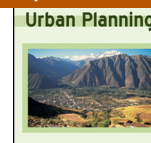




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Research Paper

Tools for evaluating and monitoring effectiveness of urban landscape water conservation interventions and programs

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H I G H L I G H T S

- Intervention research was connected to delivery of landscape water checks.
- We distinguished change due to water checks from other factors affecting water use.
- We developed several landscape water conservation assessment and monitoring tools.
- These tools can direct and tailor conservation programs for greater effectiveness.
- Results have implications for water conservation program design and delivery.

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A B S T R A C T

Our research objective was to investigate ways to evaluate landscape water use to help cities more effectively direct water conservation programs to locations with capacity to conserve. Research was conducted in connection with a landscape irrigation evaluation delivered through a city-sponsored Water Check Program. Research efforts led to development of several assessment and monitoring tools including: Landscape Irrigation Ratio (LIR), Participant Outcome Evaluation Tool, and Program Evaluation Tool. We utilized these tools to identify locations with capacity to conserve water applied to landscapes, compare water use before and after the water check, and evaluate Water Check Program effectiveness. We found the LIR approach successfully distinguished residential locations efficiently or acceptably using water applied to landscapes from ones with use considered inefficient or excessive. In analyzing change in participants' water use and eliminating explanations other than the water check, we found factors influencing landscape water use tend to be highly contextualized and the intervention itself needed to be analyzed. The majority of participants who adopted the water check recommendations successfully reduced their landscape water use, but results indicate water check programs can be designed for greater effectiveness by accommodating participants' differing knowledge and skill levels. We argue that the tools we developed provide the water conservation field with a needed set of common assessment methods. We conclude that landscape water checks have the potential to provide people with the information and problem-solving skills necessary to maintain residential landscapes using appropriate amounts of water if they are well designed, delivered, and monitored.

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1. Introduction

One of the greatest challenges in conducting behavioral change research related to water conservation is determining how to assess effectiveness of programs at the household level. The water conservation field does not have common assessment tools, making it difficult to compare program results among cities worldwide and over time (e.g., Inman & Jeffrey, 2006; Jorgensen, Graymore, & O'Toole, 2009; Rockaway, Coomes, Joshua, & Barry, 2011; Syme, Nancarrow, & Seligman, 2000). Historically, conservation has been

assessed by tracking changes in gallons per capita per day (gpcd), which does not fully capture geographic differences in contextual variability and conservation challenges unique to indoor water use as well as outdoor urban landscape irrigation. City-wide water conservation efforts through replacing aging infrastructure and improving water delivery system efficiency are distinct from behavioral change in consumer water use patterns. Yet, both forms of water saving actions are reflected in measures like gpcd and influence geographic and temporal comparisons (Bellamy, Walker, McDonald, & Syme, 2001; Friedman, Heaney, & Morales, 2014; Jorgensen, Martin, Pearce, & Willis, 2013; Larson, Wiek, & Withycombe, 2013; Saurí, 2013).

Contextual variability is especially problematic for assessing and comparing water use and conservation effectiveness across urban locations in various parts of the world. Variations in size and arrangement of urban lots, landscape plant material, and climate greatly influence geographic and temporal variability in residential water use (Cook, Hall, & Larson, 2012; Endter-Wada, Kurtzman, Keenan, Kjelgren, & Neale, 2008; Gregory & Di Leo, 2003; Kilgren, Endter-Wada, Kjelgren, & Johnson, 2010; Runfola et al., 2013; Saurí, 2013; St. Hilaire et al., 2008). While indoor water use is primarily a function of occupant number and water appliance/fixture efficiency (Friedman et al., 2014; Mayer et al., 1999), residential outdoor water need and use is a function of more complex bio-physical and technical factors: plant species selection, weather-based demand (evapotranspiration), soil-based water supply, and irrigation system design, maintenance, and operation. This complexity challenges researchers and water providers to develop methods for evaluating landscape water use and supporting people's ability to understand and integrate contextual variability in their landscape management decisions.

Urban residents face various challenges in attempting to water residential landscapes, internationally referred to as 'domestic gardens,' efficiently. These challenges include: careful maintenance and operation of static sprinkler systems in biologically dynamic residential landscapes (Bremer, Keeley, Jager, Fry, & Lavis, 2012; Cook et al., 2012); problem solving skills that enable them to assess, identify, and fix water problems (Corral-Verdugo, 2002; Gifford, 2014; Kaiser & Fuhrer, 2003; Kurz, Donaghue, & Walker, 2005); and assessing their conservation performance (Fazey et al., 2007; Grantham et al., 2010; Lehman & Geller, 2004). Specific and timely feedback to end users is crucial to equip them in setting goals, making decisions, and planning for conservation success (Doron, Teh, Haklay, & Bell, 2011; McCalley, 2006). For instance, infrequent and limited billing information impedes feedback effectiveness regarding water use, while time and financial constraints can limit the best intentions (Abrahamse, Steg, Vlek, & Rothengatter, 2007; Diekmann & Preisendörfer, 2003; Kenney, Goemans, Klein, Lowrey, & Reidy, 2008).

Landscape irrigation evaluations or "water checks" (sometimes called "water audits") are widely used in the United States as a water demand management tool intended to promote efficient water use on existing landscapes while maintaining aesthetic standards. Water checks can potentially save water, but research is scarce that evaluates information effectiveness or monitors water savings (Baum, Dukes, & Miller, 2005; Mecham, 2004; Nelson, 1992; Olmsted & Dukes, 2011; Thomas, Harrison, Dukes, Seymour, & Reed, 2009).

The conservation field recognizes the need for monitoring programs that assess goal attainment and promote better program evaluation (Knight, Cowling, & Campbell, 2006; Pullin & Stewart, 2006; Stem, Margolous, Salafsky, & Brown, 2005). Evaluating conservation in landscape irrigation is further challenged by changes in water use arising from the complex interplay of how users interpret ecological cues, understand climatic variability, and utilize irrigation technology to irrigate appropriately. Complex factors

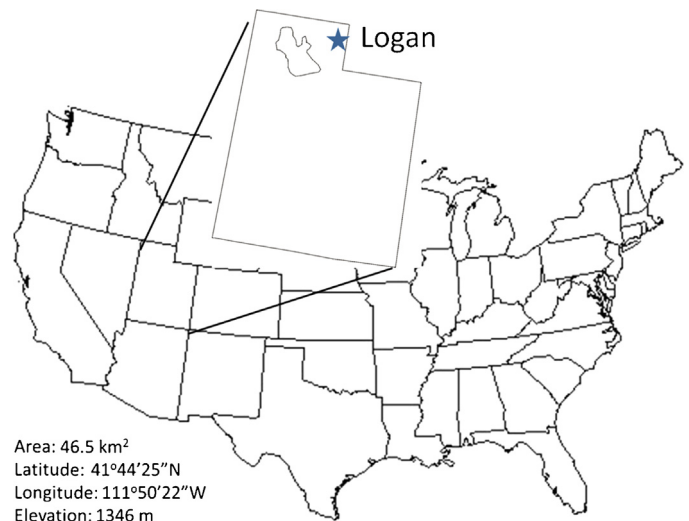


Fig. 1. Study site is located in Logan City, Cache Valley, Utah, the United States on the Great Basin's northernmost boundary in the Bear River Watershed.

influencing landscape water use are highly contextualized (Endter-Wada et al., 2008; Kilgren et al., 2010). Larson, Cook, Strawhacker, and Hall (2011) concluded future research was needed to better understand the context of urban water management decisions and practices. Critical questions need to be answered in designing landscape irrigation conservation assessment and monitoring programs. What constitutes appropriate landscape water use? What constitutes water conservation success? How do we describe and measure these two phenomena?

We report on research conducted in connection with administration of a city-sponsored but university-delivered landscape water check program. Our research design tested both the effectiveness of landscape water checks as a conservation tool and different approaches for encouraging conservation program participation (volunteers or recruits). We developed assessment and monitoring tools to analyze results. We take an in-depth look at water check programs and lessons learned that are broadly applicable to development of water check/audit programs in any locale. The topic will be of particular interest to water researchers and managers in water-scarce regions experiencing growth of low-density urban developments, increasing prevalence of domestic gardens, and recurrent drought.

Our research objective was to evaluate and monitor urban landscape water use. With cities' limited conservation program budgets, it is important to understand when, where and how to focus conservation efforts to increase overall efficiency and yield water savings (Kilgren et al., 2010; Lehman & Geller, 2004). Cities need to plan for future municipal water demand in socially equitable ways that fairly assess water use. They also need effective management tools to help them identify inefficient water use and deliver programs to people with different user profiles.

2. Methods

2.1. Water conservation interventions

2.1.1. Participant recruitment for landscape water checks

In 2004, Utah's sixth year of cyclic drought, we offered free landscape water checks to all single-family residential households that relied on city-provided potable water in Logan, Utah, the United States (Fig. 1; study site described in paragraph A1 of Appendix A). The free service was widely publicized. Water checks included a detailed evaluation of households' sprinkler system and landscape,

provision of site-specific seasonally-adjusted irrigation schedules, and conservation recommendations. Water checks and interviews were completed for 148 self-selected volunteers (hereafter referred to as “2004 volunteers”). Generally, volunteers are people most interested in an issue who may already exhibit certain levels of knowledge and skill, so this recruitment method contained an inherent self-selection bias (Brady & Collier, 2004; Hartman, 1988).

During the summer of 2005, we identified 420 single-family residential locations with above-average water use based on a preliminary analysis of city water billing records, prior to construction of detailed analytic rankings and comparisons. From this population, we recruited 105 water check participants through letters and phone calls (hereafter referred to as “2005 recruits”). Above-average water users were identified by normalizing water usage in depth units so that all lots could be compared. In Utah, landscape irrigation is precluded by freezing temperatures and plant dormancy December through February. Landscape water use was estimated by assuming winter water use represented indoor use and subtracting proportionate amounts from total summer water use. Households were characterized as above-average water users if they met both of the following thresholds for average irrigation season water use in 2004 and in one or both of the two previous years (2002 and/or 2003): (1) 4.35 or more kiloliters (1150 gal) of water per day (absolute volume); and, (2) 4.57 mm (0.18 in.) or more per day (normalized depth units).

2.1.2. *Delivery of landscape water checks*

Landscape water checks were delivered to participants at residential locations and services offered in 2004 and 2005 were identical. Water checks first assessed technical aspects of water conservation: how effectively the irrigation system delivered water to turf zones, flaws in system design, and maintenance that reduced operational efficiency. Second, water checks evaluated ecological components affecting water use and conservation: soil type, plant material, and lot characteristics (e.g., sun exposure and aspect). These data were combined with local evapotranspiration rates to provide site-specific irrigation schedules and conservation recommendations to participants on how landscape water use efficiency could be improved through irrigation system operation and maintenance. The water check’s emphasis was to convince participants to adopt the suggested irrigation schedule and conservation recommendations. The water check was a one-time water conservation intervention. A full water check description and irrigation scheduling methodology are described in paragraph A2 of [Appendix A](#).

2.2. *Human behaviors related to landscape water use*

Human behaviors related to landscape water use were assessed through gathering interview and survey data from residents at participating households utilizing protocols approved by the university’s Institutional Review Board. At the time of the water checks, pre-water check face-to-face interviews were conducted with persons responsible for landscape watering to establish baseline watering habits, conservation attitudes, conservation techniques already adopted, and participants’ understandings of utility statements and billing information. Interviews were conducted while water check personnel inspected the landscape and completed the walk-thru site evaluation. At the end of the growing season, post-intervention face-to-face interviews were conducted to discover what recommendations people adopted, problems they encountered, how they dealt with challenges in adopting recommendations, and their assessment of the water check program in aiding them to conserve water. The interviews were identical in 2004 and 2005.

During summer 2007, a follow-up survey was sent to 198 participants who indicated in their post-water check interview they

had implemented or tried to implement the irrigation schedule and for whom we had complete data (water billing records, Remote Sensing/Geographic Information System data on property characteristics, survey data, and water check data). Irrigation schedule adoption was used as a proxy for “tried to implement recommendations” because nearly all participants received a schedule and it was the simplest recommendation to adopt that did not require any financial expenditure. Surveys were mailed three times and had a 63% response rate ($n = 125$) with 77% of respondents being 2004 volunteers ($n = 96$) and 23% being 2005 recruits ($n = 29$). Survey purposes were to determine if participants continued to use the irrigation schedule, track further progress made in implementing recommendations, and assess changes in participants’ appraisal of water check effectiveness as they worked on implementing recommendations.

2.3. *Assessing landscape water use efficiency*

We assessed landscape water use efficiency using a Landscape Irrigation Ratio (LIR), which we calculated as the ratio of outdoor water used (determined through water billing data analysis) divided by landscape water need (estimated by each location’s landscape water budget). The landscape water budget quantifies the volume of water needed by a landscape, while the LIR measures water application efficiency for a given landscape. This approach is based upon estimating landscape water budgets (e.g., see [Al-Kofahi, VanLeeuwen, Samani, & St. Hilaire, 2012](#); [Dziegielewski & Kiefer, 2010](#); [Johnson & Belitz, 2012](#); [Mayer, DeOreo, Chesnutt, & Summers, 2008](#); [U. S. Environmental Protection Agency, 2012](#)).

2.3.1. *Estimating landscape water use*

Landscape water use was extracted from city meter data for each participant household for 2002–2007. Billing period lengths varied, so daily water use was determined using scaled interpolation between meter read dates. Estimated landscape water use for each location was calculated as total water consumption from April 1 through October 31 minus indoor water use estimated from winter consumption the previous November through March (when snow and low temperatures preclude irrigation) and adjusted for daily averages ([Frag, Neale, Kjølgren, & Endter-Wada, 2011](#)).

2.3.2. *Estimating landscape water need*

Parcel-level landscape water need was estimated using aerial imagery to characterize plant material integrated with calculated aggregate volume of water needed to maintain that landscape given local climatic conditions ([Frag et al., 2011](#)). We use “water need” as generally synonymous with water requirements and demand. However, we specifically use “water need” as meaning the estimate of landscape water use from evapotranspiration (ET_0) as controlled by atmospheric conditions and adjusted with plant factors for turf or woody plants.

Airborne multispectral images of the city used to characterize each parcel’s landscape type were obtained using a digital imaging system ([Cai & Neale, 1999](#); [Neale & Crowther, 1994](#)) in spring of 2002 before trees had leafed out and in summer after trees had fully developed canopies. An additional summer flight in 2004 over the entire city provided updated imagery for this study. Comparison of spring images with summer images enabled greater accuracy in estimating amount of turf, with 34% of area under tree canopies reassigned to the turf category (see [Frag et al., 2011](#) for classification methodology description). Imagery was integrated with geographic information system data on parcel boundaries and building footprints obtained from the city. Since parcel polygon shape files obtained from public records excluded parking strips and other rights-of-way maintained by adjacent property owners, a non-overlapping buffering routine was developed to expand

Table 1
Category Benchmarks for Landscape Irrigation Ratio (LIR).

Benchmark category (water used/water needed)	LIR value	Water use range ^a (mm/day)	Seasonal ET _o ^b	
			Year	ET _o (mm/day)
Justifiable water use			2002	4.4
Efficient	LIR ≤ 1	≤ 2.99	2003	4.5
Acceptable	1 < LIR ≤ 2	3.0–5.9	2004	4.2
Unjustifiable water use			2005	4.1
Inefficient	2 < LIR ≤ 3	6.0–8.9	2006	4.1
Excessive	3 < LIR	≥ 9 ^c	2007	4.0

^a Water use ranges are based on each categories' average water use (2002–2007). LIR categories were compared to water use and cut points were created to define ranges.

^b Values used to evaluate the appropriateness of the category defining water use ranges.

^c Four locations with bad meters and two locations with outlier values (water use greater than 30 mm/day) were excluded.

parcels by 40 ft (12 m). For example, if road width between parcel edges was less than 80 ft (24 m), half the area was allotted to the parcel on one side of the street and the other half to the parcel on the opposite side. Or, if two parcels shared a boundary (neighboring properties), no extension occurred. The buffering routine allowed inclusion of tree crowns overlying the street or turf parking strips in calculating total irrigated landscaped area.

Landscape water need was determined for each participant's property for 2002 through 2007 based on local seasonal average ET_o (Penman-Monteith equation; see Allen et al., 2005) for each year (Table 1, column 5) adjusted for proportion of landscaped area represented by turf, trees and/or shrubs, and turf under trees (Farag et al., 2011; Kilgren et al., 2010). Water budgets were not adjusted for soil water balance: effective rainfall, root depth, or sprinkler system distribution uniformity. Watering season was defined as April 1 through October 31 for analytic purposes and seasonal landscape irrigation ratios were calculated.

2.3.3. Landscape irrigation ratios

The Landscape irrigation ratio is defined in the following equation:

$$\text{LIR} = \frac{\text{landscape water use}}{\text{landscape water need}} \quad (1)$$

This measure of efficiency is based on a standard of ecologically appropriate water use, which is plant water need. The LIR provides an easily interpretable metric of amount of landscape water applied relative to plant water need; e.g., LIR of 2.5 means a household is using 2.5 times the water needed by landscape plants. The LIR establishes a site-specific benchmark of the appropriateness of landscape water use relative to plant water need. It allows assessment of landscape water conservation potential by quantifying (in)efficiency of a particular household's landscape water use regardless of lot size. The LIR metric has a conceptual advantage for our purposes (high LIRs equal high water use) over the "conservation effectiveness ratio (CER)" described by Survis and Root (2012) and derived from an equation that inverts Eq. (1). With their CER values, "greater than 1 indicates that actual water use was less than the target use" (high CER equals low water use).

Logan City, Utah experiences warm-to-hot days and cool nights during most of the irrigation season due to its location in a mountainous, semiarid environment. We created water use benchmarks for each LIR category based upon comparison of participants' average water use (2002–2007) in mm per day with their average LIR values for the same period (Table 1, column 3). Four LIR categories are defined for our study and shown in Table 1 (columns 1 and 2): efficient (LIR ≤ 1); acceptable (1 < LIR ≤ 2); inefficient (2 < LIR ≤ 3); and, excessive (3 < LIR). Descriptive names were based on logical interpretations of LIR values. Seasonal baseline ET_o values were calculated as the average of two years prior to intervention year. Water use ranges can be compared to the seasonal baseline ET_o for 2004 of 4.4 mm per day and 2005 of 4.3 mm per day and the larger context

of the ET_o range for the study period (2002–2007) of 4.0–4.5 mm per day (Table 1, column 5). Efficient and acceptable categories are considered justifiable water use while the inefficient and excessive water use categories are considered unjustifiable and constitute capacity to conserve water applied to urban landscapes.

2.4. Monitoring and evaluating water conservation success

We developed several analytic tools that we argue can provide the water conservation field with common measures for assessing landscape water use and monitoring conservation program effectiveness. These tools include: (1) Participant Outcome Evaluation Tool, designed to evaluate participant response to a water conservation program; and, (2) Program Evaluation Tool, designed to evaluate the intervention quality and situations in which conservation programs may need to provide more assistance. Developing these tools involved creating an outcome scoring scheme, characterizing a household's baseline and post-water check landscape water use, and evaluating the water check program's effectiveness.

For our analyses, a parcel-specific baseline LIR was calculated for each participant location by averaging annual LIRs for two years prior to the water check, and a response LIR was calculated by averaging annual LIRs for two years after the water check. Response LIRs were compared to baseline LIRs to measure change in water use post-water check. LIR values produced continuous variables used for descriptive statistics and are the basis of two monitoring tools: Participant Outcome Evaluation Tool and Program Evaluation Tool.

2.4.1. Participant Outcome Evaluation Tool

The Participant Outcome Evaluation Tool is based upon plotting participating households' baseline LIRs against response LIRs, and outcome scores are used to group participant households. We created the outcome-scoring variable by establishing 12 definitions that characterize a household's baseline water use and the direction and extent of changes in their water use after the water check (see Appendix A, paragraph A3). In order to better depict the scoring scheme graphically, the 12 scores were also coded into 4 groups with letter definitions: A—case started and remained in the efficient category; B—case reduced its LIR; C—case increased its LIR, and D—case started and remained in the excessive water use category (Fig. 2a). The water check was deemed *successful* if a household reduced its LIR or remained in the efficient water use category, while it was deemed *unsuccessful* if a household increased its LIR or remained in the excessive water use category.

2.4.2. Program Evaluation Tool

The Program Evaluation Tool takes another perspective (Fig. 3a). It focuses on effectiveness of the water check intervention and what additional action may be necessary to help participants achieve appropriate water use. This tool is based upon plotting baseline

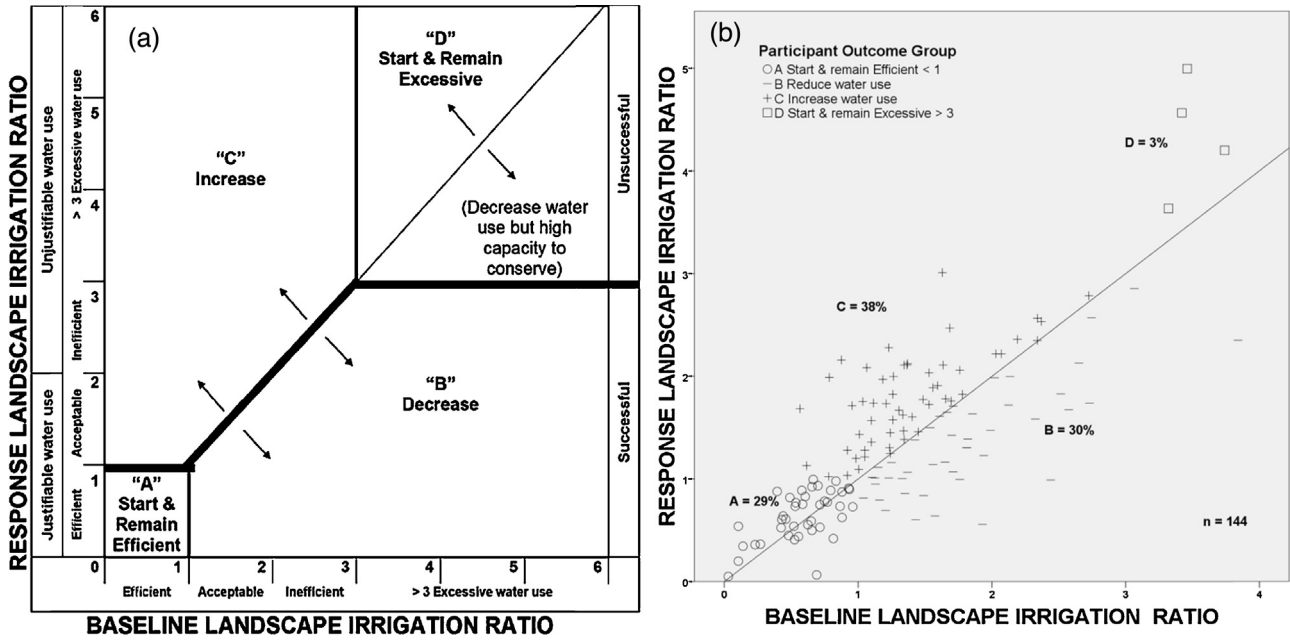


Fig. 2. (a) Participant Outcome Evaluation Tool characterizes the participant's response to the water check. It illustrates the appropriateness of water use and the direction of change. (b) Participant's Baseline Landscape Irrigation Ratio is plotted against the Response Landscape Irrigation Ratio, and based on the outcome score, placed in four groups to interpret and describe differences in water use.

LIRs against response LIRs and then, depending on how a participant's LIR changed relative to appropriateness of their resulting water use, the need for additional intervention is characterized. We defined five groups describing what further action, if any, needs to be taken by conservation program administrators. Households that *decreased* their LIR below 2 (within justifiable range) were judged to need no further intervention, while households that *increased* their LIR (above diagonal and with an LIR over 2) were deemed to need further intervention (see labels on right-hand side of Fig. 3a). For Group 5, participants who increased to the inefficient or excessive range, and/or those who start and remain in the excessive range, a

different intervention approach is likely needed. A follow-up visit is recommended to reinforce the water check for Group 4 participants who reduced their LIR but remain in the inefficient range, or to refine the water check for Group 4 participants who increased but remain in the acceptable range. For Group 3, consisting mostly of participants who start in the inefficient range (baseline LIR > 2) but end up in the acceptable range (response LIR between 1 and 2), monitoring of billing records is recommended. No further intervention is deemed necessary for Group 2, those participants who reduced their LIR and ended up in the efficient range (response LIR ≤ 1). For Group 1, participants who start and remain in the

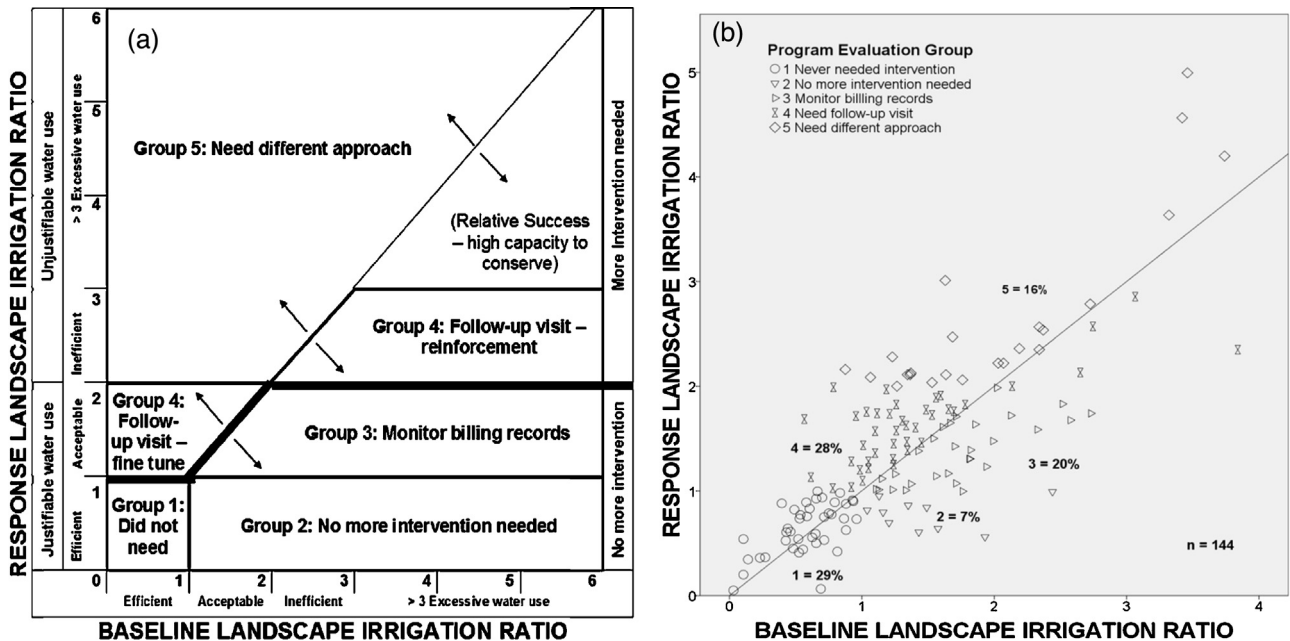


Fig. 3. (a) Program Evaluation Tool characterizes the effectiveness of the water check intervention and what additional action may be necessary. (b) Participant's Baseline Landscape Irrigation Ratio is plotted against the Response Landscape Irrigation Ratio, and based on the outcome score, placed in five program evaluation groups to evaluate the quality of the water check and identify participants who may need more assistance.

efficient range, no initial intervention was needed (see Fig. 3a for complete definitions).

2.4.3. Accurately assessing behavioral change

Our goal was to evaluate the effectiveness of landscape water checks based on changes in participant households' water use efficiency post water check. The difficulty of attributing changes in water use to water checks became apparent during analysis, which was confounded by infrastructure problems, challenges faced by field teams during water checks, and population mobility (Table 2). After the water check, a few locations developed water leaks that increased their LIR and obscured the households' behavioral efforts to conserve water ($n=4$). The 2005 field team provided several irrigation schedules with incorrect run times and/or watering frequency ($n=34$) and at 3 locations were unable to conduct sprinkler catch cup tests due to wind or sprinkler system condition. During the study period, Logan City's population grew by 12.9% and was accompanied by the housing boom (U.S. Census Bureau, 2011). We discovered that 66 (31%) of the remaining 210 property locations changed resident households one or more times; consequently, the post water check water use we observed reflected behavior of people who did not receive water checks. Therefore, our assessment of water check effectiveness is limited to the remaining 144 cases, which we shall refer to as "reliable cases," meaning those locations without leaks where residents received correct irrigation schedules and were occupied by residents who received the water check (no residential mobility). Our temporal analysis includes data from 2002 through 2007 for these remaining cases where we can fairly assess the water check as a conservation tool to motivate behavioral change.

3. Results

Our analysis of "reliable cases" ($n=144$) includes evaluation of participants' success in conserving water and evaluation of the water check program's effectiveness in promoting water conservation.

3.1. Evaluating participant water conservation success

The Participant Outcome Evaluation Tool focuses on the appropriateness of a household's landscape water use and the direction of change in its water use subsequent to the water check.

3.1.1. Households' water check responses

We utilized the Participant Outcome Evaluation Tool to conceptually interpret and describe differences in water use after the water check. Participants' baseline LIRs are plotted against response LIRs and are grouped based on their outcome score (Fig. 2b). Group A households (29%, $n=41$) were efficient to begin with (baseline LIR $M=0.58$) and remained so after the water check (response LIR $M=0.64$). Although, on average, their water use increased approximately 2% from 1.79 mm per day to 1.83 mm per day, this was well below their landscapes' water requirements. Group B households (30%, $n=44$) reduced their water use an average of 30% from 5.7 mm per day (baseline) to 4.0 mm per day (response). However, not all of them had achieved justifiable water use and some households in this group continued to use more water than the estimated landscape need, with LIR values ranging between 2 and 3 and with maximum water use of 9.0 mm per day. Group C households (38%, $n=55$) increased their water use an average of 23% from 4.3 mm per day (baseline) to 5.3 mm per day (response). We later determined that 34 of 55 households (62%) were in efficient or acceptable categories at the time of the water check; however, the recommended irrigation schedule called for increased water use. Group D households (3%, $n=4$) were in the excessive water use category

and remained so after the water check, increasing their water use an average of 18% from 11.2 mm per day (baseline) to 13.3 mm per day (response). Group D households are a primary audience for further conservation interventions.

3.1.2. Adoption of water check recommendations

At the end of the irrigation season, we conducted post-water check interviews. We expected households that reported adopting the recommended irrigation schedule and implementing plant, soil, or sprinkler system recommendations would reduce their water use. A chi-square test for independence showed a significant relationship between adoption of soil recommendations and successful/unsuccessful outcomes ($\chi^2=5.246$, $p=0.022$, $V=0.195$) (deVaus, 2002). We found that 73% of participants who mulched their soil or aerated compacted areas ($n=44$) were successful in reducing water use. During the response period (2 years after water check), participants who adopted soil recommendations used 25% (3.4 mm/day) less water on average than participants who did not adopt them (4.5 mm/day). In terms of efficiency, participants who adopted soil recommendations had lower response LIR values ($M=1.15$) than those who did not ($M=1.52$).

We did not find statistically significant relationships between any other specific recommendation and successful/unsuccessful outcomes. However, Table 3 shows a greater percentage of cases were successful in becoming more efficient for almost all recommendations they could adopt. In end-of-season interviews, participants reported a variety of steps they had taken, combinations of which varied greatly by location as many people attempted to address their specific list of water check recommendations.

We also asked participants in post-water check interviews why they chose not to adopt the water check recommendations (Table 4). Participants cited time constraints, cost of implementing recommendations, lack of motivation, personal physical impediments of age or disability, and physical limitations of their sprinkler systems (e.g., another zone could not be added to their time clock). A chi-square test of independence showed a significant relationship between reported time constraints and successful/unsuccessful outcomes ($\chi^2=3.706$, $p=0.054$, $V=0.194$) (deVaus, 2002). We found 58% of participants who cited time constraints ($n=31$) were unsuccessful in reducing their water use. During the response period (2 years after water check), participants who cited time constraints used 23% (5.2 mm/day) more water on average than participants who did not (4.2 mm/day). In terms of efficiency, participants with time constraints had higher LIR values than those who did not ($M=1.74$ and 1.44, respectively).

3.1.3. Comparison of 2004 volunteers and 2005 recruits

Table 5 presents the distribution of 2004 volunteers and 2005 recruits among LIR categories for the baseline period (2 years prior to water check), water check intervention year (2004 or 2005), and response period (2 years following water check). The distribution among LIR categories of 2004 volunteers was remarkably stable and a greater proportion of 2004 volunteers were in the efficient category compared to 2005 recruits. The 2004 volunteers' mean baseline water use (3.6 mm/day) was 39% less than 2005 recruits (5.8 mm/day). During the response period, 2004 volunteers' mean water use (3.4 mm/day) was 41% less than 2005 recruits' (5.8 mm/day). Our interviews confirmed that, overall, the 2004 volunteers were already interested in conservation and hoped to learn something new through the water check.

The 2005 recruits were drawn from a sample based upon preliminary water use analysis by establishing thresholds for absolute landscape water use (gallons) and landscape water use normalized for lot size (depth units). The baseline LIR distribution shows that 63% of 2005 recruits were justifiably using water, so this method of identifying above-average water use was not sufficiently

Table 2
Study participant attrition—cases for final analysis.

Item	Distribution of cases		
	2004 volunteers	2005 recruits	All cases
Total participants	150	101	251
Leaks	3	1	4
Incorrect or no irrigation schedule	0	37	37
Residential mobility	47	19	66
Total cases in final analysis (<i>N</i>)	100	44	144

Table 3
Distribution of water check recommendations adopted.

Water check category	Recommendations					
	Plants (%)	Soil (%)	Irrigation schedule (%)	Sprinkler system ^a		
				Adjusted (%)	Repaired (%)	Altered (%)
Successful (reduced LIR)	54	73	59	56	59	50
Unsuccessful (increased LIR)	46	27	41	44	41	50
Total	100%	100%	100%	100%	100%	100%
<i>N</i> ^b	68	44	119	86	83	28

Note: Data based on 138 cases that had no leaks, received correct irrigation schedules, had the same residents 2002–2007, and completed post-water check interviews.

^a Adjustments included cleaning clogged heads, straightening tilted heads, and adjusting spray patterns. Repairs included fixing valves, pipes, or heads. Alterations included installing pressure regulator, checking valves, separating valves, or correcting head spacing.

^b The number of cases in each column changes because adoption of more than one recommendation was possible.

Table 4
Distribution of reasons water check recommendations were not adopted.

Water check category	Reason						
	Time (%)	Cost (%)	Making decision (%)	Motivation (%)	Age or disability (%)	System constraints (%)	Misc. ^a (%)
Successful (reduced LIR)	42	57	62	57	83	55	50
Unsuccessful (increased LIR)	58	43	38	43	17	45	50
Total	100%	100%	100%	100%	100%	100%	100%
<i>N</i> ^b	31	23	21	23	6	20	26

Note: Data based on 138 cases that had no leaks, received correct irrigation schedules, had the same residents 2002–2007, and completed post-water check interviews.

^a Miscellaneous responses include a variety of reasons unique to the household.

^b The number of cases in each column changes because respondents could offer more than one reason.

Table 5
Distribution of participants in Landscape Irrigation Ratio categories by water check year for “reliable cases”.

	Baseline ^a LIR (%)	Intervention year (%)	Response ^b LIR (%)
2004 volunteers			
Justifiable water use			
Efficient $LIR \leq 1$	47	50	47
Acceptable $1 < LIR \leq 2$	46	46	44
Unjustifiable water use			
Inefficient $2 < LIR \leq 3$	5	4	8
Excessive $3 < LIR$	2	0	1
Total	100%	100%	100%
<i>N</i>	101	101	101
2005 recruits			
Justifiable water use			
Efficient $LIR \leq 1$	7	21	9
Acceptable $1 < LIR \leq 2$	56	54	47
Unjustifiable water use			
Inefficient $2 < LIR \leq 3$	28	16	35
Excessive $3 < LIR$	9	9	9
Total	100%	100%	100%
<i>N</i>	43	43	43

Note: Data based on 144 cases that had no leaks, received correct irrigation schedules, and had the same residents 2002–2007.

^a Baseline LIR is average for two years preceding intervention year.

^b Response LIR is average for two years after intervention year.

accurate. In the water check intervention year (Table 5), 75% of the 2005 recruits were very successful in reducing their LIR to justifiable levels. However, during the response period, 44% were unjustifiably using water compared to 37% during the baseline period. Many of these participants were just beginning to develop water conservation skills. Plant water need varies over time (over a season and as a plant grows) and is essentially a moving target that less experienced participants may have found difficult to perceive. They likely needed more support from the water check program than a one-time water check provided them.

3.2. Evaluating water check intervention effectiveness

The Program Evaluation Tool focuses on water check intervention effectiveness and what additional action may be necessary to help participants achieve appropriate landscape water use.

3.2.1. Determining need for additional intervention

We utilized the Program Evaluation Tool to identify participants who may need more assistance and to evaluate the conservation intervention quality (Fig. 3a). Participants' baseline LIRs for "reliable cases" is plotted against response LIRs. The relationship between them is used to assess water check intervention effectiveness and identify participants who may fall into different categories described by their program evaluation group.

Group 1 households (29%, $n=41$) were efficiently using water prior to the water check and did not need the intervention to begin with (Fig. 3b). Interestingly, 95% of households in this group are 2004 volunteers who generally were interested in water conservation already and had previously implemented conservation measures on their own. Group 2 households (7%, $n=10$) successfully reduced their response LIR below 1 and are using water efficiently. They reduced their water use on average 51% from 4.7 mm per day (baseline) to 2.3 mm per day (response). This group does not need any further intervention by water conservation managers. Group 3 households (20%, $n=29$) successfully reduced their response LIR below 2 and were using water acceptably post-water check. They reduced their water use by 25% on average from 5.5 mm per day (baseline) to 4.1 mm per day (response). Water conservation managers should monitor this group to assure durability of their water use reductions. Group 4 households (28%, $n=41$) are comprised of two groups who needed follow-up visits but for different reasons. The first group, plotted above the diagonal and below 2, was efficient to begin with but increased their LIR to greater than 1 after the water check. Participants in this group may need follow-up visits to evaluate why their water use increased and to fine-tune their actions as appropriate. Some of these participants were given irrigation schedules recommending increased water use. A follow-up visit would have provided opportunities for further evaluation and refinement of conservation assistance. The second group, plotted below the diagonal and above 2, reduced their response LIR to less than 3, but was still inefficiently using water. Participants in this group may need a follow-up visit to reinforce their efforts and determine what else could be done to reduce their water use. Group 4 as a whole increased their water use 11% on average from 4.4 mm per day (baseline) to 4.9 mm per day (response). Group 5 households (16%, $n=23$) were either using more than 3 times the water needed by plants prior to the water check and remained in this excessive water use category after the water check, or increased their LIR to >2 and their water use became inefficient or excessive. They increased their water use 23% on average from 6.5 mm per day (baseline) to 8.0 mm per day (response); during the response period, their water use ranged from 6.0 mm per day to 15 mm per day. We recruited 2005 participants because these households were identified as having above-average water use and a greater proportion of them, 35% of all 2005 recruits ($n=43$), are in group

5 compared to only 8% of all 2004 volunteers ($n=101$). The water check as delivered was ineffective for this group and they may need a different kind of intervention or approach.

3.2.2. Participants' rating of the water check

In order to assess the intervention quality from participants' point of view, we asked participants to rate how effective the water check program was in helping them to conserve water. The question was posed to participants in post-water check interviews and again in 2007 follow-up surveys. Table 6 compares rating score means for each program evaluation group revealing that all groups rated program effectiveness highly in each year the question was asked, with insignificant decreases in mean ratings in the 2007 follow-up survey. Looking at all cases, 64% (Groups 1–3) were successful or never needed the intervention, and the slight decrease in their mean ratings of the water check does not appear to have affected their ability to conserve water.

However, why would the participants who were most successful or already efficient decrease their program rating? We found some of them were not able to verify or assess the effectiveness of their conservation efforts due to lack of sufficiently detailed and timely information provided on their utility bills. Some of the Group 1 participants who never needed the intervention to begin with were hoping to learn new conservation skills and achieve even greater water savings, but the water check provided more basic information. Participants' suggestions for improving the usefulness of the water check program included providing more specific information regarding plant choices and characteristics, landscape and sprinkler system design, local maintenance resources, or conservation classes. Suggestions for improving program services included: offering follow-up calls and/or appointments to provide further assistance in addressing their landscape problems.

3.2.3. Field observations: Water check program delivery

Researchers and the water check field team made several general observations during household site visits regarding delivery of the water check program. We discovered volunteers and recruits have different motivations, information requirements, and skill levels. Generally, volunteers wanted detailed information about specific issues that would allow them to achieve even greater water savings than they had on their own. They were often "do-it-yourselfers" exhibiting practical skills and motivations to conserve. In contrast, many recruits were just beginning to address water conservation issues. Generally, they needed basic information on conservation as well as technical "how-to" information to get them started, and some of them wanted on going assistance to correctly implement water check recommendations.

Water checks were delivered as one-time interventions, which we observed may not have been the most effective water conservation program approach. Participants often commented to us, "I wish you would come back. . .," for a variety of reasons related to a general desire for more help with specific requests for certain technical information, understanding their water bills, and/or lists of local resources for plants, irrigation contractors, or service people. Participants had busy lives and often did not have time or possibly the inclination to do research necessary to achieve conservation goals.

How program administrators interact with households also appears to be important. In 2004, we observed that in some cases participants had volunteered for the water check to resolve a household dispute over landscape water use. We only met with persons who scheduled appointments and discovered in post-water check interviews that the irrigation schedule and recommendations mostly were rejected by the person who did not participate.

In attempting to recruit research participants and schedule visits, we observed people often experience constraints on their

Table 6
Means of program effectiveness rating and distribution of program evaluation group.

Program evaluation group	Program effectiveness rating ^a			Distribution of program evaluation group
	Water check year mean (SD)	2007 survey mean (SD)	Change in mean	All cases (%)
1 Never needed intervention	7.79 (1.7)	7.00 (1.8)	↓0.79	40
2 No more intervention needed	8.50 (1.0)	8.33 (1.2)	↓0.23	6
3 Monitor billing records	7.75 (2.0)	6.67 (1.8)	↓1.08	18
4 Need follow-up visit	8.15 (1.8)	7.75 (1.1)	↓0.40	30
5 Need different approach	7.86 (1.7)	8.25 (0.5)	↑0.39	6
Total				100%
N	135	70		67

Note: See Fig. 3a for group definitions. N = “reliable cases” that rated the program in each year and also received and replied to the 2007 follow-up survey.

^a Participants were asked to rate how effective the water check program was in helping them to conserve water on a scale of 1 indicating “not at all helpful” to 10 indicating “very helpful.”

time, limited availability of money, varying interest, and conflicting behaviors and goals within their households that may impede conservation efforts.

4. Discussions

4.1. Value of Landscape Irrigation Ratio (LIR) approach

Reducing landscape water use is an important municipal water demand management strategy, particularly in arid regions worldwide where outdoor water use constitutes a significant proportion of total water use in urban areas. We developed the Landscape Irrigation Ratio (LIR) so that we could equitably compare and evaluate participants’ individualized landscape water use to an ecologically-based standard of plant water need. The merit of the LIR approach is that it can be used to evaluate landscape water use efficiency and distinguish locations that are already efficient from those that are not. Our preliminary water use analysis of 2005 recruits based on volumetric thresholds did not adequately identify inefficiency and above-average water use. Water providers usually evaluate water use based on absolute gallons used at a location, but this comparison of landscape water use does not account for variability in needs between urban lots. Accurately identifying inefficient outdoor water use requires establishment of a site-specific water budget that quantifies volumetric needs based upon landscaped area, plant water requirements, and weather data. This parcel-level budgeting method allows water providers to more reliably and efficiently direct their resources and water conservation programs to locations with capacity to conserve water (Farag et al., 2011).

In addition, the LIR approach is a valuable method of analysis for water providers because it provides a means to measure, evaluate, and monitor participant as well as program performance over time. The LIR describes the appropriateness of water use in relation to landscaped area, plant type, and weather conditions. In this study, the Participant Outcome Evaluation Tool (Fig. 2a) is used to evaluate whether a household’s water use efficiency was increased or reduced after the water check and whether it is brought within an appropriate range. The Program Evaluation Tool can then be applied to focus on program effectiveness to identify participants who may need more assistance. However, for water providers, defining successful outcomes is a policy decision based on conservation program goals and they may choose to be more stringent or lenient when defining what constitutes appropriate water use.

4.2. Landscape constraints affect participant success

Households that started with low capacity to conserve water applied to their existing landscape are not primary candidates for

conservation programs, yet some still managed to reduce their water use even further after participation. For most households in this group, achieving greater water savings likely would require transitioning to more drought-tolerant plant material or reducing their landscaped area. Water managers could evaluate landscaping and plant material at these residences and direct landscape transition programs to these locations.

Some households had additional capacity to conserve water and could further reduce their water use. Some households were watering daily for short time periods and their turf had very poorly developed root systems. These situations require that lawn be weaned from over watering and the recommended irrigation schedule be phased in over a couple seasons, which may have limited these participants’ reductions in water use during the evaluation time period (either because of initial negative results or insufficient time to wean turf). Other households had poorly designed sprinkler systems and/or older controllers limiting their ability to reduce water use. If a sprinkler system zone waters turf and shrubs, the household needs to choose which plant water need to meet—turf (higher need) or shrubs (lower need). Water checkers encouraged participants to separate their zones by plant material, but also offered alternative ways to deal with poor irrigation system design short of changing the zones. Choices included watering for turf need and overwatering shrubs, which saved participants time, or, alternatively, watering for shrub need and under watering turf, which would require supplemental hand-watering and more of households’ time. Another suggestion was to adjust sprinkler heads in shrub beds to restrict water flow. Water managers could direct conservation programs that improve irrigation technology to locations with these circumstances.

Some households with excessive water use also have challenging site characteristics (wind, sun exposure, rocky soil) that are not fully accounted for in estimated landscape water need calculations and/or the recommended irrigation schedule. In addition, households in this group have interesting social dynamics with direct influences on their water use, such as our observed cases of households’ disputes over their irrigation schedule, inability to operate their controllers, or receipt of a nuisance citation for a non-irrigated weed-infested lot being a neighborhood fire hazard.

The water check program was designed to promote efficiency on existing landscapes. Our on-site participant interviews allowed us to gain a holistic understanding of people’s water management motivations and challenges. Participants’ responses reveal the interconnected nature of site characteristics, irrigation technology, plant material, and human behavior in achieving successful water conservation. Success appears to be site-specific and relies on adoption of a combination of recommendations addressing residential landscape conditions, as well as households’ conservation competency. Similarly, for those households that were not successful, they may not have been able to adopt all recommendations

during the study period. Ferguson (1987) stressed initial importance of installing well-designed urban landscapes because this sets long-term water need for a location. Rosenberg et al. (2011) later utilized their value landscape engineering model to demonstrate substantial impacts of landscape choices in water, labor, and monetary costs over a landscape's life.

Our survey data provide important insights into why participants do not act to implement conservation recommendations that previous studies have not investigated. Due to various constraints, some participants likely perceived the recommendations to be a "high-cost" situation. Diekmann and Preisendörfer (2003) found high-cost situations make it difficult for people to act despite their environmental concern. They concluded that political action, through incentive programs, could transform a situation from "high-cost" to "low-cost" and enable people to take conservation actions. Our findings have important implications for conservation program design and imply the need to include on going conservation support for program participants, monetary incentives to support infrastructure changes, better information on local resources (nurseries, landscapers, sprinkler system maintenance and repair services), and subsidies or other forms of assistance to support the elderly or disabled in undertaking conservation actions.

Our findings confirmed that 2004 volunteers had already attained a certain level of conservation knowledge and skill that they had applied and most of them were efficiently using landscape water. Fielding et al. (2013) noted voluntary conservation strategies are likely to be more acceptable to society than prescriptive strategies. They found even households with low water use could achieve further meaningful water savings, while Kilgren et al. (2010) found this to be true in institutional school ground settings.

4.3. Water check intervention effectiveness

Development and application of the Program Evaluation Tool is one of this study's key innovations. It is designed to help water managers assess the effectiveness of water check interventions and determine what additional action may be necessary to help participants achieve appropriate water use. We found some households increased their water use after the water check. This finding highlights the utility of evaluating households' current water use through the LIR approach and the importance of evaluating households' current irrigation schedule before recommending new schedules. Water check procedures called for gathering data on current schedules, but not computing weekly total runtimes. If water checkers knew households' LIR when conducting water checks, they could compare current irrigation schedules with recommended schedules, use the lesser of the two, and commend participants who are already efficient. They could make recommendations that adjust how the same amount of water is applied to improve turf health; e.g., watering less frequently but for longer times or applying water in repeated cycles to gain better soil infiltration.

Some households were efficient throughout the study and are mainly comprised of enthusiastic volunteers. These households are motivated to act and are good candidates for programs to convert existing landscapes to something that requires less water. Other households needed additional support and wanted on going assistance. This led us to understand that people desire program administrators to act as partners and engage with them in more of a problem-solving or consultancy approach. We also learned we needed to work with both heads of household during water checks in order to increase the likelihood of recommendations being adopted. Household decision makers need opportunities to participate in water checks, ask questions, and synthesize information on their own, instead of having it passed on to them by another household member. While water checks did provide

basic conservation recommendations, they did not provide much "how-to" information or technical assistance in adopting recommendations. Program administrators could act as that knowledge resource and help people to act on their best water conservation intentions by delivering more tailored and sequential conservation programming over longer time horizons.

Conservation programs have not paid sufficient attention to examining the different information needs of participants and how these differences affect conservation outcomes and success. For example, past research has stressed that information needs to address barriers to behavioral change (McKenzie-Mohr, 2011), be tailored to provide contextual relevance (Abrahamse et al., 2007), or address gaps in knowledge (Cockerill, 2010). Conservation programs also need to provide information that addresses differences in participants' skill levels. Some previous studies have found water checks and in-home visits to be an effective means for reducing water use (Bargar, Culbert, & Holzworth, 2004; Keen, Keen, Francis, & Wolff, 2010; Thomas et al., 2009) while other studies have found that water checks did not achieve their full potential (Baum et al., 2005; Mecham, 2004; Nelson, 1992), likely for the reasons we outline here.

The slight decreases in participants' program effectiveness ratings reflected some frustration in people's ability to assess and monitor their own efforts to conserve water. Content of water check information packets needs to be carefully selected to support participants' efforts to adopt conservation recommendations and subsequently monitor and assess their water savings and irrigation efficiency. These findings are consistent with Atwood, Kreutzwiser, and De Loë (2007) who found participants in an urban outdoor water conservation program could not determine if their efforts to save water were effective and stressed the importance of providing information regarding successful water use reductions. Previous studies have found people generally do not know how much water they use, but those who receive tailored billing information in a timely manner that meet their situational needs could accurately characterize their water use and evaluate their conservation progress (Abrahamse et al., 2007; Attari, 2014; Beal, Stewart, & Fielding, 2013; Doron et al., 2011; Randolph & Troy, 2008).

Water conservation programs could better take into account participants' water check feedback, objectives, information needs, preferred choices, and what constraints or opportunity costs they face in order to make fully informed and effective conservation decisions. Participants are often interested in how their conservation efforts contribute to their own longer-term household needs, as well as community values or the greater good of society as a whole, such as conserving water in times of drought.

Overall, we observed and learned water conservation is a continual process involving change, monitoring, adjustment, and reinforcement. It is iterative by its nature. Participants need time to properly absorb information they are given. They need opportunities to experiment to see what works best in a particular context. On-the-ground circumstances vary, e.g., landscapes mature and sprinkler systems become worn, so the key to effective water conservation is an ability to understand which recommendations are most effective under different conditions. Household circumstances also change and people may have periods where they do not have time and/or money to devote to water conservation. Water conservation is a process that occurs over longer time frames than most programs plan for and participants often need on going support to achieve the most successful outcomes.

4.4. Residential mobility affects program evaluation

In this study, we were primarily interested in identifying behavioral change subsequent to water checks so we deleted locations that were not occupied by residents who had received

the water check from our analysis. This is an important issue that water providers need to deal with in order to evaluate on going conservation programs. Addressing this issue requires that water providers develop and maintain databases documenting *who* has participated in a program as well as the *location* where conservation programs were received. A good tracking system would help identify key variables affecting water use. Further research is needed to identify the relative influence of structural issues tied to location and water management skills that travel with the resident. Under what conditions would a conservation program be more effective addressing sprinkler system design or plant choices (site and infrastructure factors) instead of water management issues (human behavior issues)?

5. Conclusions

Our findings suggest that water check programs can be effective in promoting water conservation when the information provided is tailored to meet participants' knowledge and skill levels. Use of the LIR analysis approach combined with the Participant Outcome and Program Evaluation Tools are effective ways that water providers can promote water conservation on urban residential landscapes. Further research is needed to evaluate the relative effectiveness of each water check recommendation and prioritize the order in which items should be addressed. Irrigated urban landscapes are the sites of complex human–environment interactions mediated by irrigation systems; they represent numerous and dispersed “end-of-the-pipe” locations on municipal water systems where water use efficiency is not easily engineered or promoted. Figuring out how best to promote water conservation in these settings is an important frontier in urban water demand management research and practice.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found in the online version, at <http://dx.doi.org/10.1016/j.landurbplan.2015.03.002>.

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