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Residential Adoption of Best Landscape Management Practices: Effects of Outreach to Reduce Non-Point Source Pollution

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Abstract: Urban waterways degradation due to runoff from residential areas can be reduced by adopting best management practices (BMPs) for irrigation, fertilizer, and pesticide use. Although stormwater runoff from urban areas has been studied extensively, we focus on single-family residential land use specifically. Outreach to individual households may have a measurable impact since decisions are being made here. We surveyed households to evaluate the effectiveness of education and outreach campaigns on self-reported use of water and chemicals and evaluated whether self-reported behaviors were reflected in the quality and quantity of water draining from the study areas before and after outreach efforts. Our research was conducted in California, which has a Mediterranean climate with distinct wet and dry periods. Runoff from residential landscapes during the dry season enters waterways undiluted by rainwater, making this runoff particularly detrimental to receiving waters. No significant differences in behavior and BMP adoption from before and after the education and outreach campaign was found. These results are not atypical and may be explained by several factors including the population approach to the survey, lag times between outreach and measurable effects, and the need for a critical threshold of adoption to be met for effects to be measurable.

Keywords: urban runoff; residential land use; water quality; Mediterranean climate; irrigation; before–after study

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1. Introduction

Non-point source pollution (NPS) is a leading cause of water quality degradation in the United States, e.g., [1]. Reducing this diffuse type of pollution is difficult because it often results from the cumulative choices of many individuals. Urban areas, and in particular residential areas, have been identified as a significant contributor to NPS pollution [2,3]. A variety of sources contribute to this pollution, including fertilizers, herbicides, insecticides, and animal waste [3–7]. It is often assumed that lack of understanding, rather than lack of concern on the part of the homeowner, contributes to these NPS inputs [2,8]. Fewer than 50% of Americans understand the term "watershed", and less than 25% know that stormwater runoff is the most common source of pollution to streams, rivers, and oceans [9]. Education and outreach programs have been proposed as a non-punitive approach to change this behavior [10,11]. We note that studies of this type frequently use the term "homeowner" without knowing whether participants actually own their homes. Because of this uncertainty, in our research we use the term resident when referring to occupants of single-family homes regardless of ownership. When research by others is being referred to, we retain the term homeowner if used in the original work.

Arid or Mediterranean climates have defined wet and dry seasons. Summer gardening activities coincide with the dry season and runoff from residential landscapes consists almost exclusively of excess irrigation. Baseflows (non-storm) in urban streams can actually be higher during the dry season compared to the wet season due to this runoff [12]. This dry-season runoff has the potential to be a significant contributor to NPS pollutant loads in urban streams [4,5,13,14]. Accidental spillage or overspray of fertilizers, and especially herbicides and pesticides to pavement and other hardscapes, will also likely wash into storm drains with no opportunity to be absorbed by plants and soil. A 2002 survey of residents in Sacramento County (Northern California) found that pest control products were used most frequently to control ants [15]. In Southern California, the widespread occurrence of the red imported fire ant (*Soenopsis invicta*) in residential areas [13] exacerbates the use of these products. These products, even when used properly, can easily become NPS pollution because they are frequently applied directly on to hardscapes [15].

A variety of best management practices (BMPs) have been developed that focus on the reduction in water use as well as NPS pollution through the proper use of water and garden chemicals. Best management practices are design, management, and behavior guidelines and procedures that can either be included in new construction or applied to existing parcels. There are two types of BMPs: (1) structural BMPs, which consist of installed or constructed devices and (2) non-structural BMPs, which, in contrast, do not entail permanent changes to infrastructure and usually involve behavior modifications [16]. For example, installing a programmable irrigation system is a structural BMP, while following fertilizer application instructions is a non-structural BMP. To organize our discussion and data collection, we divided residential landscape management BMPs into four categories: (1) reducing use of garden chemicals (including fertilizers and pesticides), (2) reducing the use of ant pesticides in particular, (3) modifying irrigation systems and behaviors to reduce landscape water use, and (4) reducing runoff through adoption of practices and design features such as mulching and permeable paving. These BMPs have great potential to improve water conservation and water quality when implemented.

The concentrations of nutrients and pesticides in urban runoff suggest that homeowners are overusing and/or misusing garden chemicals [17,18]. In a 2002 residential survey conducted in Sacramento and Orange County, 60% of respondents stated that they did not follow label directions exactly when mixing and measuring garden chemicals [15]. Best management practices for garden chemical use focus on overall reduction and proper use of chemical products, as well as increasing use of alternative methods including organic and nonchemical approaches [19]. Proper use constitutes knowing how much, and how often, fertilizer is required by turf or plants in the garden and sweeping any spilled granular product off hardscapes. In addition, proper disposal of garden chemicals is a practice that can limit the amount of chemicals in runoff. Proper disposal includes not sweeping, hosing, or pouring chemicals into drains or gutters and taking unused products to a household hazardous waste disposal site rather than throwing them into the trash [19].

Past surveys of California households, as well as sales records from home and garden supply stores, have shown that ants are the most common pest treated by homeowners [15]. Perimeter sprays with insecticides, including pyrethroids, fipronil, and organophosphates, to control ants are believed to be a major source of insecticides that contaminate urban creeks and waterways [13,15,20]. Best management practice recommendations [21] suggest alternatives that integrate nonchemical methods, such as removing food and water sources and using caulking and other exclusion methods. When chemical means are necessary, the use of bait and spot treatments instead of perimeter spraying is recommended. Adoption of these practices and reduction or elimination of perimeter sprays would make a significant impact on reducing pesticides in urban runoff [15,21].

It is not just the quality of runoff that is important, but also the quantity. This is particularly true in places where water is more limited, such as arid or Mediterranean climates characteristic of California, and in which chemicals in runoff are necessarily more concentrated as a result [22]. As might be expected, modification to irrigation systems and

practices are the primary approach for reducing unnecessary landscape water use [23]. Best management practices for reducing landscape water use include changes to behaviors, such as watering early in the morning to minimize evaporation from sun and wind, adjusting watering schedule seasonally, and shutting off or stopping irrigation altogether during wet weather, as well as watering deeply but less frequently [24,25]. Additional equipment or modifications to existing systems include using a sprinkler timer, particularly for lawns and large areas, drip irrigation or soaker hose for other landscape plants, and irrigation devices with rotor heads. "Smart" irrigation controllers and soil moisture sensors can be used to ensure plants are only receiving as much water as they need and that application rates do not exceed the soil infiltration rate, i.e., not adding water faster than it can be absorbed into the soil [26].

In addition to changes to the irrigation system itself, there are a variety of landscape features and practices that function to reduce runoff [24]. The implementation of terracing, French drains, swales/buffers, mulch, compost, and slotted or permeable paving can have a significant impact on runoff reduction. Conserving water is important in and of itself. Our focus here, however, is on runoff reduction in combination with proper chemical use. The interaction of these two BMPs is important for understanding resident impact on NPS pollution and resultant water quality.

Best management practices to reduce water and chemical use will only reduce NPS pollution to receiving waters if they are effectively communicated to households making land management decisions. Research on homeowner adoption of BMPs has shown that knowledge of BMPs is the strongest predictor of use [2] though it may not be enough [8,27]. Given the limited budgets that many organizations have for education or monitoring, employing an effective methodology for increasing knowledge is crucial. Media (e.g., radio, TV, mailings, and signs) and intensive training (e.g., workshops, consultations, and guidebooks) have been shown to be the most effective methods of homeowner education [28]. Media and television campaigns have a lower cost at several cents per resident influenced, but also a lower response of behavioral change compared to intensive training. Intensive training, on the other hand, is more effective at changing actual home lawn and garden practices but can cost several dollars per resident influenced [9].

Intensive training programs can have a measurable effect on relatively short time scales. A study evaluated the effectiveness of education campaigns to reduce stormwater pollution from a shopping center with 26 small businesses in a 9-ha area [29]. They found a modestly positive result in the eight months of the education program. In a separate study, site assessments at 34 homes in a 6-ha treatment area were combined with a series of workshops for residents [28]. These intensive resident outreach activities over the course of 22 months resulted in a significant effect of outreach on both behavior and water quality. Although both studies demonstrated the positive effect of outreach over a short period, their scope was quite small. While no cost estimate was provided in either study, the expense and effort required to scale up their methods would be sizeable, limiting feasibility for larger areas. It is important to continue to monitor results of outreach and education campaigns, both on behavior and on water quality and quantity parameters, to determine the efficacy before continuing to use those same methods.

To evaluate the effectiveness of education and outreach campaigns on self-reported adoption of BMPs, we conducted resident surveys before and after BMP outreach campaigns. In addition, to determine whether the quality and quantity of water draining from the study areas reflected self-reported behaviors, water sampling was done before and throughout the BMP outreach campaigns. We addressed the following questions:

1. How did education and outreach change self-reported behavior and adoption of BMPs?
2. Do water quality and quantity measurements reflect self-reported behavior, including changes due to outreach?
3. Does the method of outreach have an effect on BMP adoption?

2. Materials and Methods

2.1. Site Delineation and Characterization

To address our research questions, we implemented a paired watershed study [30]. Urban residential lands can be delineated into watersheds using topography. However, drainage infrastructure must be considered, as this infrastructure can route water differently than topography. "Drainsheds", therefore, combine both topography and infrastructure into their delineation. We used drainshed areas in this study in which a single outfall pipe collected all surface runoff. These storm drain outfalls were easily accessible such that water samples could be collected directly from the outfall pipe before the runoff flowed into a stream, detention basin, or pond.

Residential drainsheds were selected using existing GIS databases, maps containing parcel-level information, census data, hydrologic maps, aerial photography, and storm drainage infrastructure. A total of 8 drainsheds were identified for use—4 in Northern California in Sacramento County and 4 in Southern California in Orange County (Figure 1a).



Figure 1. (**a**) The state of California, USA with the orange polygon indicating the location of Sacramento County in the north and Orange County in the south; (**b**) a visual of one of the residential drainsheds outlined in red. Red dots indicated inlets to the drainage network and yellow dots the outlets. Within the drainshed, homes shaded green were constructed in 2000, those shaded yellow were constructed in 2001, and the red-shaded homes were constructed in 2002; (**c**) equipment box above an outfall pipe and an autosampler pick-up tube in the pipe.

The drainsheds were comprised solely of single-family residential land-use, but also contained small parks or other communal areas. The drainsheds contained between 152 and 460 houses (Table 1) that were built between 1986 and 2003 (Figure 1b). The average parcel size among the 4 drainsheds in Sacramento County ranged from 568 m^2 to 834 m^2 and in Orange County from 476 m^2 to 1174 m^2. A greater difference among drainsheds was found in median household income levels between Sacramento and Orange County. The median household income of drainsheds in Sacramento County ranged from USD 60,063 to USD 90,466 and from USD 105,167 to USD 117,572 in Orange County [20]. All drainsheds had one outfall pipe which ranged in diameter from 0.76–1.22 m in Sacramento County and 1.07–1.52 m in Orange County (Figure 1c).

Table 1. The number of homes surveyed in each of the study drainsheds—4 in Sacramento County and 4 in Orange County.

Sacramento County	# Homes in Study Site	Orange County	# Homes in Study Site
Antelope (AT)	337	Aliso Viejo (AV)	307
Folsom 1 (F1)	188	Laguna Niguel (LN8)	243
Folsom 2 (F2)	158	Laguna Niguel 9 (LN9)	449
Natomas (NA)	168	San Juan Capistrano (SJ)	155
Total	944		1154

Two of the drainsheds in each county were selected as "treatments" and two as "controls". The treatment drainsheds received outreach developed by this project, whereas the control drainsheds did not. The experiment was conducted in Northern and Southern California in order to determine how differences in climate and outreach activities influence behavior and potential changes in water quality and quantity. Orange County, in Southern California, has a longer gardening season with an average annual temperature of 18.1 °C, which is higher than the average annual temperature for Sacramento County (16.8 °C) in Northern California over the same time period (1931–2014) [31]. In addition, over the same span of years, Orange County receives lower average annual precipitation (34.5 cm) than Sacramento County (51.8 cm), which may lead to greater water use in the landscape. During both years of the study, 2007 and 2008, precipitation was lower than average, and temperatures were higher than average (Table 2) [31]. Year two of the study had lower precipitation and higher temperatures than year one.

Table 2. Total precipitation and average temperature during the two years of the study. Climate data are calculated based on the water year (e.g., October–September).

		Year 1	Year 2
Sacramento County	Precipitation (cm)	46.2	33.8
	Temperature (°C)	16.6	16.9
Orange County	Precipitation (cm)	17.0	14.8
	Temperature (°C)	17.7	18.1

2.2. Outreach Activities

An extensive outreach program was launched in early 2007. Outreach was conducted by the University of California Cooperative Extension (UCCE) Master Gardeners, who received approximately 15 h of training on topics including watershed science and water efficient landscape design, irrigation methods and timing, plant and hardscape selection, less pesticide intensive pest management, and the impact of pollutants on water quality [32]. Training and outreach content focused on the four BMP categories—reducing use of garden chemicals, reducing ant control pesticides, modifying irrigation systems, and adopting other features to reduce runoff.

Participants in all outreach activities received the same written materials. These included a set of "quick-tip" cards and a quarterly project newsletter developed by the project team and the University of California Statewide Integrated Pest Management Program (UC IPM) that addressed landscape design and water quality, watering, and fertilization of landscape plants—including lawns, ant and lawn insect management, and safe use and disposal of garden chemicals. The type of outreach event, however, differed between Sacramento and Orange County as described below. It was intended that each location would receive the alternate approach in the following year. However, due to state budget cuts, the outreach efforts were discontinued after the first year creating a confounding effect between location and outreach methodology. Despite not being completed as planned, the outreach activities were extensive and more ambitious than generally conducted, e.g., [11].

In Orange County, outreach activities were conducted on individual residential parcels. Four homes within each treatment drainshed were selected as demonstration homes. These homes received a landscape assessment completed by the Master Gardeners, which provided personalized suggestions on how to improve the design of their specific landscape and incorporate management practices to reduce chemical and water use and reduce runoff. In return, each of the residents allowed their driveways to be used for an outreach workshop. Immediate neighbors were invited to attend these "cul-de-sac" events. These events grew via word of mouth and, though only immediate neighbors were invited, the largest event had 15 drainshed residents in attendance. The Master Gardeners were available to answer gardening questions and disseminate the outreach materials. In addition, residents were directed to a project website for additional information and invited to visit BMP demonstration landscapes at the UC Agriculture and Natural Resources' South Coast Research and Extension Center (Irvine, CA, USA) where they could tour targeted BMPs [32].

In contrast, the outreach events in Sacramento County had a broader focus and attendance to these events was offered to all the residents within the treatment drainsheds. Events took place at neighborhood parks and consisted of informational tables with the outreach materials and informal presentations hosted by Master Gardeners, UC IPM, and other Cooperative Extension and local agency personnel. Topics focused on the program BMPs: reducing use of garden chemicals, less toxic management of ants and other pests, irrigation management, and ways to reduce runoff.

2.3. Best Management Practices Survey

In August of 2007, residents of the drainshed neighborhoods in both Orange and Sacramento Counties were surveyed to assess their awareness of the four targeted BMPs prior to any outreach activities (Appendix A). Doorhanger flyers with an attached survey were distributed to every house in the eight study drainsheds, and a prize incentive was used to encourage participation. Residents were asked to stamp and mail the survey back. After a few weeks, postcard reminders were mailed. Due to continued poor response to the mail-back surveys, door-to-door surveying was implemented to increase response rates. The survey consisted of questions about pesticide and garden chemical use, as well as other yard care practices such as irrigation and design features that reduce runoff. The initial survey in 2007 provided a baseline for the landscape practices employed by residents in the study area and allowed characterization of the drainshed and development of priorities for outreach.

A second survey was conducted in fall 2008, in an attempt to determine whether the year of outreach resulted in increased knowledge of BMPs compared to the control sites that did not receive outreach. The same individuals did not necessarily complete the survey in both years; we used a population approach by sampling a representative subsample of the residents in the study areas. The 2008 survey was mailed to all residents, asking them to answer the survey online or mail back the completed form, which already included postage. Because of the success of door-to-door survey collection, this method was again employed a few weeks after the initial mailing. We again offered an incentive prize to encourage participation. Survey questions from year one were modified slightly, but still enabled comparison of responses between years.

The survey consisted of 15 questions, and they were phrased to capture information on BMP awareness and use (Appendix A). In the first year (2007) seven of the questions were related to use of garden chemicals, and these questions asked about frequency of fertilizer and pesticide application, types of fertilizers used, and pesticide application practices. Of these questions, two of them asked specifically about use of ant control measures. One asked which methods the residents used to control ants on their property with a checklist of practices. The other asked whether residents or pest control professionals applied ant control pesticides around the perimeter of the house or on hardscapes. Two questions were asked about irrigation systems and watering habits. One asked what time of day the residents watered their lawn or landscape and the other listed several types of irrigation

controllers and asked whether the respondents had either heard of these or had used them. Two more questions asked about features designed to reduce runoff. The first listed several water conservation BMPs and asked whether the resident had heard of and/or used any of them. The second question asked specifically whether the resident had made any changes to their landscape in the last year to reduce runoff. In addition, one question asked whether respondents maintained their own landscape or whether it was maintained by a professional and one question asked whether respondents were aware of hazardous household waste disposal services.

2.4. Water Quality and Quantity Sampling

Sensors situated inside the outfall pipe continuously collected runoff measurements including water velocity, water depth, pH, temperature, and electrical conductivity. Data were logged using Hach Sigma 950 Flow Meter data loggers. During the dry season, runoff was collected weekly to monthly as grab samples by UC personnel with the assistance of Master Gardeners in Northern California. Storm samples were collected from inside the outfall pipe or at the opening using Hach Sigma 900 Max autosamplers. Samples from Sacramento County were packed on ice and shipped overnight to UC Riverside for analysis of nutrient and pesticide constituents. Samples collected from Orange County were transported on ice directly to UC Riverside. For a more complete description of water quality and quantity sampling please see [13].

2.5. Data Analysis

We compared treatment drainsheds to control drainsheds before and after the outreach activities. The variation in responses from year one to year two indicated whether there was a reduction, an increase, or no change in awareness and use. Sacramento and Orange County were first analyzed together and then the counties were analyzed individually (Part I of Tables 3, 4, 6 and 7). We then considered the impact of treatment by comparing results before and after the activities, again first analyzing the counties together and then analyzing them separately (Part II of Tables 3, 4, 6 and 7). The same was done for drainsheds receiving no outreach (Part III of Tables 3, 4, 6 and 7).

The survey(s) consisted of three distinct question formats. The first format was yes or no questions. These questions had four response options: yes, no, I don't know, and decline to state. Frequencies of response options were calculated and distributions were compared using a Kruskal–Wallis analysis of variance. The second format contained a checklist with several response options and asked respondents to choose one or more. For analysis of the question related to ant control measures, the options were divided into chemical/pesticide and non-chemical/pesticide, and frequencies were compared with a Kruskal–Wallis test. Another checklist style question addressed types of fertilizers. More fertilizer types were listed in the question than discussed in the BMP outreach materials. Only the fertilizer types discussed in the BMP outreach materials were analyzed (slow release and organic). Responses were coded into yes or no for each type, and frequencies were analyzed using a Kruskal–Wallis test. Within this question format, there were two questions with a slightly different structure. One related to irrigation BMPs and the other related to additional BMPs included in the outreach materials. These two questions had two separate checklists, one asking whether the respondent had heard of the BMP and the second asking whether they had used it. For the irrigation question, since all options on the list are BMPs, responses about each irrigation type were not analyzed individually. If the respondent had heard of and/or used any of the irrigation systems, their response was marked as yes. In the other questions, all practices mentioned were analyzed individually. The third question format was also a checklist, but respondents were asked to choose only one option. Two of the questions related to garden chemical use asked about frequency of application for pesticides and fertilizers, respectively. Responses to these questions were coded and ranked, with "not at all" ranked as one and each successive category ranked

one higher. Mean rank was calculated, and a Kruskal–Wallis test was used to compare the distribution of ranks. For the full text of survey questions, see Appendix A.

All water quality and quantity data are reported based on a water year (October–September). Nutrient and pesticide concentrations below detection limits were replaced with method detection limits and the annual average was calculated for the water year. Flow measurements were recorded on a continuous basis every two minutes for the duration of the study. Measurements with negative values, zero values (when corresponding velocity was >0), and those which exceeded the maximum flow of the outfall pipe were discarded. Remaining values were averaged over the water year. Annual average flow and constituent concentrations were used to calculate the annual average load of each constituent. Although the calculations used to obtain these measures are somewhat crude, our purpose was to compare treatment and control drainsheds and compare geographic regions; these measures are not intended to accurately describe water quality and quantity in and of themselves. For a more comprehensive analysis of water quality parameters, see [13].

3. Results

The 8 drainsheds encompassed 2098 homes. In 2007, 21.9% (460 homes) responded to the survey and in 2008, 26.4% (553 homes) responded (Table 1). Results in the tables are organized by comparisons before and after outreach such that treatment and control drainsheds are compared between years and regions, followed by comparisons between years and regions among treatment drainsheds and among control drainsheds.

3.1. Survey

3.1.1. Reducing Use of Garden Chemicals

For both years, about 82% of respondents had used fertilizers and/or pesticides in the last year. Just under 30% of respondents said they actually measured how much product they were using, while about 40% said they estimated. Slightly more than 40% of respondents said that fertilizer or pesticide granules sometimes spilled onto paving or hard surfaces when they were using them, and 17% said they washed these granules down storm drains or left them on hard surfaces instead of sweeping them back into the landscape.

When treatment and control sites were compared grouping both Sacramento and Orange Counties together, the only significant changes from before outreach to after were in the treatment drainsheds (Table 3, Part 1). Residents in the treatment drainsheds reported a decrease in use of slow-release fertilizer and an increase in the use of any fertilizer or pesticides on their landscapes in the past year.

In Sacramento County, treatment drainsheds showed a significant increase in the proportion of residents who reported using pesticides and/or fertilizers on their landscapes and there was a significant increase in the proportion of residents who reported using slow-release and compost fertilizers. In addition, there was a significant decrease in the frequency of pesticide application. In Orange County, treatment drainsheds showed a significant difference in the proportion of residents who measure vs. estimate when using fertilizer with a significant decrease from year one to year two in respondents that measured. (Table 3, Part II).

Significant changes were also seen in the control drainsheds between the two years of the study. Sacramento County control sites showed a significant decrease in use of slow-release fertilizer between year one and two. In Orange County, the control drainsheds showed a significant decrease in frequency of pesticide application between years (Table 3, Part III).

Table 3. Percent change in use of garden chemicals from before outreach to after outreach. Significant increase in use shown in red and significant decrease shown in blue. A zero indicates no significant change. * indicates $p < 0.05$ and ** indicates $p < 0.01$. Question number is included in column headings, see Appendix A for survey questions.

	Use of Garden Chemicals					
	Use of Pesticides or Fertilizers	**Pesticide Application Frequency**	**Fertilizer Application Frequency**	**Measuring Fertilizer**	**Slow Release Fertilizer**	**Compost**
I. Treatment vs. Control *	#5	#7	#8	#9	#11D	#15G
Sacramento and Orange	13.9 **	0	0	0	19.3 *	0
Sacramento	9.7 *	0	0	25.6 *	23.6 *	14.7 *
Orange	0	0	0	0	0	4.7 *
II. Treatment drainsheds only						
Sacramento and Orange	0	0	0	0	0	0
Sacramento	10.1 *	21.9 *	0	0	82.0 *	9.0 *
Orange	0	0	0	35.2 *	0	0
III. Control drainsheds only						
Sacramento and Orange	0	0	0	0	0	0
Sacramento	0	0	0	0	66.4 *	0
Orange	0	4.9 *	0	0	0	0

3.1.2. Reducing ant Control Pesticides

When asked about ant control measures, 87% of respondents said they used one or more methods. Just over 80% used a chemical or pesticide method, while 17% used a non-pesticide method. A total of 56% of respondents stated that they or their pest control company used perimeter sprays on hard surfaces as an ant control method.

The only significant change before and after the outreach activities for either of the questions relating to ant control were in the control drainsheds within each county. In Sacramento County, the control drainsheds showed a significant increase in both the use of chemical methods of ant control and the use of pesticides on hardscapes (Table 4, Part III). In Orange County, for both treatment and control neighborhoods, there was a noticeable decrease in the proportion of respondents who answered "yes" (and a corresponding increase in "no" responses) to the question about application to hardscapes after the outreach. However, the change was only significant for the control drainsheds.

Table 4. Percent change in use of ant pesticides from before outreach to after outreach. Significant decrease shown in blue. A zero indicates no significant change. * indicates $p < 0.05$. Question number is included in column headings, see Appendix A for survey questions.

	Use of Ant Pesticides	
	Chemical Methods	**Perimeter Sprays/Application to Hard Surfaces**
I. Treatment vs. Control *	#3	#4
Sacramento and Orange	0	0
Sacramento	0	0
Orange	0	0
II. Treatment drainsheds only		
Sacramento and Orange	0	0
Sacramento	0	0
Orange	0	0
III. Control drainsheds only		
Sacramento and Orange	0	0
Sacramento	0	0
Orange	0	31.0 *

3.1.3. Modification of Irrigation Systems and Behavior to Reduce Runoff

A total of 89% of homes had sprinkler timers, while 50% used drip irrigation, and less than 10% used rotor heads, smart controllers, soil moisture sensors or "can tests" to schedule watering. Following outreach, there were no significant differences between control and treatment drainsheds in the proportion of respondents who had heard of or used BMP irrigation for either of the counties. However, the proportion of residents who claim to use one or more of these irrigation systems was already quite high, with self-reported use ranging from 88–92%. When Sacramento and Orange County were analyzed separately, the strongest result ($p = 0.06$) was in the timing of watering in Orange County treatment sites following outreach such that there was an increase in the proportion of respondents watering during the coolest time of the day (Table 5, Part I).

Table 5. Percent change in modification of irrigation practices from before outreach to after outreach. Significant increase in modification shown in red. A zero indicates no significant change. * indicates $p < 0.05$. Question number is included in column headings, see Appendix A for survey questions.

	Modifying Irrigation Practices	
	Timing of Watering	**Heard of/Use Water Saving Irrigation Tools**
I. Treatment vs. Control *	#12	#13H
Sacramento and Orange	0	0
Sacramento	0	0
Orange	12.9 * (12 a.m.–8 a.m.)	0
II. Treatment drainsheds only		
Sacramento and Orange	0	0
Sacramento	0	0
Orange	9.4 * (12 a.m.–8 a.m.)	0
III. Control drainsheds only		
Sacramento and Orange	0	0
Sacramento	0	0
Orange	0	0

3.1.4. Adoption of Features to Reduce Runoff

Few of the respondent's gardens included design features to reduce runoff. Less than 10% incorporated terracing, French drains, swales or buffers, slotted pavers, or permeable paving. Mulch was a component of about 45% of landscapes and just over 30% used compost. Results showed a slight increase in the proportion of people who reported making changes to reduce runoff in the treatment neighborhoods, however the change was not significant for any of the analyses (Parts I, II, and III, Table 6). In many of the analyses, there was a significant increase in the proportion of respondents who have heard of and/or used runoff reduction features. A complete list of these results is in Table 6.

Table 6. Percent change in awareness or use of water reduction features from before outreach to after outreach. Significant increase in awareness or use shown in red. A zero indicates no significant change. * indicates $p < 0.05$ and ** indicates $p < 0.01$. Question number is included in column headings, see Appendix A for survey questions.

	Runoff Reduction Features	
	Implemented Changes	**Heard of/Use Features**
I. Treatment vs. Control *	#14	#15
Sacramento and Orange	0	0
Sacramento	0	Use of use terracing (72.9 *) and mulch (25.5 *)
Orange	0	Heard of French drains (24.5 *) and swales/buffers (19.4 *); Use slotted pavers (88.8 *)
II. Treatment drainsheds only		
Sacramento and Orange	0	Heard of mulching (25.1 **) and slotted pavers (75.4 **)
Sacramento	0	0
Orange	0	Heard of slotted pavers (103.3 *)
III. Control drainsheds only		
Sacramento and Orange	0	Heard of mulch (13.6 *) and slotted pavers (47.6 *); Use slotted pavers (155.4 *), terracing (119.8 *), and French drains (59.9 *)
Sacramento	0	Heard of French drains (53.8 *), swales/buffers (289.6 *), mulch (38.8 *), and slotted pavers (112.8 *)
Orange	0	Use terracing (151.9 **) and slotted pavers (718.1 *)

3.2. Water Quality and Quantity

3.2.1. Nutrients

When Sacramento and Orange County were grouped together, and treatment and control drainsheds were compared, nitrate and total N concentrations in drainshed runoff were significantly lower from the treatment drainsheds following outreach (Table 7, Part I). However, neither county individually showed significant change in the concentration of nitrate or total N in runoff following outreach. Despite neither county showing a significant change from before to after treatment, (inherent) differences in the two counties, such as lower nitrate and total N in Orange County, may account for the significant decrease noted when the counties are grouped. Concentrations of phosphate and total phosphorus in runoff showed no change when control and treatment drainsheds were compared.

Comparisons were also made within the control and treatment groups, with Sacramento and Orange County grouped and also separated. In the grouped analyses, differences in nitrate concentrations were non-significant, while differences in total N concentrations were significantly lower for treatment drainsheds, but non-significant for controls. Comparisons of phosphate concentrations showed no significant differences for treatment drainsheds but did show significant differences between years for control drainsheds, while total phosphorus concentration had the opposite pattern (Table 7 Part II and III).

In Orange County, differences in nitrate concentrations before and after the outreach were non-significant for both treatments (outreach) and controls, while differences in total nitrogen concentrations were significantly decreased for treatments, but non-significant in controls. Differences in phosphate concentrations were non-significant for treatments, but were significantly increased for control sites, while differences in total phosphorus were significantly decreased for treatments, but non-significant for controls. In Sacramento County, differences in nitrate concentrations were non-significant for both controls and treatments, while differences in total nitrogen concentrations were significantly decreased

for both controls and treatments. Differences in phosphate concentrations were non-significant for both treatment and control sites, while comparisons of total phosphorus concentrations showed significant decreases in treatments sites, but not in controls (Table 7 Part II and III).

Table 7. Percent change in nutrient concentrations in runoff from before outreach to after outreach. Significant increase in use shown in red and significant decrease shown in blue. A zero indicates no significant change. * indicates $p < 0.05$.

	Nitrate	Total Nitrogen	Phosphate	Total Phosphorus
I. Treatment vs. Control *				
Sacramento and Orange	18.0 *	28.0 *	0	0
Sacramento	0	0	0	0
Orange	0	0	0	0
II. Treatment drainsheds only				
Sacramento and Orange	0	16.3 *	0	35.4 *
Sacramento	0	29.6 *	0	30.2 *
Orange	0	16.0 *	0	40.8 *
III. Control drainsheds only				
Sacramento and Orange	0	0	111.7 *	0
Sacramento	0	24.0 *	0	0
Orange	0	0	125.9 *	0

3.2.2. Pesticides

When treatment and control drainsheds were compared with Sacramento and Orange County grouped together, differences were non-significant for all pesticides, however, cis-permethrin tended ($p = 0.059$) to be higher following outreach. In Sacramento County, no change was indicated for any of the pesticides (Table 8, Part I). For diazinon, chlorpyrifos, fipronil, cis-permethrin, and trans-permethrin, differences between control and treatments sites were either non-significant or were significant in both years, showing no change with outreach. Differences in concentrations of bifenthrin and cypermethrin between control and treatment were significant the first year and non-significant the second year. In Orange County, differences between control and treatments were either non-significant or showed no change for either year. Differences in concentrations of chlorpyrifos and cypermethrin between treatment and control drainsheds were statistically non-significant in the first year and significantly higher in the treatment drainshed runoff in the second year.

When comparisons within control and treatment drainsheds were made before and after outreach, and Sacramento and Orange County were grouped together, results for diazinon, fipronil, and trans-permethrin were all non-significant for both treatment and control drainsheds. Following outreach, runoff from the treatment drainsheds had significantly greater concentrations of cis-permethrin and significantly lower concentrations of bifenthrin. Runoff from the control drainsheds following outreach had significantly higher concentrations of bifenthrin and significantly lower concentrations of chlorpyrifos (Table 8).

In Sacramento County differences between years were non-significant for both treatment and control for all pesticides except cis-permethrin, which was significantly higher in runoff from treatment drainsheds. In Orange County, fipronil significantly increased and cis-permethrin significantly decreased in runoff from treatment drainsheds; no change was found in any other pesticide concentration from either treatment or control drainsheds.

Table 8. Percent change in pesticide concentrations in runoff from before outreach to after outreach. Significant increase in use shown in red and significant decrease shown in blue. A zero indicates no significant change. * indicates $p < 0.05$.

	Fipronil	Bifenthrin	Cis-permethrin	Trans-permethrin	Cypermethrin	Chlorpyrifos	Diazinon
I. Treatment vs. Control *							
Sacramento and Orange	0	0	0	0	0	0	0
Sacramento	0	0	0	0	0	0	0
Orange	0	0	0	0	373.7 *	121.8 *	0
II. Treatment drainsheds only							
Sacramento and Orange	0	32.1 *	167.9 *	0	0	0	0
Sacramento	0	0	121.9 *	0	0	0	0
Orange	56.1 *	0	170.6 *	0	0	0	0
III. Control drainsheds only							
Sacramento and Orange	0	17.2 *	0	0	0	63.9 *	0
Sacramento	0	0	0	0	0	0	0
Orange	0	0	0	0	0	0	0

3.2.3. Flow, Loading, and Concentration

Flow measurements showed an increase in runoff, though not significant, in both treatment and control drainsheds from year one to year two. The magnitude of the increase was slightly less in the treatment drainsheds (Figure 2). This increase in flow in year two in part accounts for the large differences in concentration vs. load for nitrate and phosphate. The magnitude of this increase overwhelms any differences in the concentration data; therefore, no significant results were found in load values for any nutrients and pesticides when analyzed in the same way as the concentration data.

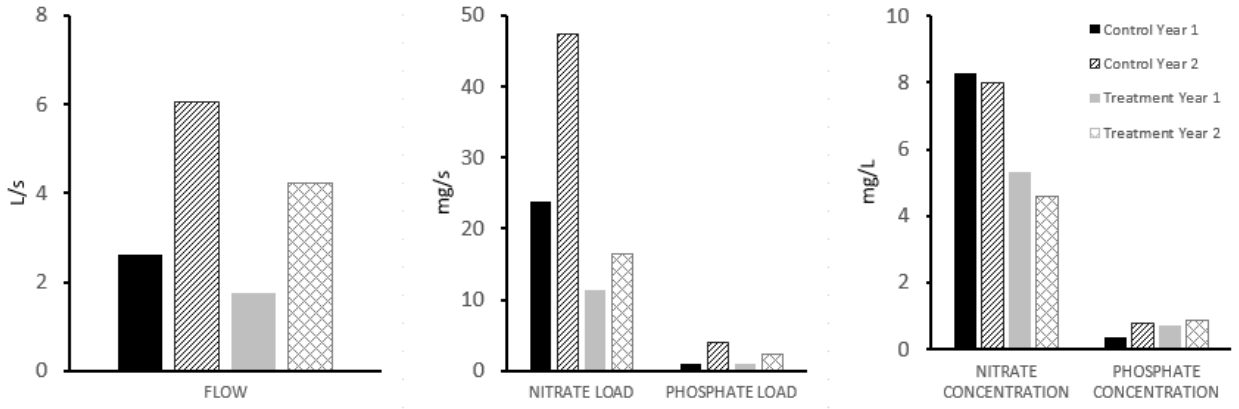


Figure 2. Comparison of concentration vs. load for nitrate and phosphate for all treatment and control drainsheds in year one and year two. Nitrate and phosphate were used to demonstrate the effect of flow, but all nutrients and pesticides followed the same pattern.

4. Discussion

For each of the four BMP categories, our outreach program produced little to no effect in either self-reported behaviors or in water quality and quantity measurements. Comparisons within Sacramento County and within Orange County showed no difference between control and treatment drainsheds before and after outreach for frequency of fertilizer use, type of fertilizer used, or whether or not fertilizers were measured before application. Since use of slow-release fertilizer is a BMP that was encouraged by the outreach campaign, we would have expected an increase in its use in treatment drainsheds rather than a decrease. An increase, however, was only found in one of the counties.

Survey results showed a slight increase in the proportion of people who reported making changes to reduce runoff in the treatment neighborhoods, however the change was not significant, nor were the proportions significantly different from the control neighborhoods in either region. Based on these results, we would expect no changes to water quantity, and yet there were increases in flow. In addition, overall rainfall during the second year of the study was lower. Increases in flow may be due to residents overcompensating for the lower rainfall by irrigating more than in the previous year. If they had made few to no changes in their landscape to reduce runoff, this increased irrigation would lead to increased runoff.

Water quality data showed variability in change of concentrations of ant-control pesticides in all drainsheds. This pattern is consistent with survey answers, which showed increases, decreases and no change in ant control pesticide use, particularly on hardscapes. Increases in flow caused the loading of all nutrients and pesticides to increase. For example, nitrate concentration showed a significant decrease in treatment drainsheds from year one to year two despite the load calculation indicating an increase. This result highlights the importance of examining loading in addition to concentration when evaluating changes in water quality, and failure to do so may lead to different conclusions. Using changes in concentration as evidence of outreach success should be approached with caution. Even when behavioral changes lead to reduced concentrations of nutrients or pesticides, using more water can increase runoff that transports more of those nutrients and pesticides into the system.

Given the time, effort, and expense of an intensive outreach and monitoring program such as this, we would expect a measurable effect in behavior, water quantity/quality, or both. Public education and outreach measures have been required since 1999 as part of Phase II of the Clean Water Act [33]. This legislation requires that all Municipal Separate Storm Sewer Systems (MS4s) have a storm water management plan that includes outreach and public education about strategies to reduce runoff and non-point source pollution [33]. Despite the ubiquity of public outreach and education campaigns, results are variable and based primarily on self-reported behavioral changes with little to no measurable water quality results to back them up [11,27]. Such outcomes suggest that some crucial element or elements are missing from these standard approaches [34].

One element that may not be properly addressed is the potential lag time between outreach and education and changes in behavior. Water quality measurements may not capture potential changes because they are taking place too soon after education and (1) there is residual product in the system even after behavior changes, (2) residents have remaining yard care products they want to use up before making changes, or (3) some changes, especially structural changes, may take longer to enact because of expense and/or the need to hire professionals. For example, organophosphates, such as diazinon and chlorpyrifos, were banned from residential use by 2004 but were still detected in our study in 63% and 50%, respectively, of water samples in the Sacramento County, and 93% and 95%, respectively, of water samples in Orange County [13,20].

Alternatively, outreach may be having an undetectable effect. This may be due to the "population approach" that was taken in the surveys. Change in knowledge and behavior was only assessed at the neighborhood level, not at the individual household level. In addition, resident awareness may need to reach a threshold before enough behavioral change occurs to be measurable and significant. This may be because individuals require repetition of information before adopting new behaviors. Our results, after one year, showed increases in respondent awareness of some BMPs (Table 4) but not necessarily implementation. Past research on storm water education and management in rural areas has shown that behavior changes can require 7–10 years of efforts to have a measurable effect [35] as cited in [10]. This threshold may also be caused by the need for a critical mass of people to adopt new behaviors in order for change to be detected. It has been suggested that one of the greatest challenges faced by water quality managers is simply the sheer number of people whose attitudes and behaviors must be altered [9]. Based on 1999 populations, [9] estimated that 35% of the US population over-fertilizes, while

40% use sprayed pesticides. There may be a tipping point that needs to be reached but it may be able to happen more organically rather than via continued intensive outreach. Conforming to neighborhood norms is important to residents and they get much of their information and ideas, directly or indirectly, about yard care from their friends and neighbors [34,36,37].

Given these results, an obvious question to ask is: "is there a better way to achieve the ultimate goal of reduced NPS pollution?" Swann [9] advocates a mixed methods approach involving media, ideally public service announcements on television, in combination with intensive training. Television ads have the potential to reach the largest audience, at a fraction of the cost of intensive training, and although there is high recall by viewers of television messages, intensive training is more likely to cause a change in behavior [9]. Because intensive training has been shown to produce the highest rates (10–20%) of actual behavior change, these approaches could be expanded in scope and depth [10]. However, intensive training methods are also the most expensive. The costs in materials, time, and personnel associated with these methods may be beyond the range of possibility for some agencies, municipalities, or organizations. In such cases, collaboration between organizations may be necessary to achieve the desired outcomes.

It is possible that outreach and education alone is insufficient to elicit significant change and that a more regulatory approach is needed [38]. Lehman et al. [39] showed a significant reduction in total phosphorus loading following enactment of a restriction on phosphorus fertilizer. They noted that this ordinance was part of a larger pollution reduction effort that included a campaign to educate homeowners about the consequences of yard waste discharge into storm drains. Therefore, the effects can be attributed neither solely to the ordinance nor to the education; instead, they appear to be a result of both. Galvin [11] also reviews several instances where years of education and outreach had a minimal effect, but nearly complete compliance with regulations was almost immediate and suggests that an increased awareness of the issues due to the education and outreach had paved the way for the success of the regulatory measures.

An additional option is to take action at a level above the resident, specifically, the lawn care/landscaping industry and retail nursery and garden center employees. Residents rely heavily on labels and store attendants for lawn and landscaping care information [9]. Therefore, enlisting home and garden retailers in the promotion of less polluting behavior and adoption of BMPs could have a significant impact on reducing NPS pollution. A crucial part of this strategy is substitution of currently available chemical products with more environmentally friendly, less toxic, products so that retailers still have incentive to promote them [9]. Training employees in proper use of lawn and garden products may also be an important component of disseminating this information.

5. Conclusions

Urban non-point source pollution must be reduced or there will be dire consequences for water quality and the health of aquatic organisms. Resident education which leads to changes in landscape management behavior and BMP adoption is a potential solution. However, most education and outreach campaigns—including ours—have small and varied effects on changing landscape management behavior [27]. In addition, very few actually attempt to correlate education and behavioral changes with any kind of water quantity or quality measurements (but see [28,40]). Because public education and outreach is mandated at part of the Clean Water Act, we must continue these efforts. Therefore, for environmental as well as financial reasons, finding/developing more efficacious methods will be necessary. Greater success has been shown by those campaigns that use mixed methods approaches, either different types of outreach or outreach in combination with regulation [11,27,38,41]. Costs of education and outreach may be prohibitive if campaigns and/or monitoring is done continuously. Success rates would possibly be improved if education and outreach programs took a long(er) range planning approach; monitoring or resurveying after 5 and/or 10 years rather than yearly or after 1–2 years. Our results

suggest that on short time scales, the method of outreach may not have a significant effect. This supports the idea that longer time frames are needed in general and that perhaps differences between methodologies would become evident.

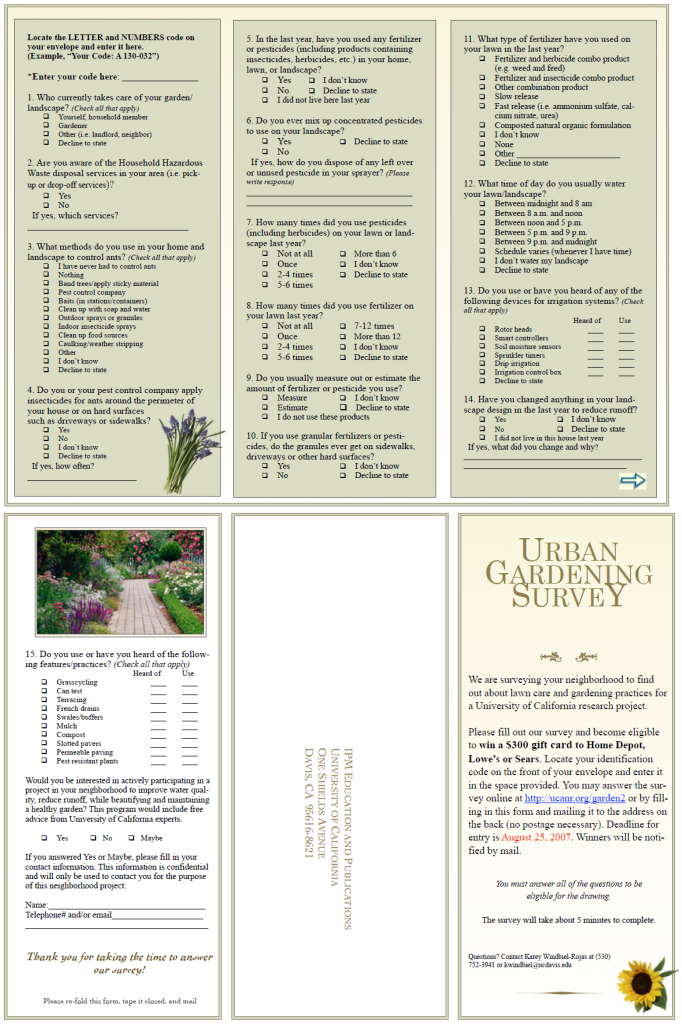
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Appendix A. Survey Instrument



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