U.S. Geological Survey, 2014). However, these strategies do not ensure long-term relief for water shortages; in fact, the effect on reducing the water demand has a limit, especially in urban areas where the population is rapidly growing (Finley and Basu, 2020). This is the case even in regions with abundant water supplies (Minnesota Department of Natural Resources, 2021a; Takacs, 2018). Furthermore, a recent report by Phyn (2020) found that U.S. households increased their daily water use by 21% during the COVID-19 crisis because people spent more time at home.

Because lawns and gardens provide households with outdoor spaces for sports and leisure activities (Barnes et al., 2020) and help mitigate environmental impacts of urbanization (Monteiro, 2017), Americans continue to use significant amounts of

water on their lawns and landscapes. The water use of a U.S. household is estimated to be 320 gal per day; of this amount, ~30% is for outdoor purposes and overwhelmingly dominated by watering lawns and gardens (Cole and Stewart, 2013; U.S. Environmental Protection Agency, 2013). Water use for landscape irrigation can be even higher in arid and semi-arid regions; for more water-intensive landscapes of the United States, ~40% to 75% of the total domestic water supply is used for landscape irrigation (Maupin et al., 2014). The average American household uses more water on lawns and landscapes than for showering and laundry combined (U.S. Environmental Protection Agency, 2021a). Home lawns and landscapes are often overwatered (Maupin et al., 2014; Minnesota Department of Natural Resources, 2021a), and the adoption of automatic landscape irrigation systems (sprinklers) is another reason why outdoor water consumption achieves record peaks. A household with an automatic landscape irrigation system that is not properly maintained and operated can waste up to 25,000 gal of water annually (U.S. Environmental Protection Agency, 2021b).

Water conservation can relieve water demand stress and is of particular interest because it is a low-cost option that has diverse environmental benefits compared with other supply-side water management plans (Brooks et al., 2006; Inman and Jeffrey, 2006). Outdoor water use is a major source of peak demand, especially during hot, dry weather; therefore, it is often a target for water conservation campaigns (Renwick and Green, 2000). In practice, outdoor water use is generally the first to be reduced during droughts or other shortages because it is easier to adjust than indoor water use (U.S. Environmental Protection Agency, 2016). There is an opportunity to save an even greater volume of water by reducing water used on Americans' home lawns and landscapes. Confronted with excessive irrigation

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Units			
To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
3.7854	gal	L	0.2642

demands, what conservation strategies can draw households' attention to the pressing need of further outdoor water use reductions?

Education campaigns that engage the public on water conservation concerns are one of the most extensively used policy instruments and have a long history of promoting water conservation by alerting residents about water shortages and providing detailed water-saving suggestions (Lant, 1993; Russell and Fielding, 2010; Schultz, 2002). This approach suggests that people who engage in fewer water-saving practices are often unaware of water scarcity problems. Additionally, individuals' water-saving behaviors are constrained by a lack of knowledge about what types of adaptations can be made and how, thus eliciting a knowledge deficit (Schultz, 2002). Therefore, by filling this knowledge gap through education campaigns, individuals can be led to conserve water, and the key factor for those education campaigns to succeed is to learn necessary knowledge for carrying out water-saving behaviors as well as why water conservation is important (Corral-Verdugo et al., 2002). However, the effectiveness of using education tools to change water use behaviors is mixed (Landon et al., 2016). Some researchers have found water-saving signage at the point of purchase can impact consumers' landscape plant purchasing decisions (Knuth et al., 2020). Some argue that education campaigns are likely necessary but not sufficient to promote behavior changes on their own (Beattie, 2010; Dolnicar and Hurlimann, 2010). A study of an education campaign through media broadcasts has shown there is no significant lagged effect, suggesting that the influence of education efforts lasts only as long as publicity continues (Billings and Day, 1989; Fielding et al., 2013); therefore, the education campaign requires a long-term goal of creating and maintaining lasting behavior change.

Another body of literature in the residential water conservation field has examined the effects of feedback information, which is known to address the information deficit, on future behavior changes (Schultz et al., 2016). Providing feedback information refers to informing households about their water usage with the intention of influencing subsequent water use (Abrahamse

et al., 2005). Some studies have shown that providing household consumption information can have an immediate impact on water use, and households that received water use data significantly reduced their water consumption (Boyle et al., 2013; Nguyen et al., 2018; Seyranian et al., 2015; Tom et al., 2011). However, the results are mixed, with some studies concluding that descriptive information does not necessarily influence consumers' decisions and that the effects could be relatively ephemeral (Fielding et al., 2013; Schultz et al., 2007).

To enhance the effect of feedback information on behavior changes, strategies that deliver water consumption information in the context of norms of behaviorally relevant groups are often adopted. Leveraging social norms to encourage behavioral changing in real-world contexts has a long tradition of addressing environmental and social sustainability issues (Schultz et al., 2016), such as the focus theory of normative conduct (Cialdini et al., 1990) and community-based social marketing (McKenzie-Mohr, 2000). Based on the social comparison theory of Festinger (1954), individuals tend to behave in a way that is consistent with that of their peers. Studies have consistently shown that providing information to individuals that describes their behaviors in relation to that of their peers will cause individuals to alter their behavior to be more closely aligned with that of their peer group (Cialdini et al., 2006; Fielding et al., 2013; Schultz et al., 2007, 2016). Specifically, water conservation research has suggested social comparison information was effective in significantly reducing water consumption (Beal et al., 2013). Studies of applying social comparisons further indicated that information alone is not sufficient to influence behavior changes; instead, the information must be presented in a way that activates specific motivational processes (Schultz et al., 2007, 2016). Moreover, such strategies can be combined with other financial tools to create a cascade of improvements. Strategies supplemented with rebates have been used often; for example, daily water use feedback information combined with a rebate has reduced households' water usage by 30% (Clark and Finley, 2008; Geller et al., 1982; Iglesias and Blanco, 2008).

Additionally, because promoting water-saving behavior is a complex task, it is necessary for policymakers to understand what factors shape household water conservation behavior. In general, research studies of the determinants of water conservation behavior fall into two broad categories: 1) studies focusing on knowledge, attitudes, and beliefs and 2) studies focusing on economic and socio-demographic factors. Although positive attitudes toward water conservation and water-saving appliances are linked to households' water-saving behavior, households' socio-demographic backgrounds have a varied impact on water conservation. Because the amount of water used outdoors is also dictated by lot size and the vegetative makeup of the landscape (Syme et al., 2004), it is also necessary to consider households' landscape characteristics.

Urban water conservation is an important issue even in water-rich regions; however, little evidence exists to validate the effectiveness of policy measures to conserve water in cities located outside of traditionally water-scarce regions. Historically, Minnesota has been recognized as a water-rich state with substantial groundwater and surface water supplies and adequate precipitation. However, the growing population of Minnesota consumes water faster than some aquifers can replenish, and some areas are beginning to feel water demand stress from water quality and/or quantity issues, such as the fast-growing urban centers in the Twin Cities Metropolitan area (Minnesota Department of Natural Resources, 2021a). Groundwater usage in Minnesota has increased by 35% since the 1990s, and it continues to increase (Minnesota Environmental Quality Board, 2015). In 2021, Minnesota issued drought warnings in mid-July, and many cities imposed watering restrictions (odd/even day restrictions or restricted hours) on residential landscapes as drought conditions continued (Minnesota Department of Natural Resources, 2021b). Water scarcity is a serious issue for arid regions where unsustainable water consumption is a real challenge; however, regions with abundant water also have concerns about their current and future water use (Takacs, 2018).

This study builds on previous studies and aimed to find strategies

that would be best for promoting water-saving behavior among U.S. urban residents and identified the key determinants for successful water conservation campaigns. This includes households' watering-saving actions, lawn-watering knowledge, awareness of local water scarcity, attitudes toward water conservation, socio-demographics, and landscape characteristics. Specifically, there were three hypotheses that we tested: 1) both education information and social norm-based information have effects on promoting water-saving intentions; 2) adding financial incentives such as rebates to social norm-based information can achieve greater effectiveness when promoting water conservation; and 3) water-saving intentions are influenced by past water-saving actions, lawn-watering knowledge, awareness of local water scarcity, attitudes toward water conservation, socio-demographics, and landscape characteristics.

Methods

DATA COLLECTION. To identify feasible and effective ways to improve residents' water conservation efforts in the Minneapolis-Saint Paul metropolitan area, especially their lawn-watering practices, we conducted an online survey targeting homeowners with home lawns in the seven-county metropolitan area in Minnesota during 2020–21. There were three screening questions for individuals willing to participate in the survey. Participants must be at least 18 years old, they should have a home lawn, and they should be responsible for maintaining their home lawns instead of hiring others to perform the maintenance. In addition to these screening questions, we also included attention check questions and implemented a survey duration check. Regarding the attention check question, participants were asked to select a specific response from the available options; those who failed this check were excluded from the final sample. Those participants who completed the survey within less than one-third the average time were excluded from the final sample.

Based on official statistics, Minneapolis–Saint Paul–Bloomington, Minnesota–Wisconsin metropolitan area (MN–WI metro area) comprised 86% of the population within its seven counties in 2019 (U.S. Census Bureau, 2020). The sample of 2077 participants

was provided by Qualtrics (Seattle, WA), a professional survey company; this sample was selected randomly from Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington counties. The proportion of the sample from each county was aligned with the population proportion of the MN–WI metro area. Our study passed the human subject review (Institutional Review Board approval number: STUDY00010003).

We included three water conservation messages aiming to influence the intentions to reduce water use (Supplemental Material 1). To address the knowledge deficit, message A was a “use water wisely” message that included a piece of general information about why one should use water wisely and several tips for conserving water. Tips included items such as washing a car using a bucket instead of a hose, storing runoff in rain barrels and using it to water gardens, as well as how much water could be saved in each scenario. To deal with the information deficit, we adopted the social norm comparison approach and further combined it with a rebate. Message B, which comprised a home water use comparison, provided information regarding a household's water consumption and how it compares to that of the neighbors. Message C, which comprised a home water use comparison and rebate, offered an additional rebate incentive for reducing water use. The more they save water during the current measurement period compared with the last measurement period, the higher the rebate values they would receive. These messages were adapted from previous literatures. Specifically, message A was from a study of household water conservation conducted in Singapore (Goette et al., 2019). Messages B and C were adapted from research of how households respond to information and monetary incentives involving electricity consumption in India (Sudarshan, 2017).

To determine the effectiveness of the three water conservation messages, each participant was randomly assigned to receive one of the three messages during the survey distribution. We further tested and found there were no significant differences in socio-demographics and landscape characteristics across three groups. After reading the

water conservation messages, each participant was asked to choose the degree of intention to reduce water use based on a 7-point Likert-type scale ranging from “very unlikely” to “very likely.” According to the theory of planned behavior, intentions, which reflect a motivation or plan to engage in an action, are the most immediate predictors of behavior (Ajzen, 1991).

Additionally, we gathered information about the participants' water-saving practices, lawn knowledge, and awareness of local water scarcity using yes/no questions. We also gathered information about their attitudes toward water conservation and water-efficient technology using a 7-point Likert-type scale ranging from “strongly disagree” to “strongly agree.” The socio-demographic characteristics of participants as well as their home landscape characteristics were also collected during the survey.

EMPIRICAL ESTIMATION STRATEGY.

Because the dependent variable of interest is a discrete and ordinal variable that was measured using a 7-point Likert-type scale, we used ordered probit models to explore the effectiveness of each message and how participants' intentions to reduce water use were affected by their water-saving actions, lawn-watering knowledge, awareness of local water scarcity, attitudes toward water conservation, socio-demographics, and landscape characteristics.

Ordered probit models are a widely used approach to estimate models with an ordinal dependent variable that is not continuous (Greene and Hensher, 2010). Examples include rating systems (poor, fair, good, excellent), opinion scales ranging from strongly disagree to strongly agree, ranking, grades, bound ratings, and others. The ordered probit model originated from biostatistics but was later brought into the social sciences (Aitchison and Silvey, 1957; McKelvey and Zavoina, 1975).

The central idea of an ordered probit model is that there is a latent variable underlying the ordinal observed outcome. The latent variable can be expressed by a linear combination of some predictors and an error term that has a standard normal distribution. Ordered probit models allow us to interpret the effects of predictors on the latent

variable. Therefore, we estimated the following model:

$$Y_i^* = \beta_1 K_i + \beta_2 A_i + \beta_3 X_i + \beta_4 L_i + \varepsilon_i$$

$$\varepsilon_i \sim \text{Normal}(0, 1)$$

where Y_i^* is the unobserved latent variable representing the true level of intention to reduce water use for participant i ; K_i represents the variables for participants' water-saving practices, lawn-watering knowledge, and awareness of local water scarcity; A_i is a vector of variables representing participants' attitudes toward water conservation and water-efficient technology; X_i is a vector of participants' socio-demographic variables, including expected years living at the current residence, age, sex, education, marital status, income, and household size; L_i represents a set of landscape characteristics, such as lawn size, frequency of lawn watering, type of grass and type of soil at the home lawn, and others; and ε_i is an error term assumed to follow a standard normal distribution. We calculated heteroskedasticity-robust SES for all regressions to improve efficiency.

The link between the latent variable and the observed dependent variable is:

$$Y_i = j \text{ if } \mu_{j-1} < Y_i^* < \mu_j$$

$$j = 1, 2, 3, 4, 5, 6, 7$$

$$\mu_0 = 0, \mu_7 = \infty$$

where Y_i^* is participant i 's response to the Likert-type scale survey question, which is the observed dependent variable; j is the 7-point rating; and μ_j is the cut-point or threshold parameter. Thresholds divide the real line into a series of intervals corresponding to various ordered categories and are estimated to match the probabilities associated with each ordered category. The probability that observation i will choose the degree j is:

$$\begin{aligned} \Pr(Y_i = j) &= \Pr(\mu_{j-1} < Y_i^* < \mu_j) \\ &= \Pr(\mu_{j-1} < \beta_1 K_i + \beta_2 A_i + \beta_3 X_i + \beta_4 L_i + \varepsilon_i < \mu_j) \\ &= \Pr(\mu_{j-1} - \beta_1 K_i - \beta_2 A_i - \beta_3 X_i - \beta_4 L_i < \varepsilon_i < \mu_j - \beta_1 K_i - \beta_2 A_i - \beta_3 X_i - \beta_4 L_i) \\ &= F(\mu_j - \beta_1 K_i - \beta_2 A_i - \beta_3 X_i - \beta_4 L_i) \\ &\quad - F(\mu_{j-1} - \beta_1 K_i - \beta_2 A_i - \beta_3 X_i - \beta_4 L_i) \end{aligned}$$

where F is the standard normal cumulative distribution function.

Results

SUMMARY STATISTICS OF SURVEY PARTICIPANTS. Table 1 presents the summary statistics of participants' socio-demographic information. A total of 2077 participants completed the survey. In our sample, nearly half of participants expected to stay at their current residence for at least the next 10 years. The median age range of our participants was 46 to 55 years, and slightly more than 60% of participants had college diplomas. Approximately 65% of participants were female and 59% were married. The median income range was \$65,001 to \$80,000, and the average household size was 2.75 people. Although our sample had more participants who were older, married, and had college diplomas than the population in the MN-WI Metro Area (U.S. Census Bureau, 2020), we were confident that that sample was generally representative of homeowners who have home lawns.

PARTICIPANTS' LANDSCAPE CHARACTERISTICS AND LAWN-WATERING PRACTICES. Detailed information about participants' home lawn characteristics and watering practices were collected (Table 2). The majority of participants had a yard of at least 0.25 acres, and $\approx 35\%$ used an underground/installed automatic irrigation system (sprinkler system). More than half of participants watered their lawn for at least 20 min in each irrigation zone, and the frequency of lawn watering varied from less than twice per month to more than 13 times per month; fewer than 10% of participants did not know the answers to these two questions. Approximately 31% of participants reported that they generally continue to water their lawns until fall. A moderate percentage of participants were unsure about the type of grass (34%) and the type of soil (38%) of their home lawn. Among those who were aware, most participants reported they had a mixture of grasses and clay soil comprising their home lawn.

Moreover, when comparing the frequency and duration of watering home lawns of participants who had an automatic irrigation system and those who did not, we found that participants who had an automatic irrigation system watered their lawns more frequently and for a shorter period of time. Those who did not have an automatic irrigation system watered their lawns less frequently and for a

longer period of time. Furthermore, the percentage of participants who did not know the duration of lawn watering was significantly higher than that of those who did not have an autonomous irrigation system (Fig. 1). We have conducted t-tests of these comparisons, and all the differences were significant.

PARTICIPANTS' WATER CONSERVATION PRACTICES AND ATTITUDES. The results of participants' water-saving practices and attitudes toward water conservation are presented in Table 3. In general, most participants refrained from watering lawns during and after rain events, and they were aware of the risks of overwatering lawns. Nonetheless, less than 20% believed Minnesota has water scarcity issues (Table 3, panel A). Statistics suggested that participants were concerned about water scarcity issue, and that they had a positive view of technologies that can help save water (Table 3, panel B). We conducted t-tests and found that participants who received the three messages were not significantly different in terms of their demographics and water conservation practices and attitudes.

PARTICIPANTS' RESPONSES TO DIFFERENT WATER CONSERVATION INFORMATION. Table 4 compares the average level of intention to reduce water use for the three groups of participants after they read the corresponding message. Overall, participants' intentions to reduce water use would be favorably affected by all three messages, with message C receiving the highest rating. Specifically, message A (use water wisely), which provided detailed instructions about how to use water wisely, had the least impact on motivating participants to reduce water use. Compared with the results of message A, t-test results showed that message B (water use comparison) and message C (water use comparison and rebate) had significantly higher impacts on increasing participants' intentions to conserve water. When the additional rebate incentive was added to the comparison information (message C), t-test results showed that it did not significantly increase the impact compared with message B, which informed participants of their water usage in comparison with that of their neighbors.

Table 1. Summary of demographic characteristics of participants in the landscape water use survey in the Minnesota seven-county metropolitan area (N = 2077). The mean and SD of each variable are reported, as are the frequency and percent for each value.

Demographic characteristic	Survey participants		
	Mean (SD)	No.	%
Expected years living in current home	2.66 (1.46)		
1 = <5 years		612	29.47
2 = 5–9 years		478	23.01
3 = 10–14 years		367	17.67
4 = 15–20 years		241	11.6
5 = >20 years		379	18.25
Age	3.82 (1.70)		
1 = 18–25 years		216	10.4
2 = 26–35 years		358	17.24
3 = 36–45 years		324	15.6
4 = 46–55 years		323	15.55
5 = 56–65 years		464	22.34
6 = 66–75 years		328	15.79
7 = 76 years and older		64	3.08
Sex	0.65 (0.49)		
1 = Female		1,360	65.48
0 = Male		717	34.52
Education	0.60 (0.49)		
1 = College diploma and higher		1,253	60.33
0 = Other		824	39.67
Marital status	0.58 (0.49)		
1 = Married		1,215	58.5
0 = Other		862	41.5
Income	5.85 (2.03)		
1 = ≤\$15,000		78	3.76
2 = \$15,001–\$25,000		81	3.9
3 = \$25,001–\$35,000		141	6.79
4 = \$35,001–\$50,000		243	11.7
5 = \$50,001–\$65,000		270	13
6 = \$65,001–\$80,000		297	14.3
7 = \$80,001–\$100,000		345	16.61
8 = >\$100,000		622	29.95
Household size	2.75 (1.44)		
1 person		307	14.78
2 people		850	40.92
3 people		375	18.05
4 people		313	15.07
5 people		142	6.84
6 people		56	2.7
>7 people		34	1.64

FACTORS INFLUENCING PARTICIPANTS' INTENTIONS TO REDUCE WATER USE. Table 5 shows the results of the order probit regressions that examined the effectiveness of each message to improve resident water conservation intentions and how their intentions to conserve water differed based on their water conservation practices, attitudes toward water conservation, socio-demographics, and landscape characteristics. Model 1 shows the main results of the message effectiveness and the factors

influencing participants' water-saving intentions. Model 2 additionally introduced interaction terms to the influential factors. Model 3 compares the differences in the effectiveness between the education information and social norm-based information by comparing participants who received message A to those who received messages B or C. In this comparison, messages B and C were used as the base. We further compared the effectiveness difference between messages B and C by using

message B as the base for the subsample of these two groups (model 4).

Overall, the message effectiveness and the relationships between water conservation intentions and influential factors were consistent across the four specifications. Our main results presented in model 1 show that the effectiveness of message B was significantly higher than that of message A, whereas message C showed no significant improvement in the effectiveness compared with message B. Regarding participants' demographic characteristics, participants who expected to stay at their current residence for a longer period of time, those who were older, those with a higher income, and larger households were less likely to reduce water use. Conversely, female participants and those with college degrees were more likely to save water. We found no significant influence of marital status on water conservation intentions. Regarding landscape characteristics and lawn-watering practices, we found that participants with larger lawns, those who often had a longer watering duration and watered more frequently, and those who continued to water their lawns in the fall had significantly fewer intentions to reduce water use; however, there were no significant differences in water-saving intentions, whether the lawn had an irrigation system, or the reported grass or soil type for their lawns. Finally, the results revealed that participants who saved water during storms, those who knew the risk of overwatering lawns, those who were aware of the water scarcity issues in the state, those who considered water conservation as more important, and those who had a positive view of water-efficient technology were more likely to reduce water use. Moreover, the interaction terms in model 2 suggested that participants who favored water-efficient technologies were more inclined to conserve water if they often had a longer watering duration compared with those with a shorter watering duration; however, no analogous result was observed in terms of the watering frequency.

The comparison of the effectiveness of the three messages also showed interesting results. Results of model 3 showed that compared with messages B and C, message A was not as effective for reducing water use. However, message A was more

Table 2. Descriptive statistics of home lawn-watering practices of participants in the landscape water use survey in the Minnesota seven-county metropolitan area (N = 2077). The frequency and percent for each value are reported.

Watering practices	Survey participants	
	No.	%
Lawn size		
Less than 1/8 acre ²	559	26.91
1/8 acre	358	17.24
1/4 acre	487	23.45
1/2 acre	269	12.95
1 acre	103	4.96
>1 acre	116	5.58
I do not know	185	8.91
Have an automatic irrigation system		
1 = Yes	719	34.62
0 = No	1,358	65.38
Duration of lawn watering		
<5 min/zone	205	9.87
5–10 min/zone	357	17.19
11–20 min/zone	499	24.03
21–30 min/zone	435	20.94
31–40 min/zone	159	7.66
41–50 min/zone	69	3.32
51–60 min/zone	106	5.1
>60 min/zone	89	4.29
I do not know	158	7.61
Frequency of lawn watering		
<2 times/month	474	22.82
2–4 times/month	576	27.73
5–7 times/month	319	15.36
8–10 times/month	253	12.18
11–13 times/month	147	7.08
>13 times/month	204	9.82
I do not know	104	5.01
Irrigate home lawn in fall		
1 = Yes	651	31.34
0 = No	1,426	68.66
Type of grass of the home lawn		
Kentucky bluegrass (<i>Poa pratensis</i>)	227	10.93
Tall fescue (<i>Festuca arundinacea</i>)	27	1.3
Perennial ryegrass (<i>Lolium perenne</i>)	30	1.44
Fine fescue (<i>Festuca ovina</i>)	36	1.73
A mixture of grasses	1,046	50.36
I do not know	711	34.23
Type of soil of the home lawn		
Sand	427	20.56
Loam	365	17.57
Clay	490	23.59
I do not know	795	38.28

²1 acre = 0.4047 ha.

effective for male participants, participants who did not know their lawn size, those who often had a longer watering duration and watered more frequently, those who preferred water-efficient technology, those who had not taken water-saving actions, and those who were not aware of water scarcity problems. Other characteristics, such as lawn-watering

knowledge and water-saving importance, were found to have no significant impact. Estimates of model 4 suggested that compared with message B, message C was not more effective in general, but it became more effective for participants who knew their grass type, those who watered longer, and those who did not know their normal watering duration.

Discussion and conclusions

Increased population, increased irrigation demands, and the growth of industries that require greater water inputs have started to strain global water resources (Brookshire et al., 2004; Dieter et al., 2018). Climate changes and droughts that have occurred in recent years further pose a serious challenge to sustainable development (Cayan et al., 2010; University of Nebraska-Lincoln, 2021). Apart from traditionally water-scarce regions, there is an increasing interest in water conservation campaigns, even in historically water-rich regions. Outdoor water usage is sensitive to climate variations (Mayer et al., 1999) and is closely linked to behavioral factors and cultural expectations of yards (Fielding et al., 2012; Polsky et al., 2014), thus making it an attractive target for water conservation programs. Using data of 2077 randomly selected homeowners from the Twin Cities metropolitan area, where the fast-growing population has started to challenge the city water supply system, we provided evidence of the effectiveness of different information-based strategies for reducing urban residents' water use intentions and identified the key determinants that could be targeted by water conservation campaigns.

We found that the education and social norm-based messages generated different levels of water conservation intentions. Specifically, regarding the education message (message A: use water wisely), which addressed the knowledge deficit, participants were only slightly likely to lower their water consumption after reading it. This was expected because past research indicated that the efficacy of education campaigns often varies by areas, and that those programs that urge people to conserve water lead to significant water demand reduction only in the western United States, where water shortages are more prevalent (Nieswiadomy, 1992; Renwick and Green, 2000). Nonetheless, this positive intention to conserve water supports the idea that water-saving behaviors usually happen when the nature of water shortages and water-saving options are understood, and the idea that household members believe they can implement at least some of the available water-saving options.

Fig. 1. Comparing lawn-watering practices of participants with and without automatic irrigation systems. The duration of lawn watering has the following values: 1 = <5 min/zone; 2 = 5–10 min/zone; 3 = 11–20 min/zone; and 4 = 21–30 min/zone. The frequency of lawn-watering has the following values: 1 = <2 times/month; 2 = 2–4 times/month; 3 = 5–7 times/month; and 4 = 8–10 times/month.

The social norm-based messages that addressed the information deficit in the context of social comparison (message B regarding water use comparison and message C regarding water use comparison and rebate) practically yielded higher intentions to reduce water use compared with message A. Participants were somewhat likely to

reduce water consumption after reading message B, and they were slightly more likely to reduce water use after reading message C. This reveals that the normative description feedback information with social comparison and a combination of the feedback information and a rebate will be likely to reduce household water use.

However, the cost-benefit analysis of rebate programs should be considered because message C showed no significant improvement in water use reductions compared with message B.

The effectiveness of the interventions we found were consistent with those of other studies of social psychology and behavioral economics that

Table 3. Water conservation practices and attitudes toward home lawns of participants in the landscape water use survey in the Minnesota seven-county metropolitan area. Variables in panel A have a value of 1 if the response of the participants is “yes” and a value of 0 if their response is anything other than “yes.” Variables in panel B have values based on a 7-point Likert-type scale, with 1 = “strongly disagree” and 7 = “strongly agree.”

		Survey participants	
Watering practices and attitudes	Description	Mean	SD
Panel A: Water conservation practices			
Water-saving action (1 = yes)	I change how I water my lawn based on the weather forecast	0.80	0.40
Lawn-watering knowledge (1 = yes)	I agree that overwatering can damage grass	0.79	0.41
Water scarcity awareness (1 = yes)	I believe my state has water scarcity issues	0.19	0.39
Panel B: Water conservation attitudes			
Water-saving importance	Conserving water is important to me	5.41	1.49
Water-efficient technology preference	I am interested in technology that can help me optimize the amount of water	5.00	1.66

Table 4. Responses to different water conservation information of participants in the landscape water use survey in the Minnesota seven-county metropolitan area. The observations of each group of participants are reported. Means and SD are based on a 7-point Likert-type scale, with 1 = “very unlikely” and 7 = “very likely.”

After reading this message, how likely are you to attempt to reduce water use?	Survey participants		
	No.	Mean	SD
Panel A: Education information			
Message A: Use water wisely message	699	5.19	1.48
Panel B: Social norm-based information			
Message B: Home water-use comparison	686	5.38	1.66
Message C: Home water-use comparison and rebate	692	5.51	1.54

used information-based approaches to achieve behavior changes regarding residential water conservation (Bernedo et al., 2014; Ferraro et al., 2011). Such information-based strategies are also widely used to promote energy conservation. For example, Allcott (2011) identified a substantial and cost-effective intervention to reduce energy consumption: residential utility customers received home energy report letters comparing their electricity use to that of their neighbors. Additionally, Dolan and Metcalfe (2015) found large financial rewards work well for reducing energy consumption. Because of the relatively small rebate reward (\$5 for every 5% reduction) offered during our study, it was reasonable that the addition of that rebate was not quite effective. Although providing information about best practices to reduce lawn water use can have some effect, efforts should focus on approaches that directly create incentives for reduced lawn water use, such as how water use compares to that of the neighbors. However, how much the intentions to reduce water use can be translated into real water-saving behaviors remains unknown.

We concluded that the effectiveness of the strategies would vary depending on household water-saving practices, knowledge, awareness of local water scarcity, and water-saving attitudes. The results are consistent with findings in the literature showing people’s past experiences with and awareness of drought, and that their involvement with water conservation efforts and their interactions with plants impact how they value the water needs of plants (Behe et al., 2018; Knuth et al., 2018a, 2018b, 2019). Past water-saving practices and lawn-watering knowledge of the households had different influences on the results. Because the education message encourages households to save water and provides water-saving

suggestions that can be performed easily, regardless of their knowledge of watering lawns, it is more effective for those who are not aware of water storage issues and have not performed water-saving actions before; however, the success of the social norm-based strategies relied on residents’ knowledge of water conservation. Nonetheless, residents’ water-saving attitudes and understanding of local water scarcity issues have impacts on water-saving intentions, which could be an important target of water-saving interventions. Research has consistently shown that positive attitudes toward water conservation and water-saving appliances are linked to households’ water-saving behaviors (Dolnicar and Hurlimann, 2010; Syme et al., 2004; Willis et al., 2011). These findings highlight the value of policies that promote long-term education programs that shift how people think about and use water.

Additionally, we found homeowners’ sociodemographic, attitudes, and past knowledge and the characteristics of the landscape are highly relevant to understanding outdoor water conservation intentions. First, it has been observed that households’ water saving-intentions are influenced by their income. Past literatures have summarized that household income often has diverging effects on water conservation decisions: whereas more affluent households can afford to invest in water-saving technologies, a diminishing marginal utility of income indicates that wealthy households are less motivated to conserve water and face a higher opportunity cost because of the time needed to install water-saving equipment or engage in time-consuming water conservation activities (Millock and Nauges, 2010). Our results indicate that high-income households would find it more costly to adopt conservation behaviors that involve greater time investments in water-using

activities. Second, age has been found to influence participants’ water-saving intentions. The effects of age on water conservation correspond to aspects of the household life cycle; for example, elderly households may use less water for recreation purposes (Fielding et al., 2012). This was also observed by our data; we found that older participants had a shorter water duration and watered less frequently (on average) than younger participants (not reported). Third, although both the education message and social norm-based messages are more effective for females in general, the education message was more effective for males, who have often have more hands-on experience. Fourth, better-educated households are expected to be more likely to conserve water because saving water requires understanding watering requirements for different landscapes as well as water-saving options (De Oliver, 1999; Lam, 2006). For other socio-demographic variables, we found a negative effect of large households and no significant effect of marital status, which was different from the results of Millock and Nauges (2010) and Sauri (2013), who found a positive relationship between household size and the adoption of water-saving technologies, and the results of Aprile and Fiorillo (2017), who found that married couples were less inclined to adapt their water conservation habits.

Reported landscape characteristics were also shown to be important to water conservation practices. First, larger lawns generally require more inputs than smaller ones; therefore, it would be more expensive to adopt water-saving practices and equipment for those with larger lawns. Similarly, a higher frequency of lawn watering reflects a higher water requirement that may become habitual; however, households with a longer watering duration would choose to conserve

Table 5. Factors influencing participants' responses to different water conservation information during the landscape water use survey in the Minnesota seven-county metropolitan area. Statistics show coefficients and robust SE (in parentheses) from ordered probit regression models. The dependent variable is the participants' self-reported likelihood of reducing water use.

Variable	Model 1 ^z	Model 2	Model 3	Model 4
Message A (dummy)	−0.21*** (0.06)	−0.20*** (0.06)	−0.47** (0.20)	
Message C (dummy)	0.08 (0.06)	0.08 (0.06)		0.08 (0.08)
Expected years living in current home	−0.04** (0.02)	−0.04** (0.02)	−0.05*** (0.02)	−0.05** (0.02)
Age	−0.09*** (0.02)	−0.10*** (0.02)	−0.10*** (0.02)	−0.09*** (0.02)
Sex (1 = female)	0.20*** (0.05)	0.20*** (0.05)	0.26*** (0.07)	0.23*** (0.06)
Education (1 = college diploma and higher)	0.59** (0.07)	0.58** (0.07)	0.67** (0.07)	0.56** (0.09)
Marital status (1 = married)	0.03 (0.06)	0.02 (0.06)	0.03 (0.06)	0.00 (0.07)
Income	−0.04*** (0.01)	−0.04*** (0.01)	−0.04*** (0.01)	−0.03 (0.02)
Household size	−0.04** (0.02)	−0.04** (0.02)	−0.04** (0.02)	−0.06** (0.02)
Lawn size (1 = more than 1/2 acre) ^y	−0.15** (0.08)	−0.15** (0.08)	−0.15* (0.08)	−0.12 (0.10)
Lawn size (1 = unknown)	−0.14 (0.09)	−0.14* (0.09)	−0.26** (0.11)	−0.27** (0.10)
Have an automatic irrigation system (1 = yes)	−0.02 (0.06)	−0.02 (0.06)	−0.00 (0.06)	0.03 (0.07)
Duration of lawn watering (1 = more than 30 min/zone)	−0.16*** (0.06)	−0.50** (0.21)	−0.24*** (0.07)	−0.36*** (0.10)
Duration of lawn watering (1 = unknown)	−0.08 (0.11)	−0.08 (0.11)	−0.10 (0.11)	−0.47*** (0.18)
Frequency of lawn watering (1 = more than 7 times/mo.)	−0.12* (0.06)	−0.42** (0.19)	−0.20*** (0.07)	−0.21*** (0.08)
Frequency of lawn watering (1 = unknown)	−0.08 (0.14)	−0.08 (0.14)	−0.05 (0.14)	0.03 (0.18)
Type of grass of home lawn (1 = unknown)	0.08 (0.05)	0.09 (0.05)	0.09* (0.05)	0.26*** (0.09)
Type of soil of home lawn (1 = unknown)	−0.08 (0.05)	−0.08 (0.05)	−0.09* (0.05)	−0.07 (0.06)
Irrigate home lawn during the fall (1 = yes)	−0.14** (0.05)	−0.14** (0.05)	−0.13** (0.05)	−0.16** (0.07)
Water-saving action (1 = yes)	0.14** (0.05)	0.15** (0.05)	0.20** (0.07)	0.18** (0.07)
Lawn-watering knowledge (1 = yes)	0.12** (0.06)	0.13** (0.06)	0.12* (0.06)	0.13 (0.07)
Water scarcity awareness (1 = yes)	0.13* (0.06)	0.13* (0.06)	0.22*** (0.08)	0.21** (0.08)
Water-saving importance	0.22*** (0.02)	0.22*** (0.02)	0.22*** (0.02)	0.24*** (0.03)
Water-efficient technology preference	0.08*** (0.02)	0.05** (0.02)	0.05** (0.02)	0.03 (0.02)
Duration of lawn watering (1 = more than 30 min/zone) × water-efficient technology preference		0.07* (0.04)		
Sex (1 = female) × message A (dummy)			−0.18* (0.10)	
Lawn size (1 = unknown) × message A (dummy)			0.37* (0.17)	

(Continued on next page)

Table 5. (Continued)

Variable	Model 1 ^z	Model 2	Model 3	Model 4
Duration of lawn watering (1 = more than 30 min/zone) × message A (dummy)			0.23* (0.12)	
Frequency of lawn watering (1 = more than 7 times/ month) × message A (dummy)			0.23** (0.10)	
Water-saving action (1 = yes) × message A (dummy)			−0.25*** (0.13)	
Water scarcity awareness (1 = yes) × message A (dummy)			−0.25** (0.13)	
Water-efficient technology preference × message A (dummy)			0.07** (0.03)	
Type of grass of home lawn (1 = unknown) × message C (dummy)				−0.28** (0.13)
Duration of lawn watering (1 = more than 30 min/zone) × message C (dummy)				0.27** (0.14)
Duration of lawn watering (1 = unknown) × message C (dummy)				0.49** (0.24)
Observations	2077	2077	2077	1378

^zModel 1 shows the main results of the message effectiveness and the factors influencing the participants' water-saving intentions. Model 2 additionally introduced interaction terms of the influential factors. Model 3 compares the differences in the effectiveness between the education information and social norm-based information by comparing participants who received message A to those who received message B or message C. In this comparison, message B and message C were used as the base. We further compared the effectiveness difference between message B and message C by using message B as the base for the subsample of these two groups (model 4).

^y1 acre = 0.4047 ha.

*, **, ***Significance at 10%, 5%, or 1%, respectively.

water if they favor water-efficient technologies (Beal et al., 2013; Fan et al., 2017; Gilg and Barr, 2006). Additionally, the type of turfgrass present in a lawn determines the water needed for optimal growth, and the soil's ability to retain water is strongly related to its type (i.e., the particle size). Recent literature has shown the utility of turfgrass species as a water-use reduction strategy. For example, kentucky bluegrass (*Poa pratensis*) and perennial ryegrass (*Lolium perenne*) are popular cool-season turfgrasses that require more water (Fu et al., 2004; Su et al., 2008), whereas low-input turfgrasses such as hard fescue (*Festuca brevipila*) and colonial bentgrass (*Agrostis capillaris*) can perform well with less water (Braun et al., 2020; Hugie and Watkins, 2016; Watkins et al., 2011).

These findings highlight the importance of information-based behavioral intervention policies that can be used to reduce the use of natural resources, further the understanding of the role of these social, psychological, and sociodemographic factors in

influencing outdoor water use, and contribute to a body of knowledge that informs the development of effective water conservation policies. To address increasing water demands, it is important to encourage water conservation by asking people to be wise about watering practices for home lawns and to maintain a sustainable and eco-friendly landscape.

Our results have important implications for municipalities and utility companies when designing demand-side water conservation programs. In water-rich urban areas, social norm-based interventions are generally more effective for promoting water-saving intentions than educational interventions. Adding rebates of moderate value to social norm-based interventions does not effectively achieve significantly greater conservation intentions in such areas. Program designers should focus on using social norm interventions to encourage conservation behaviors. However, when considering a water conservation program, policy designers should consider the factors that have roles in

determining households' water-saving intentions. Water conservation programs can be more effective if they can also increase households' lawn-watering knowledge, raise their awareness of the local water scarcity issue, develop households' positive attitudes toward water conservation, and can involve customized interventions based on households' socio-demographics and landscape characteristics.

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Supplemental Material 1

Water conservation messages in the landscape water use survey in the seven-county metropolitan area in Minnesota. In the survey, each participant was randomly assigned to one of three messages that encourage water conservation. The content of messages is as follows:

Message A: Use water wisely message

Suppose you receive a use water wisely message and a piece of general information why one should use water wisely as follows:

Every society shares the responsibility to promote the sustainable use of water. There are many ways to save water:

- Washing a car using a bucket instead of hosing would save 8 gal per 5 min.^z
- Storing runoff in rain barrels and using to water gardens between rain

storms would save 50 gal per rain barrel.

- Replacing old dishwasher with WaterSense approved dishwasher would save up to 16 gal per load.
- Washing only full loads of clothing would save up to 20 gal per load if the washing machine is WaterSense approved.
- Sweeping sidewalks instead of hosing would save 2 gal per minute.

Message B: Home water-use comparison

Suppose you receive a feedback message as follows:

The average water consumption of your neighborhood is 3750 gal per person per month, whereas your water use in the last measurement period is 4500 gal per person per month, which is 20% higher

than the average water use of your neighborhood.

Message C: Home water use comparison and rebate

Suppose you receive a feedback message as follows:

The average water consumption of your neighborhood is 3750 gal per person per month, whereas your water use for the last measurement period is 4500 gal per person per month, which is 20% higher than the statewide average water use.

You will receive a rebate of \$5 for every 5% water reduction in the current measurement period compared to last measurement period. For example, if you save 10% water use in this measurement period compared to the last measurement period, you could receive a rebate of \$10. The rebate can be used to pay for your future water bill.

^z1 gal = 3.7854 L.