Evaluating the Effects of Turf-Replacement Programs in Los Angeles County

The Metropolitan Water District of Southern California's Incentive Program Since 2015

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Executive Summary

In 2014, the Metropolitan Water District of Southern California (MWD) undertook an unprecedented investment to incentive turf replacement throughout Southern California in response to the state's serious drought. MWD devoted $350 million to the program, resulting in more than 46,000 rebate payments to remove 165 million square feet of turf. The funding boost served as a tremendous natural experiment to better understand the effects turf replacement programs.

As part of an evaluation of this program, UCLA and the University of Utah examined socio-economic and demographic characteristics of program participation and assessed changes in vegetation and landscapes of front yards resulting from turf replacement. We examined address-level records of 24,921 participants who applied for turf replacement rebates between February 2014 and April 2016 in Los Angeles (LA) County. We analyzed the socioeconomic and spatial determinants of program participation. Further, we used *Google Earth Street View* to characterize the landscapes and plants resulting from turf replacement based on a set of randomly selected participating properties. We ascertained the types of turf replacements that were installed and developed a classification system for landscape design types.

The research, which we conducted between 2015 and 2017, yielded significant findings:

- In front yards of surveyed properties, seventy percent of sampled homes had completely removed turf, while 11% had partially removed turf. Nineteen percent had no visible turf removal from available imagery, which did not capture turf replacement approved in side or back yards.
- The majority of front yards contained no turf. Multiple land cover types following replacement. Several categories of plants were found in completed projects, including shrubs, trees, succulents, perennial herbs, and grasses.
- Properties replaced turf with either one or several types of land cover. The number of properties undertaking each option was approximately equal.
- The City of Los Angeles, which offered a significant supplemental rebate, constituted more than 80% of program participants in the County of Los Angeles (our study zone) during the period.
- Participation rate in a utility service area was found to be a useful metric for statistical analysis.
- The range of participation rates across LA County retailers, calculated as the number of participating properties in a retailer divided by the total connections, varied from 0.2% to 3.0%.
- Supplemental rebates by local retailers likely results in higher rates of participation in LADWP territory. But supplemental rebates did not consistently yield higher participation across retailers.
- Participation rates were positively correlated with higher rates of home ownership and negatively correlated with median income.
- Evidence of "neighborhood effects" and spatial clustering of projects exists.
- A longitudinal study is required to assess long-term water savings and biodiversity effects from turf replacement incentives in Southern California.
- Backyard turf replacements need to be studied to fully assess the success of the turf replacement program and the categories and types of land cover utilized.

Introduction

In 2014, the Metropolitan Water District of Southern California (MWD) implemented the largest single investment to date in turf replacement for Southern California in response to the state's serious drought. Urban areas in California use approximately 20% of the state's developed water supply, but over half of urban water consumption in the residential sector is used for outdoor irrigation (Hanak and Davis, 2006). Like many places across the country, lawns are dominant landscapes in many California residential neighborhoods. But in California's highly seasonal climate, with long periods of little to no precipitation, preserving such landscapes requires significant summertime irrigation. As a result, reducing outdoor water use was a predominant response to drought for water utilities across the state (Mitchell et al., 2017). But incentive programs increasingly look to change landscapes and resident behavior to achieve long-term water savings rather than just short-term reductions (Office of the Governor of California, 2016).

This report describes results of a yearlong investigation into the adoption habits and landscape effects of recent MWD turf replacement investments. The research sought to answer two questions:

1) What was the impact of the MWD turf replacement incentive program on landscapes in front yards?
2) What, if any, differences in participation existed among socio-demographic groups?

Why Turf Replacement?

Turf replacement or turf rebate programs focus on removing turf from residential and commercial properties to reduce water consumption. Cities across the arid Western U.S. built significant water conveyance systems to support urban life and landscapes that needed more water than was typically available from local supplies. With population growth and increasing competing uses for water, Phoenix, Las Vegas, Tucson, Albuquerque and others now look to turf replacement as a way to achieve long-term reductions in water demand while maintaining vibrant and attractive communities (see for example Sovocool et al., 2006). Yet, despite the investments on the part of some water utilities to fund turf replacement, research on the water use and landscape effects of such programs is limited (DeOreo and Mayer, 2012; Mayer et al., 2015). Identifying the drivers of turf replacement within a household is a complicated and multifaceted problem, often requiring significant amounts of data to control for the many variables that influence resident behavior (Mini et al., 2014b, 2014a; Tull et al., 2016).

Turf Replacement in Southern California

Turf removal incentives may be provided at local, regional, or state levels. The availability of monetary incentives is not consistent throughout service areas. In southern California, residents have been able to access local or state funds to support the conversion of existing lawns to water-efficient and drought-tolerant landscapes. Resident access to such programs varies by geography and time period. The Metropolitan Water District of Southern California (MWD), which is the regional water importer serving a

5,200 square mile region and nearly 19 million people, has run the primary regional program. In 2014, MWD approved an ambitious funding effort to incentivize turf replacement in its service territory, devoting $350 million to the program. Over 46,000 rebate payments were given out at $2.00 per square foot. MWD received over 85,000 applications to remove to more than 165 million square feet of turf. By mid-2015, the program funds had been exhausted.

Some agencies within MWD's larger service territory also supplement the MWD rebates or had existing programs. For instance, the Los Angeles Department of Water and Power also provided supplemental turf rebate incentive payments of $1.75 per square foot for 1,500 square feet (Sq. Ft.) maximum. When MWD announced in July of 2015 that the funds were exhausted, some of these cities and agencies continued funding turf replacement at levels below the full MWD amount. For example, Long Beach still funds turf replacement projects at a reduced rate per square foot, despite the lack of available MWD funds.

Understanding Potential Effects

Many Southern California cities have been slow to transition to low-water landscapes, in part due to the region's access to multiple sources of imported water. The boost in program funding from MWD, however, created a unique environment among turf replacement initiatives. Participants had significant freedom to choose their new landscapes, resulting in a diversity of post-replacement landscapes based on participant preferences regarding design, composition, drought-adapted plants, and non-turf land cover types. A comprehensive evaluation of turf replacement habits can help summarize and understand these effects, including important questions such as -- if all participants converted turf to drought resistant landscapes. Another significant potential effect is outdoor water use. To date, no comprehensive analysis of water savings exists that is based on longitudinal water consumption data of program participants for LA County. Finally, there is no data on the floristic composition, species richness, or structure of these new landscapes.

Classifying Urban Landscape Changes

Classification of urban landscapes has traditionally been accomplished using the USGS Anderson classification system (Anderson et al., 1976). This hierarchical system identifies land use land cover types over multi-spatial scales from macro-level classifications (e.g. urban) to micro-level classifications (e.g. artificial turf). The highest resolution land cover types (level 4) contain many categorizations for the United States and Los Angeles County. However, these traditional land cover types may not be appropriate or detailed enough for classifying novel landscape types that were created during the turf replacement program. Although classifications like lawn, artificial turf, and barren exist in the USGS hierarchy, they do not include the percent cover of these high-resolution land cover types and there are novel combinations of land cover created by MWD program participants. Thus, there is a need to ascertain the novel landscapes and types of turf replacements that were installed and to develop a new classification system for these landscape design types, as well as the percent landscape cover of different ground cover types.

Data Availability and Surveying: Front Yards, Back Yards, and Biodiversity

New imagery and remote sensing data have significantly expanded the potential tools available for assessing landscape changes due to events such as the MWD turf replacement program. These vary in cost and accessibility, ranging from *Google* tools that are free and easily accessed to very expensive data sets that can cost $30,000 or more. The resolution of data and the period when it was captured are significant influences on the usefulness of various data sets for evaluating turf replacement.

For this analysis, we identified *Google* tools as the most cost effective option for assessing landscape changes quickly and efficiently. These tools, however, only provide reliable access to images of front yards with sufficient resolution to assess landscape categorizations. The process of quantifying landscape changes in back yards of homes is more complex and expensive. It requires purchasing multiple imagery data sets to characterize changes over time, or a labor-intensive household survey whereby owners provide access to back yards. Each has advantages and disadvantages.

Biodiversity, or the mix of flora and fauna species found within a landscape, is another significant area of uncertainty. Conducting surveys to assess biodiversity is labor-intensive and requires expertise. As such, these are best performed as part of long-term longitudinal analyses, whereby teams of researchers are available for an extended period to gain access to yards, collect and analyze data, and structure surveys to account for differences in annual plant growth. Research initiatives such as the Long Term Ecological Research (LTER) sites for studying urban ecology in Baltimore and Phoenix provide examples of the sorts of studies that cities and water utilities can support to better understand changes in landscapes and their impacts.

Research Objectives and Timeline

This research had several primary research objectives:

1) What, if any, geographic variations existed across the study area in access to turf replacement rebate programs?

2) Did program participants convert turf in their front yards to alternative landscapes?

3) What are the socio-demographic, economic, and geographic characteristics of turf replacement program participants?

4) Did participants reduce the percent vegetation cover after implementing turf replacement, and do these replaced areas have high functional plant diversity and species richness?

5) Is there evidence of neighborhood transitions effects, whereby a resident who participates in a program spurs additional nearby neighbors to also replace their turf?

The project included key specified Task Orders from MWD that guided the research in answering the above questions. These included describing existing turf replacement programs among local retail agencies (Task 1), creating and applying a typology for classifying landscapes before and after turf replacement (Tasks 2 and 4), creating and applying a typology for assessing landscape biodiversity before and after turf replacement (Tasks 3 and 5), mapping program participation and impacts (Task 7), and developing a final report (Task 8). The tasks associated with the topics are specified throughout the report.

The research began in 2015 and ended in 2017. It included several deliverables associated with each task. UCLA and the University of Utah provided interim presentations of findings in 2016 and 2017. The researchers also provided regular progress reports to MWD and submitted a draft version of this report for initial review by MWD personnel in June 2017.

Methods

The study devised a methodology to systematically evaluate the effects of turf replacement in LA County at multiple geographic scales. For the LA County region, participation data was mapped and correlated with socio-demographic and other variables to understand general trends. At the more detailed scale, a survey of homes that completed turf replacement was performed using imagery to evaluate post-replacement landscapes. We collected data from multiple sources, developing databases to correlate individual or aggregated records for turf replacement with geographic, socio-demographic, economic, and other potential explanatory factors. The methods for each step of the analysis procedure are detailed below.

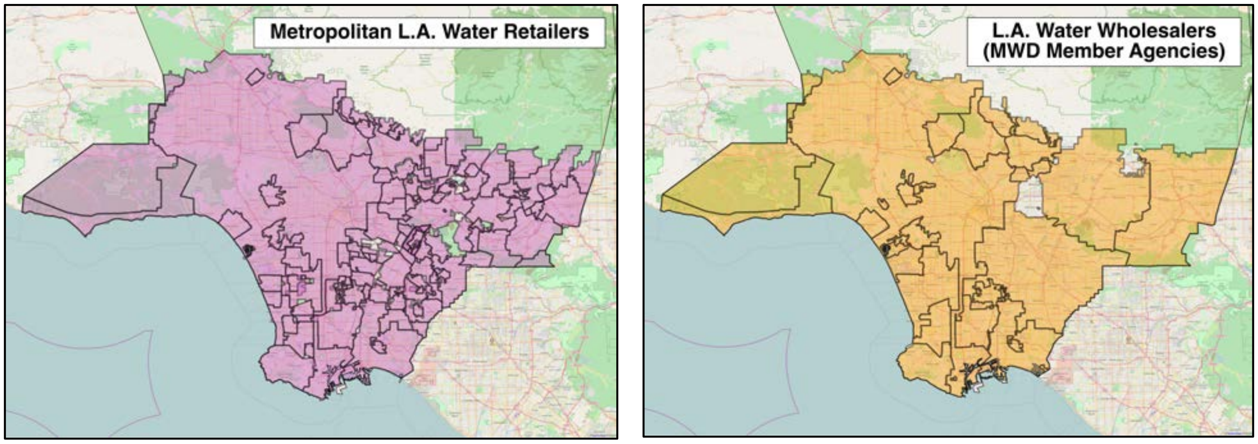
Study Area

The program evaluation focused on Los Angeles County (LA County). LA County has over 10 million residents and more than 100 sizeable water agencies as shown in Figure 1 (Census, 2013; Pincetl et al., 2016). MWD, the Los Angeles Department of Water and Power, and the San Gabriel Valley Water District all import water to the region, with MWD and LADWP being the dominant sources. Agencies also use groundwater, recycled water, and stormwater capture to meet demands and recharge local groundwater basins. MWD sits atop a hierarchy of water utilities that include importer, wholesaler, and retailer agencies that are all involved in integrated water management, including both demand and supply measures, for the region.

Participant Data

We received confidential program participation data for turf replacement program participant directly from MWD. The database provided included 24,921 distinct records. Properties participating in the MWD Turf Replacement Program were provided as street addresses, which were geocoded using the Geographic Information System software *ArcGIS*.

Figure 1: Metropolitan LA County water agencies and wholesalers



The study focused on the front yards of single-family residences, which comprised over 96% of the rebated replacement projects in our data. Using the MWD program participation data, we mapped where participants were located. This enabled a participant count by U.S. Census Tract or Block Group. The participation rate was calculated by dividing the number of turf replacement projects of the single family homes in a Block Group by the total number of households in the Block Group.

Retail Water Agency Turf Rebate Programs

As part of Task 1, to understand existing utility turf replacement programs, we collected data on the availability and amount of rebates for 109 water retailers in LA County. Using the *Google* or *Google Scholar* search engines, we conducted searches based on the following key words: "turf rebates", "Los Angeles", "Los Angeles water", "turf replacement programs", "water conservation turf", and all of the agency names and websites (when available).

We created a database (see Supplemental Data) with individual records for each water agency in the region. We recorded information on: supplier type, program name, program start year, program development, rebate amount, and program status. This spreadsheet is a comprehensive document indicating the available turf rebate programs. The names of all of the agencies are written horizontally on the x-axis and the questions / key factors are listed vertically on the y-axis. There are 20 questions / key factors listed. The majority of questions receive Yes (Y) or No (N) answers. Not all questions were answered for every agency.

Within the database, there are four sections: 1) MWD and member agencies, 2) Agencies within MWD territories that are not direct members of MWD but may receive imported water through an intermediary wholesaler, 3) Turf replacement programs from city retailers that do not supply retail water to residents, and 4) Other turf rebate programs or information. The first section provides information found regarding turf replacement programs offered by the Metropolitan Water District and its seventeen member agencies in LA County. These rebates would all be part of the MWD program. The second section describes turf replacement information from local water retailers, which we initially hypothesized would direct interested participants to the MWD program without supplemental funding or information. Many of these retailers are smaller, including mutual water companies and special water districts. The third section lists city retailers in LA County, some of which have their own municipal utilities that may facilitate MWD rebates or supplement with local investments. The fourth section is intended to list any other turf rebate programs that came up in the search but may not be associated with any particular known city or water agency in Los Angeles. All four sections also include an "Additional Comments" space, as some programs have notable additional criteria or requirements.

We additionally expanded on the Internet survey by administering a detailed questionnaire to the set of water agencies that had limited or incomplete information online. The goals of the survey were to: 1) expand the search for agencies with limited publicly available information and 2) validate data collected through online sources. In total, 35 agencies were identified for the follow-up questionnaire. To begin this phase of the project, team researchers received an Institutional Review Board (IRB) certification to confirm that the conducted research is ethical and followed protocol. After receiving confirmed certifications, we began by reaching out to the city and water agencies directly. Using each agency's contact information gathered from Internet searches and scanning agency websites, we contacted the agencies to determine whether they offered rebates and if this was accurately reflected on their websites.

Provided that the agency did offer turf rebate programs, we then asked agencies for potential participation in a survey concerning the availability and the functionality of turf rebate programs offered by their agency. The survey is based on a template created by the authors of the project to ensure uniformity in its structure, and is a condensed version of the 20 questions /key factors listed in the database. Composed of fifteen points, the survey featured questions asking for a main contact person, their title, and contact information. It also asked questions about the program, its affiliation if at all with MWD, offered rebate amounts, target amounts of turf replacements and actual replacement amounts by square footage. At the end of the survey, we included space for additional comments and questions to be completed by the agency for the researchers. To those agency representatives who agreed to take the survey, we sent a personal email with an attached survey document. Per agency, we inputted researched information about the specific agency, if any, into the survey document for them. We then asked the agency representative to fill-in any missing information and to review any information that we had found, for the purpose of ensuring efficiency and accuracy in the information collected and recorded in our spreadsheets. This research contributes to a better understanding of the MWD turf replacement program and the different approaches of member agencies.

Statistical Analysis

We calculated descriptive and spatial statistics to understand program participation characteristics and geographic dispersion. We also developed statistical models to investigate program participation trends based on variables from multiple data sets. The statistical analysis supported work for Task 7.

We investigated socioeconomic and spatial determinants of participation in LA County properties. A common source for socio-demographic data is the US Census. A geographic resolution for Census data typically used in research is the *Block Group* level. Block groups are standardized high-resolution geographic units for the entire country with populations of 600 to 3,000 people. The US Census Bureau regularly publishes Block Group level data with hundreds of associated descriptive characteristics based on surveys from the decadal Census, the *American Community Survey,* and others.

It is often necessary to aggregate address-level data for utility and public programs. This can occur for several reasons. Many organizations have concerns about protecting privacy of customers. Identifying trends in a program such as turf replacement also requires correlating participation with other characteristics, most of which are not reliably available at the household level. Geographic aggregation provides a method for integrating building-level data with other standardized data sets.

We conducted statistical analyses of the data at both disaggregated (household level) and aggregated scales. Disaggregated data was mapped and basic statistics were quantified, such as the number of rebates and associated project size. We then aggregated the data, quantifying and mapping participation by US Census Block Groups. We assessed participation as a standardized metric, *participation rate*, to normalize for differences in population. The participation rate was quantified by dividing the number of turf replacement projects in single-family homes within a Block Group by the total number of households in that Block Group. We included only Block Groups with at least one completed turf replacement project in the analysis. As noted, only single-family homes were included, which comprise 96% of the projects reported in our study set. We then mapped the distribution of program participation by Block Group. The turf replacement rate by Block Group served as the response variable for the modeling of turf replacement participation. Block Group size did not differ significantly other than in Bel-Air, where a large area is mountainous with very few residential dwellings. By converting the raw count of projects into participation rates, we addressed the issue of different population sizes across Block Groups. This method also ensured individual customer privacy.

We overlaid turf replacement rates with water agency boundaries and socioeconomic data from the American Community Survey (US Census, 2014). We also incorporated the LA County Assessor data to include the parcel area of properties (Table 2). Together, these depicted physical and socioeconomic factors potentially associated with participation. Based on an initial investigation of the spatial distribution of the completed replacement projects, we hypothesized that the motivation to participate was high when the economic benefit gained from replacement surpassed the cost of replacement, including time, water use conservation, effort, and expense.

Table 1: Explanatory variables used in modeling the Block Group level participation in turf replacement initiatives. Each variable focused on one or more factor in our hypothesis of participation

Explanatory Variable	Data Source
Median income	US Census
Median household income	US Census
Median parcel area	LA County Assessor's Parcel Database
Rebate rate	Retailer survey
Owner occupation rate	US Census

To investigate influencing factors of participation, we used several statistical methods, including Ordinary Least Squares (OLS) regression, Fixed Effects regression, and Geographically Weighted Regression (GWR) models, along with a Local Indicator of Spatial Autocorrelation (LISA) procedure. Using models with good fit, we evaluated factors influencing the participation rate, including potential spatial aggregation. For each, participation rate at the block group level was included as the response variable. For example, a fixed effects model, which showed best fit, is depicted as:

$$y_i = X_i\beta + \alpha_i + u_i,$$

where y_i is the participation rate of Block Group i, X_i is the explanatory variable matrix, β is a vector of coefficients for the independent variables, α_i is the fixed effect parameter to address the unobserved neighborhood or water retailer effect, and u_i is the standard error term.

Evidence from rebate programs in other sectors such as energy efficiency indicates that homeowner participation in rebate programs, especially when facilitated by third parties, may correlate with income or other factors that are geographically heterogeneous (Porse et al., 2016). As such, explanatory variables for socio-demographic indicators and rebate program characteristics were tested for correlation with participation through several procedures. A Queen's Contiguity Weighted Matrix, which is a first step in univariate or bivariate LISA procedures, was calculated and mapped by block group using the *GeoDa* spatial statistics software to illustrate potential clusters, while a Geographically Weighted Regression (GWR) procedure was devised to investigate clustering relationships. Results from the weighted matrix, OLS model, and Fixed Effects model are described below. GWR model parameters and results are described in the Supplemental Data but not presented.

Understanding Landscape Change

We devised a methodology for collecting data and classifying landscapes before and after turf replacement. This methodology supported evaluation of landscape changes and ecological impacts related to plant functional groups. The methodology is straightforward and inexpensive. It is also scalable and can use imagery recognition algorithms to speed the process of large-scale assessment.

We randomly selected a sample set of 1,000 properties contained in the provided database to analyze using *Google Earth Street View* images. We performed two layers of analysis. First, for all 1,000 properties, we assessed the landscape using the most recently available image available in *Google Earth Street View*. Second, for a subset of properties (n = 400) with available pre- and post-replacement imagery, we assessed resultant landscapes following turf replacement. For both, the evaluation only included front yards based on available images in *Google Earth Street View*. We focus below on results from the full survey of 1,000 properties based on the latest available image. Results from the pre- and post-analysis were described in an interim presentation.

Surveying Front Yards of Participants

For the 1,000 selected properties, we visually surveyed landscapes using *Google Earth Street View*. We collected 12 variables in front yards of participants from *Street View* imagery based on vegetation cover, plant lifeforms, plant species richness, and vegetation change (Table 2). Photos for the 1,000 properties and an address list are included in Supplemental Data.

Table 2: Variables quantified using Street View imagery for 1,000 front yards in Los Angeles County

Variable	Description	Unit
Current Data	Record of last *Google Earth Street View* image.	Month-Year (mm-yy)
Length and Depth	Measured yards through Google distance too, does not include city property or driveways.	Meters
Lawn Removed?	Describes if the lawn was removed.	Yes, No, Partial
Vegetation Cover	Amount of yard covered by vegetation.	Four categories of percent vegetation cover: 0-25, 26-50, 51-75, 76-100.
Grasses	Presence of lawn or ornamental grasses.	Yes or No
Perennial Herbs	Presence of perennial herbs.	Yes or No
Succulents	Presence of succulents.	Yes or No
Shrubs	Presence of shrubs.	Yes or No
Trees	Presence of trees, with a diameter at breast height (1.3m) of 2.5cm	Yes or No
Natives	Presence of prominent native species.	Yes or No
Number of Species	Species richness, the number of different species present.	Count
Classification Type	Surface type ordered from greatest present to least present.	Grass, woodchips, stones, Artificial turf, groundcover, shrubs, etc.
Neighborhood Impact	One or more neighbors changed their lawn.	Yes or No

Each address was entered into *Google Earth Street View* between June and December 2016. For each, we recorded the date (month and year) the *Street View* image was collected. We estimated areas of landscape cover using the distance measurement tool in *Google Earth Street View*. We measured the length and depth in meters of each front yard on private property, excluding city property and driveways. Vegetation cover was then estimated into four categories based on percent vegetation cover on front yards (0-25%, 26-50%, 51-75%, 76-100%).

While we identified the most recent available image for all properties, not all properties could be included in the results. This occurred for several reasons. Not all properties in the sample set had available images of landscapes corresponding with a date after turf replacement (the mail-in rebate date) listed in the database. In others, images were unavailable or obstructed.

Classifying Land-Cover and Vegetation

We used imagery in *Street View* to examine front yard landscapes after the on-site replacement project was conducted, using the mail-in rebate data within the database as the temporal marker. Lawn changes were recorded as "Yes", "No", and "Partial". A change was considered "Partial" if residents only changed some of the original lawn or if they only added stone, brick, woodchips, or paved walkway.

Table 3: Land cover types identified as part of analysis of parcels with turf replacement

Land Cover Types	Description
Artificial turf	Synthetic turf, noticeable via imagery
Bare ground	No vegetative ground cover visible
Woodchips	Wood chips or mulch
Gravel	Small to medium-sized stones
Plants	Various plant types, which can be dispersed evenly or clustered. Includes low-lying or shrubby plants, but not turf
Lawn	Grass or turf

We developed a classification typology for the landscapes that received turf replacement funding. We devised a list of land cover types, including lawns, bare ground, gravel, and woodchips, based on an initial survey of several properties (Table 3). We aggregated these into landscape classifications using observational data that considered relative percentages of each type (Table 4). We validated the landscape classifications using a small set of properties and then applied the classifications to the entire data set of 1,000 properties with surveyed front yards using *Google Earth Street View*. This work supported Tasks 2-5. Figure 3 below shows pictorial examples of each classification type.

Across landscape classifications, a primary component of variability was the presence of plants and lifeforms. We identified the presence/absence of five plant functional types (grasses, perennial herbs, succulents, shrubs, and trees) for each location to quantify lifeform diversity. We calculated plant species richness by systematically navigating the front yard from the sidewalk to the residence and identifying the number of unique plant species visible in *Street View*. We identified species native to California and recorded their presence/absence at each location. Figure 2 below breaks down the landscape classification types by percentage of plant cover.

Table 4: Categories of landscape classifications and associated criteria used to assess change, including approximately percentages of each land cover type included in the category

Landscape Classification	Description Criteria
Artificial Turf	0-10% vegetation cover, dominant cover type is synthetic turf
Bare Ground	0-10% vegetation cover, bare ground rarely with plant pots, planted plants, or gardening materials
Gravels	0-10% vegetation cover, Gravels with sparse potted plants, in-ground plants, or gardening materials
Woodchips	0-10% vegetation cover, woodchips with sparse potted plants, in-ground plants, or gardening materials
Evenly-Space Plants with Ground Cover	10-50% vegetation cover, Evenly spaced plants frequently with woodchips, sometimes with bare soil and gravels
Clustered Plants with Ground Cover	30-80% vegetation cover, Clustered plants frequently with woodchips, sometimes with bare soil and gravels
Shrubby Plants	80-100% vegetation cover, Compacted any kind of plants, no turf
Lawn	80-100% vegetation, Lawns/turf
Other	Unclassified design types (e.g. paving stones, agricultural plants)

Figure 2: Landscape classification typology with associated approximately percentage of plant cover

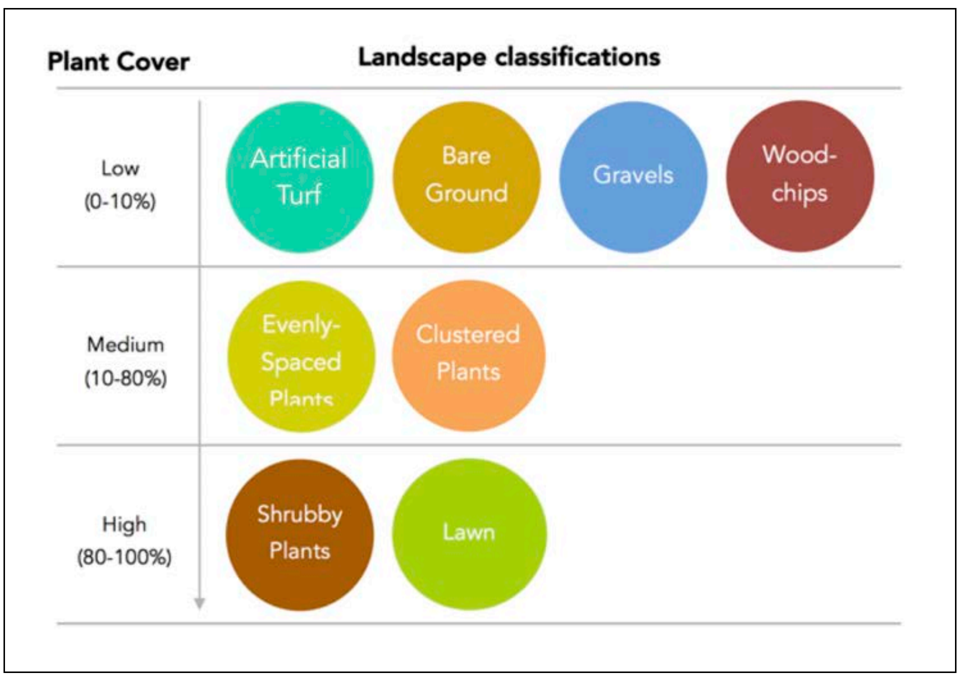


Figure 3: Examples from Google Earth Street View of Landscape Classification Types Used in Analysis

Assessing Neighborhood impacts

For 750 properties that underwent turf replacement, we used *Google Earth Street View* to view neighbors to the right, left, and across the street of the program participant. We examined available imagery for each of the neighboring properties and used the same classification criteria to assess landscape types.

Results

The study identified trends in both the types of landscape outcomes from program participants and spatial variability in program uptake. We detail results below.

Program Availability by Agency (Task 1)

Based on the Internet survey and questionnaire, we researched the availability of turf replacement rebates for over 100 municipalities and water agencies in LA County. The breakdown of agencies by type is shown in Table 5. Most agencies primarily offered the MWD rebate amounts and guidelines, with local water conservation managers assisting interested residents in directly accessing MWD funds. A few local agencies, including LADWP, the City of Long Beach, and the City of Santa Monica had supplemental rebates available. The collected data was incorporated into the statistical analysis as an explanatory variable.

Table 5: Breakdown of agencies included in online research, by agency type.

Agency Classification	Count	Percent of Total
MWD Member Agencies (Direct members)	18	16.5
Agencies in MWD Territories (Not direct members)	57	52.3
Cities with no water retailing utility	32	29.4
California State Agencies (DWR)	1	1.8

Eighteen of the 109 total agencies (16.5%) were MWD and its LA County member agencies. Fifty-seven were agencies in MWD territory, many of which are indirect members receiving water from an MWD member wholesaler (52.3%). Thirty-two were non-MWD member city agencies (29.4%). Finally, one agency outside the region, the California State Department of Water Resources, was surveyed as it provides state level water conservation efforts and rebates.

Of the total agencies researched, 68% had clear information available online regarding turf rebates. MWD and its seventeen member agencies all had accessible information online, with all agencies providing turf replacement programs either through MWD or a supplemental program of their own. Of the agencies in MWD territories that are not direct members, 58% had information readily available online, while 69% of city agencies had information readily available online.

From the total of 109 agencies researched, 32% of the agencies had insufficient information available online to answer all survey questions. We selected these 35 agencies for follow up. Prior to calling the agencies, we determined that only five of these 35 agencies had any information online regarding turf rebates. In the remaining thirty agencies, data insufficiency ranged from no existing websites to disconnected or changed phone numbers that were not updated on their websites. Even in some agencies with a functioning website, the content lacked references to turf rebates or, more broadly, water conservation programs and recommended actions. To make up for insufficient contact information, some of the phone numbers had to be searched through phone directory websites. Overall, this second phase is a part of a larger effort to evaluate how helpful or up-to-date the content on agency websites were for customers to apply for rebates, primarily by comparing what they said they offered versus what they actually offer.

Initially, we sought a main "point of contact" at an agency to discuss outdoor water conservation efforts and turf replacement. The initial round of calls took several days to complete. Some phone numbers were disconnected, others continuously redirected the call, and some did not return voicemails. Within some agencies, representatives and secretaries were less willing to participate even in a discussion. When our messages were not returned we continued a second round of calls on a different day of the week in hopes of speaking with an agency representative.

Of those contacted, 19 agencies declined to take the survey and 12 could not be reached, leaving four of 35 agencies that agreed to participate. Within the 12 agencies that could not be reached (34% of the total sample for questionnaire), we were not able to determine an individual who would speak on the agency's behalf. Such difficulties reflect potential accessibility issues that customers may face when considering rebates. Furthermore, a lack of organization capacity and communication at the local level may inhibit the customer's ability to be aware of the existence of such programs and rebates, for which they may be eligible.

Statistical Analysis of Program Participation Factors (Task 7)

Program participation was not evenly dispersed throughout LA County (Figure 4). Neighborhoods with high homeownership rates and relatively large properties had higher participation rates. Additionally, properties lying within the service territory of a water retailer that offered supplemental rebate amounts in addition to MWD comprised the vast majority of participants, dominated by one retailer, LADWP, which had more than 20,000 of the 24,000 records used in the analysis. We found that home ownership (as opposed to rental units) and the presence of a supplemental rebate, primarily from LADWP, yielded higher participation rates than for other parts of the County (Figures 5). Property area (size) was not a significant contributor to the participation rates.

Figure 4: Mapping single-family households that participated in the MWD turf rebate program

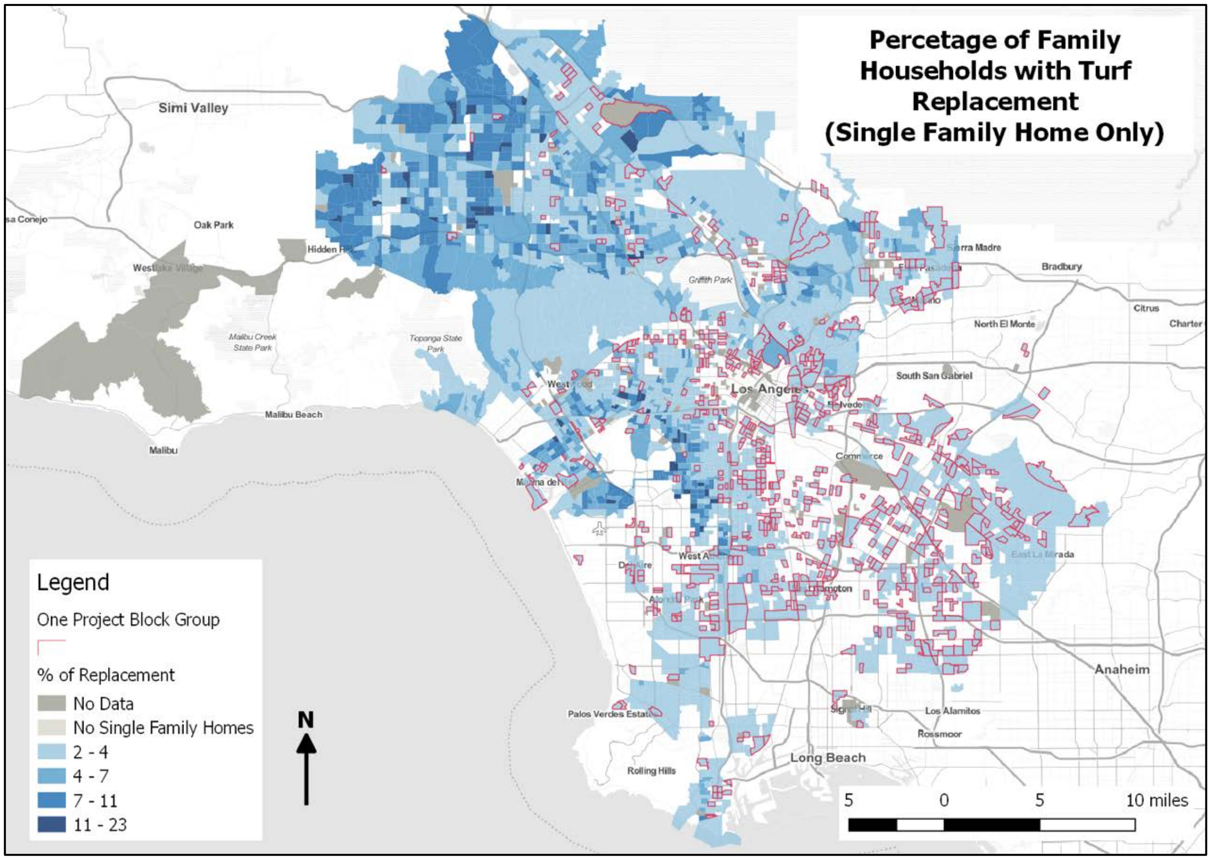
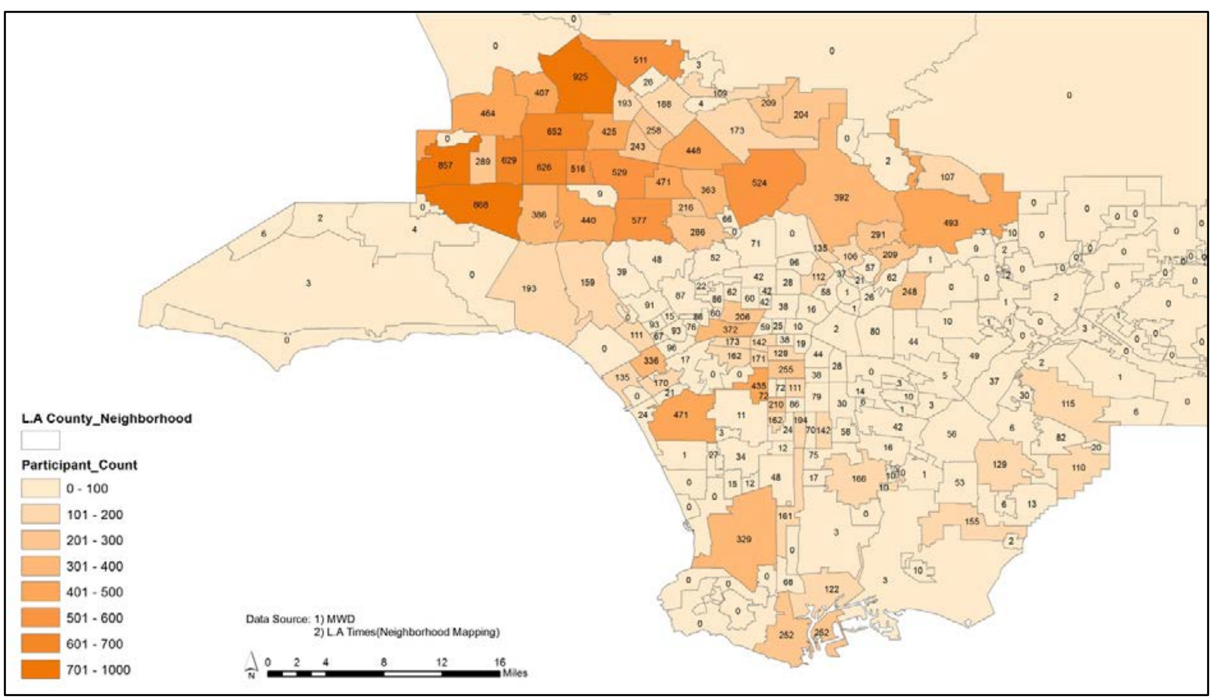


Figure 5: Aggregated counts of turf replacement participation by Census Block Group across LA County.



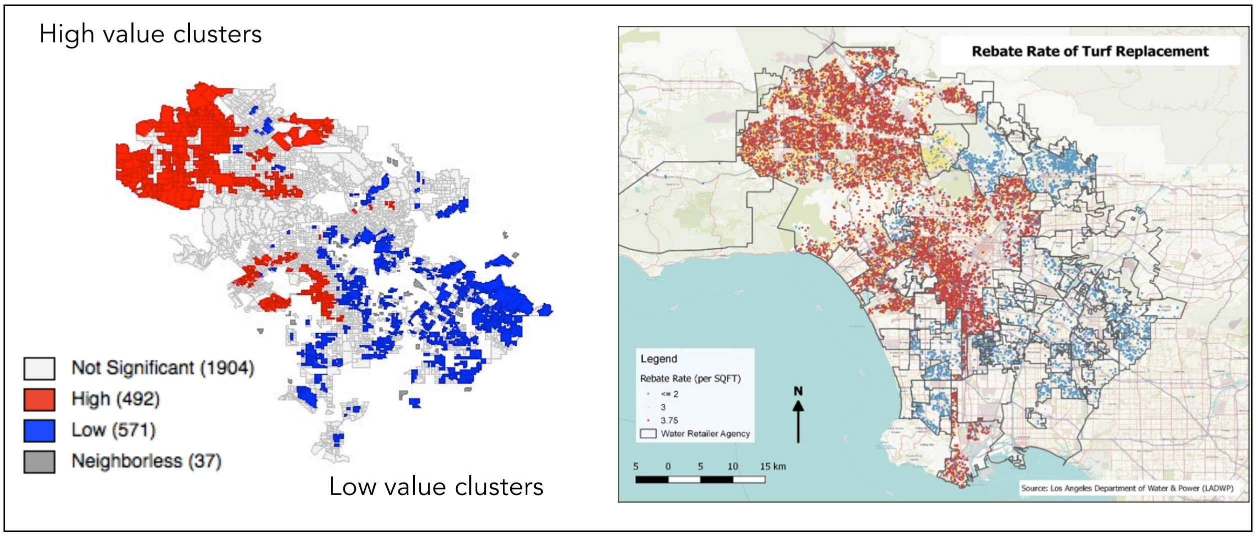
The distribution of participating properties across retail water utility service areas varies across LA County (Table 6). LADWP, which serves nearly 50% of metropolitan LA end-users, constituted 85% of the participants during the time period. Cities with municipally owned utilities, including the cities of Los Angeles, Pasadena, Burbank, and Glendale, together had the vast majority of program participants. Investor-owned utilities also had noticeable numbers of participants, including areas within Golden State Water, Park Water Company, and Suburban Water Systems. Comparing participation rates across utilities, however, which are calculated as the number of participating properties divided by service area connections (from 2010 Urban Water Management Plans), shows a smaller range. LADWP and other municipal utilities still rank high, but the range of penetration rates is smaller across retailers.

Table 6: Turf replacement program participation by agency. Columns are: 1) number of participating properties, 2) percent of participants; and 3) Penetration rate, based on service area connections

No.	Retail Agency	Count	% of Total	Penetration Rate
1	LADWP	20,438	85.94%	3.00%
2	Pasadena Water and Power	571	2.40%	1.55%
3	Burbank Water and Power	511	2.15%	1.92%
4	Glendale, City of	354	1.49%	1.07%
5	Golden State Water	344	1.45%	-
6	Torrance, City of	312	1.31%	1.20%
7	Park Water Company	250	1.05%	0.93%
8	Suburban Water Systems	226	0.95%	-
9	Lakewood, City of	126	0.53%	0.62%
10	Compton, City of	92	0.39%	0.61%
11	Beverly Hills, City of	88	0.37%	0.83%
12	CA Water Service	58	0.24%	0.11%
13	Whittier, City of	52	0.22%	0.46%
14	Downey, City of	50	0.21%	0.22%
15	San Gabriel Valley Water Company	42	0.18%	0.09%
16	Orchard Dale Water District	35	0.15%	0.84%
17	South Gate, City of	33	0.14%	0.23%
18	Pico Rivera, City of	26	0.11%	0.28%
19	San Fernando	26	0.11%	0.52%
20	Bellflower-Somerset MWC	21	0.09%	0.35%
21	Montebello Land and Water Co	19	0.08%	0.48%
22	Lynwood, City of	15	0.06%	0.15%
23	Cerritos, City of	12	0.05%	0.08%
24	Huntington Park, City of	12	0.05%	0.18%
25	Pico Water District	11	0.05%	0.21%
	Total	23,782		

Results from statistical analysis revealed correlations with explanatory variables and potential clustering of projects. Visual inspection of the weighted matrix indicated evidence of geographic clustering (Figure 6). The San Fernando Valley and areas in West LA had higher clustering of participation among block groups, while some areas to the east and south of LADWP territory and outside of the city showed lower participation. These included Long Beach, Cerritos, Lakewood and Downey.

Figure 6: High- and low-value spatial clustering effects (left) and the amount of available turf replacement rebates (right). Clustering effects are not entirely explained by rebate amount.



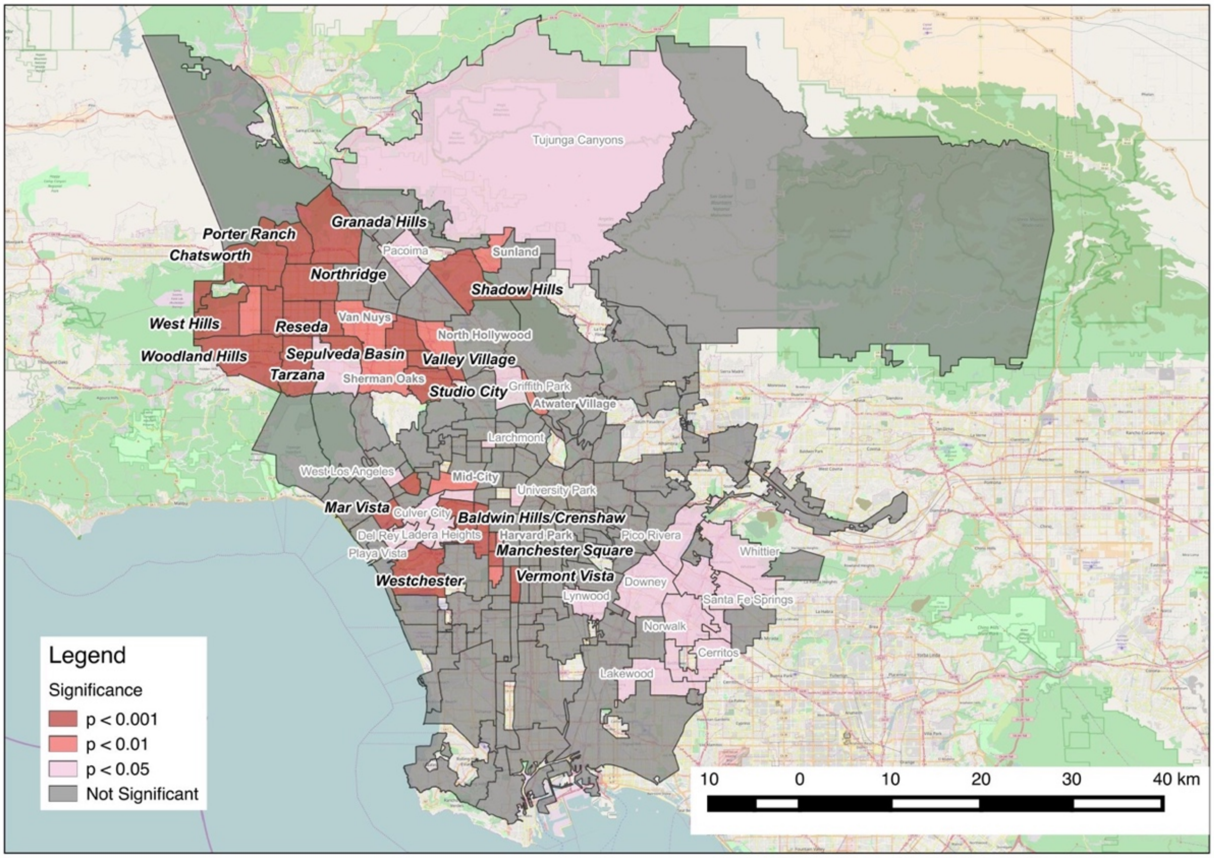
From results of the regression model analysis (at the block group level), the Fixed Effects model, with a higher R^2, indicated that participation rates were positively correlated with owner-occupancy and negatively correlated with median income (Table 7). Rebate rate was also significant, but inconsistent across retailers and likely dominated by LADWP participants. The OLS regression model also showed similar correlations, though the coefficient of determination was lower. Mapping significance of the Fixed Effects model showed potential neighborhood effects, which would need further investigation (Figure 7).

Table 7: Results from regression models using fixed effects (R^2 = 0.722) and Ordinary Least Squares (R^2 = 0.346) procedures. The response variable for both models was participation rate by Block Group.

Explanatory Variable	Coefficients	
	Fixed Effects Model	OLS Model
Owner-Occupied Rate	3.87E-02*	4.51E-02*
Median Income	-6.80E-08*	-1.20E-08
Median Household Income	-2.10E-05*	-9.50E-06*
Rebate Rate	6.89E-03*	1.78E-02*
Property Size	4.00E-09	-3.00E-09

*$p < 0.001$

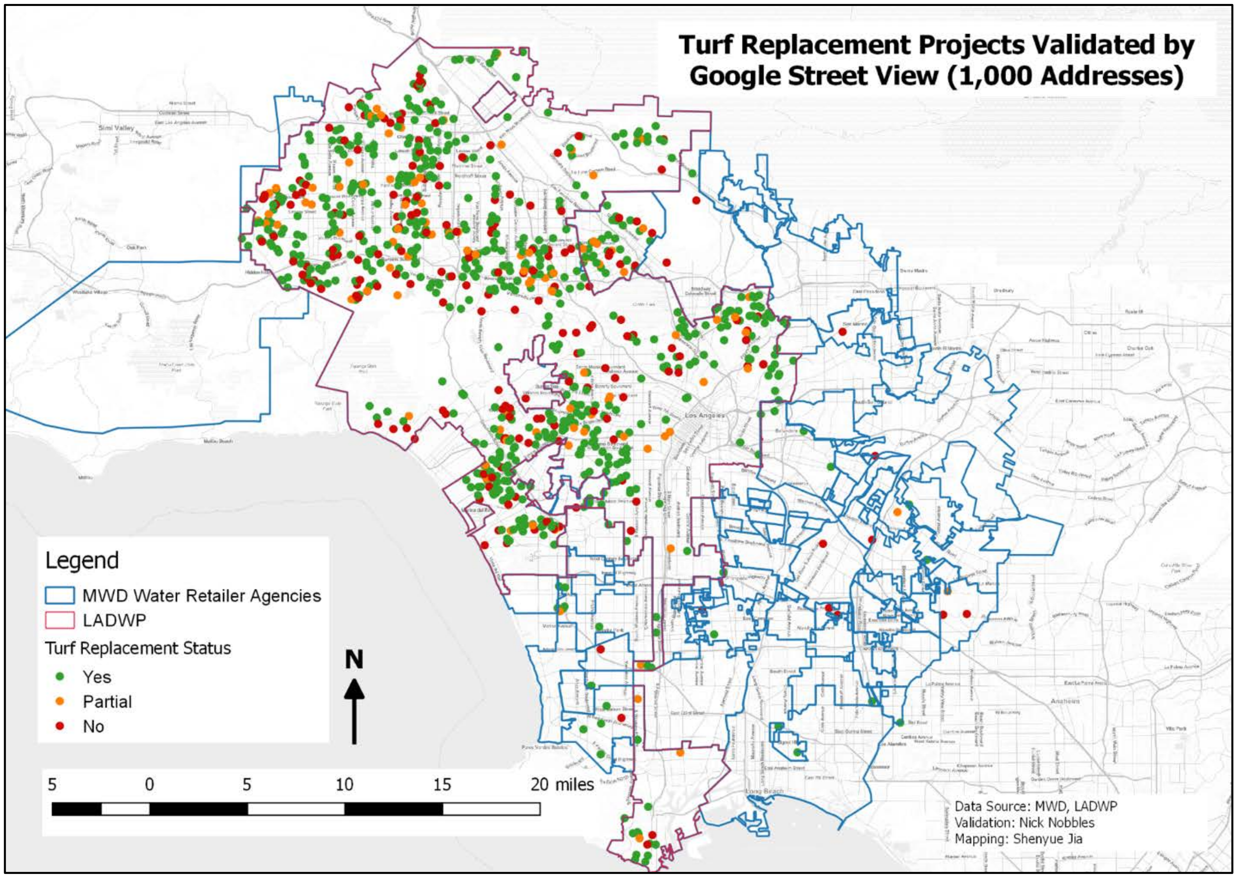
Figure 7: Mapping neighborhood effects for turf replacement projects across LA County based on the fixed effects model. Darker red indicates higher significance.



Landscape Change Analysis with Google Earth Street View (Tasks 2-5)

The sample set of 1,000 properties was spatially dispersed throughout LA County (Figure 8). Ideally, the pre- and post-replacement images would have been viewed to empirically verify landscape changes. This was not possible, however, for all 1,000 properties selected in the sample set. This occurred for two primary reasons. First, a majority of the imagery available in *Street View* is from 2015, so pre-replacement or post-replacement images (or both) are not available. Second, for some properties, images of front yards are obscured. As such we focus on reporting results below for the subset of properties with available front yard images having dates after the date of replacement. We surveyed the number of occurrences of each landscape type (Figures 9, 10 & 11).

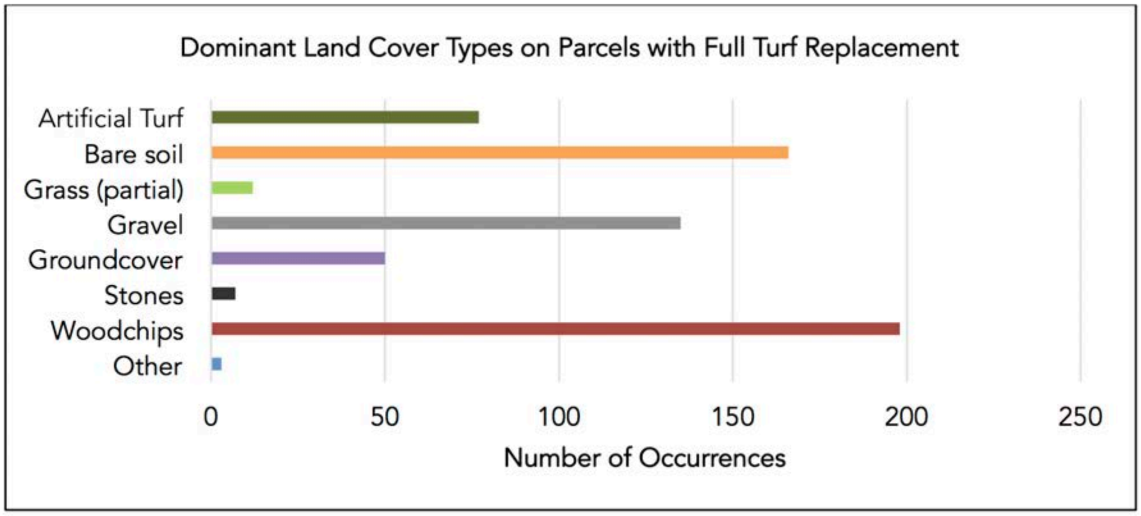
Figure 8: Location of Turf Replacement Projects Validated by Google Earth Street View (1,000 addresses)



Of the 1,000 properties in the sample set, 653 properties showed full removal of lawns, 98 showed partial removal of lawns, and 178 showed no removal of lawns based on images of front yards available at the time of analysis. The remaining 71 addresses could not be validated because the front yards were visually blocked or imagery was not available for the appropriate time periods. Of just the properties with available imagery, 70% of participants had full lawn removal, 11% had partial removal, and 19% showed no front lawn removal.

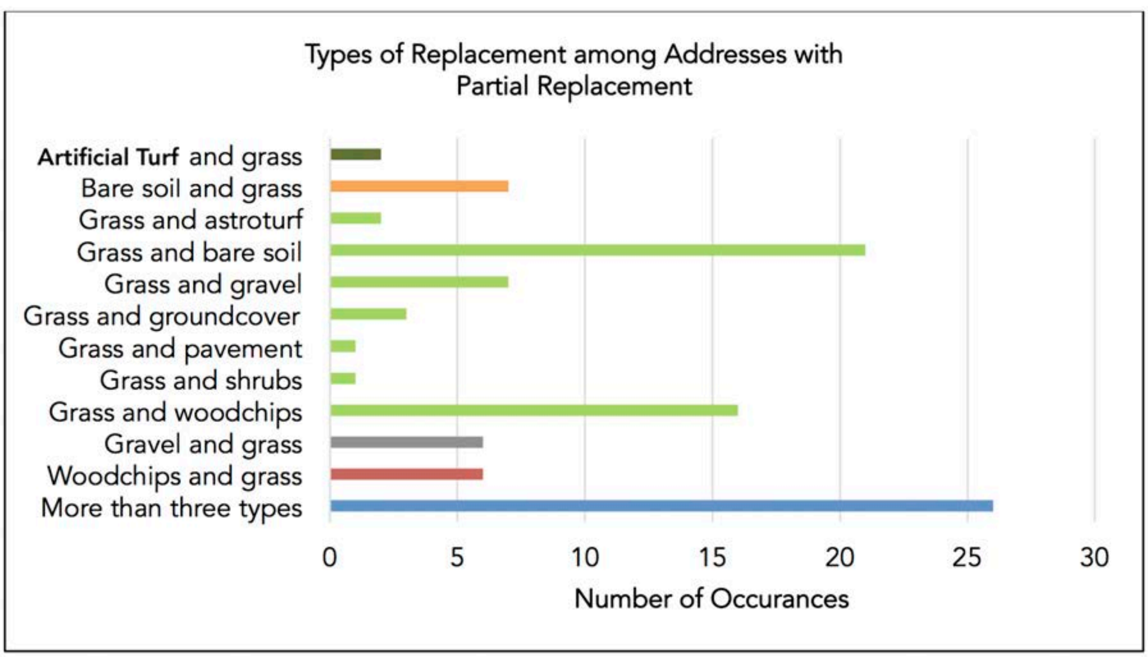
The dominant type of land cover differed somewhat between parcels with either full or partial replacement of turf. In parcels with full turf replacement (n = 653), land cover types were dispersed among many materials (Figure 9). The four dominant replacement classifications for parcels with complete replacement were woodchips, bare soil, gravel, and artificial turf (Figure 9).

Figure 9: Graphing the dominant (largest) land cover types on properties having undertaken full replacement of turf (n = 653).



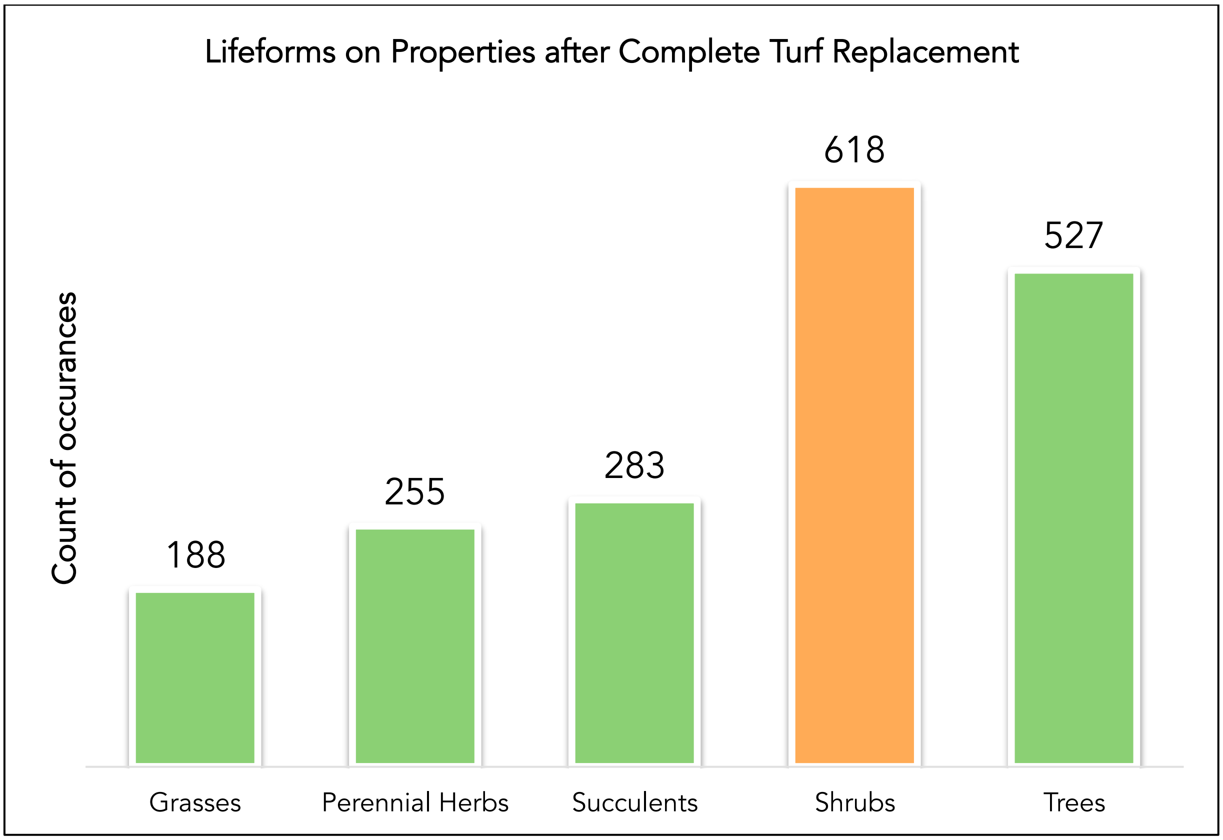
Examining properties that undertook only partial replacement of turf (n = 98) showed that grass was still a predominant component of the resulting landscape classification. It was often interspersed with other land cover types, including bare soil, gravel, and shrubs (Figure 10). Table 7 below lists the percentages of landscape classifications for a subset of the 1,000 properties (n = 597).

Figure 10: Occurrences of different plant types on properties with partial turf replacement (n = 98)



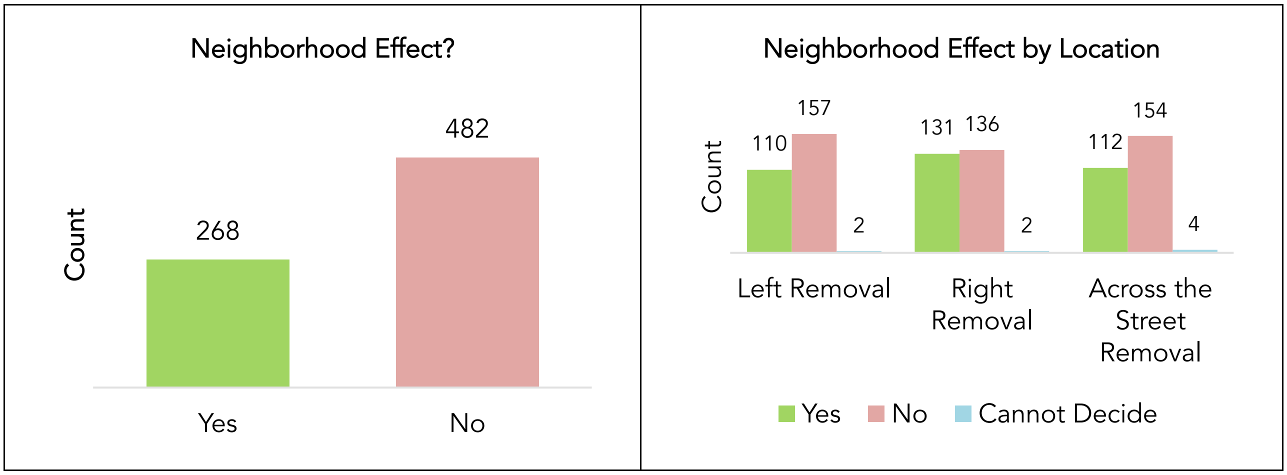
Vegetation cover was relatively evenly distributed across the cover classes, with a majority of properties having vegetation cover between 0 to 25%. Most parcels contained a diversity of plant functional types following replacement of turf (Figure 11). Shrubs were the most common functional type at each location (67%) followed by trees (57%), succulents (30%), perennial herbs (27%), and grasses (20%). Most locations had between 6-10 species (33%), followed by 11-15 species (28%), 0-5 species (8%), and 20 or more species (4%). Based on visual inspection of imagery, native species were rare. This assessment includes some uncertainty, as on-the-ground verifications would best identify presence of native species.

Figure 11: Occurrences of different plant types identified in properties with turf replacement



We found that a sizable percentage of turf replacement sites had nearby neighbors (directly left, right or across the street) that also showed landscape change. For 750 properties showing some amount of turf replacement that we assessed, 36% had nearby properties that also had partially or fully-replaced landscapes (Figure 12). We found, using available *Google Earth Street View* imagery, that the numbers were evenly dispersed across left, right, and across-the-street properties. This indicates a potential demonstration effect, though more detailed analysis, including interviews with residents, would need to be conducted to understand diffusion effects.

Figure 12: Neighborhood effects of front-yard turf replacement by presence and location. Of the sampled subset, over one-third had a neighbor home also with replacement.



Discussion

The analysis indicated a number of findings of relevance for future program implementation within MWD territories and other regions of California. We discuss below some key implications highlighted by the research along with potential opportunities for collecting future data that could yield additional useful improvements for program outcomes.

Participation

Middle- and higher-income homeowners participated at higher rates, particularly in the LADWP service territory where the increased rebate that combined MWD and LADWP incentives was likely a strong motivator. Many participants were clustered in the San Fernando Valley a region that is significantly hotter than coastal areas of LA and more suburban, with generally lower population density and as such more yard space, keeping in mind that these results are for front yards only. Replacing turf in these areas could result in greater per household water savings due to climate while also yielding more significant household economic savings as a percentage of income. Other factors could also explain increased uptake in the region, including program messaging, cultural views, or geographic targeting by third-party providers. Further research with participant surveys and pre- and post-project analysis of water savings could elucidate the findings.

Our model also revealed that although the rebate rate is a determinant of clustering in some high participation communities, the relationship is not always true and other effects are likely at play. For instance, during analysis of *Google Earth Street View* imagery, we noticed geographic homogeneity in building architectures and landscape sizes for properties within the sample set of 1,000. Neighborhoods tend to have characteristic lot sizes, landscaping, and building architecture types that originate from initial construction. We noticed general clustering patterns for typologies of landscape changes, building sizes, and lot sizes that spanned geographic areas. These could potentially reveal behavioral preferences that influence turf replacement decisions. More research, including participant interviews, is necessary, however, to both understand these potential trends and to categorize them.

The preponderance of new imagery and geospatial data through sources such as *Google Earth Street View*, commercial providers, and the Los Angeles Regional Imagery Acquisition Consortium provides many rich possibilities for improving evaluation and implementation of turf replacement programs in Southern California. We showed through this analysis for the first time that *Google Earth Street View* is an extremely helpful tool in assessing turf replacement conversions (front yards) with high resolution for land cover classifications and general species identification. At the same time, it is not high-resolution land cover imagery data. Current leading research uses such imagery-derived data sets for classifying urban land cover and assessing critical variables related to urban water consumption (Cadenasso et al., 2007; Litvak et al., 2017a). In addition, the types of species found on properties critically influence long-term water use budgets and drought tolerance (Litvak et al., 2013, 2017b; Litvak and Pataki, 2016; Porse et al., 2017). Water agencies must continue to engage in cutting-edge science that informs species-specific estimates of water use, which if combined with landscape architecture expertise, can produce urban landscapes that are both water-efficient and ecologically productive.

Limitations

Google Earth Street View is an efficient and inexpensive means to see the effects of subsidizing turf replacement in front yards. Matching the parcels that have replaced their turf with other variables, such as socio-demographic information and supplemental rebate availability, provides additional insights into potential patterns in turf replacement program participants. Such insights can be useful for targeting further turf replacement. *Google Earth Street View* also allows a preliminary classification of turf replacement typologies, though yards will change over time as plant material grows or is changed out. The typologies developed from *Street View* observations show high use of shrubby plants often surrounded by gravel, woodchips or bare soil. At the same time, there is indication of a high degree of variability among the turf replacement approaches. Again, over time, this may lead to variegated landscape types in the region, replacing the more homogeneous lawn and shrub landscaping tradition, or these yards will evolve in yet-to-be seen ways. Other factors that might be important to understand include urban albedo and urban heat island effects from different landscape replacement types.

But *Google Earth Street View* also has limitations. Images can be obstructed or taken at too early a date, which reduces the number of properties that can be evaluated. We were also not able to view backyards, given that *Street View* is only for front yards. Overhead imagery is available in *Google Earth* with temporal resolution to assess all yards for the implementation period of the properties in the database, but the geographic resolution is limited for determining landscape typologies. It is more useful for quick verification of implementation. Given the limitations, we were unable to ascertain the effects of turf replacement on backyard landscapes. To understand the full impacts of the MWD program, back yards would have to be looked at as well, involving permissions to access the yards.

Further, while landscape change in front yards is viewable, water use change remains uncertain and derived from previous literature. Water use change may also be predicated on landscape change in backyards, not simply front yards, and the combination could be important to study program impacts on water consumption.

Finally, classifying landscapes requires judgment and interpretation. Tools of *Google Earth Street View* are very useful in quantifying landscape characteristics, especially the distance measurement tool. The land cover categorizations drew on team member expertise in geography, urban ecology, and landscape architecture research, including knowledge assembled as part of the development of UCLA's *Biodiversity Atlas* and significant research on species-specific water use of urban landscapes in LA. Even still, as with any fieldwork, the process of classifying landscapes does include subjectivity on the part of surveyors. To minimize this, we trained multiple team members, and results for the 1,000 properties in the sample set were verified across research groups.

Conclusions

The Metropolitan Water District's turf replacement program is an unprecedented investment in future urban landscapes that can help reduce long-term urban water demands in California. The significant boost in funding in 2014 offered a prime opportunity to test the effects of such programs on landscapes and behavior using new imagery technologies and integrated large-scale data sources.

Results from this analysis indicated insights for both program implementation and outcomes on properties. Based on an analysis of 1,000 properties that implemented turf replacement (2.3% of program participants in the provided database), residents made significant reductions in space dedicated to lawns. They predominantly replaced lawns with shrubby plants and artificial turf (14.6%, 9.6% each), along with many landscapes with mixed land cover types. Analysis of nearby homes from program participants provided evidence of "neighborhood adoption" effects, whereby approximately one-third of program participants had a neighbor building that also had a replaced lawn.

At larger geographic scales, we also found a strong correlation between participating Block Groups and home ownership, income and additional turf replacement program funding from LADWP. Eighty percent of the properties in the database were located in the service territory of LADWP. To understand in greater detail the landscape implications of this program, site visits to ascertain the vegetation, biodiversity, and land cover would have to be conducted. Further, backyard turf removal impacts are as yet unverified through this method, as well as longitudinal impact on outdoor irrigation.

This study was the first to develop methodologies for using free imagery and mapping platforms, namely *Google Earth Street View*, to assess urban landscapes changes from turf replacement in an inexpensive manner. In addition, we devised a novel method for classifying diverse landscapes within the context of a program where participants had significant freedom to select replacement landscape types. These innovations provide an important framework for future studies. Further research should evaluate biodiversity effects of landscape changes and achieved water savings over time, based on analysis of pre- and post-project metered water use data. Such analysis would help validate current investments and guide future program improvements that improve Southern California's resilience to future drought.

References

Anderson, J.R., Hardy, E.E., Roach, J.T., Witmer, R.E., 1976. A Land Use and Land Cover Classification System for Use with Remote Sensor Data, Geological Survey Professional Paper. U.S. Department of Interior.

Cadenasso, M.L., Pickett, S.T.A., Schwarz, K., 2007. Spatial heterogeneity in urban ecosystems: reconceptualizing land cover and a framework for classification. Frontiers in Ecology and the Environment 5, 80–88.

Census, 2013. 2010 Census of the United States of America. U.S. Census Bureau, Washington, D.C.: Government Printing Office.

DeOreo, W., Mayer, P., 2012. Insights into declining single family residential water demands. Journal - American Water Works Association 104. doi:10.5942/jawwa.2012.104.0080

Hanak, E., Davis, M., 2006. Lawns and water demand in California (PPIC Research Reports). Public Policy Institute of California, San Francisco, CA.

Litvak, E., Bijoor, N.S., Pataki, D.E., 2013. Adding trees to irrigated turfgrass lawns may be a water-saving measure in semi-arid environments. Ecohydrology n/a-n/a. doi:10.1002/eco.1458

Litvak, E., Manago, K., Hogue, T.S., Pataki, D.E., 2017a. Evapotranspiration of urban landscapes in Los Angeles, California at the municipal scale. Water Resources Research.

Litvak, E., McCarthy, H.R., Pataki, D., 2017b. A method for estimating transpiration from irrigated urban trees in California. Landscape and Urban Planning.

Litvak, E., Pataki, D., 2016. Evapotranspiration of urban lawns in a semi-arid environment: an in situ evaluation of microclimatic conditions and watering recommendations. Journal of Arid Environments 134, 87–96.

Mayer, P., Lander, P., Glenn, D.T., 2015. Outdoor Water Efficiency Offers Large Potential Savings, But Research on Effectiveness Remains Scarce. Journal of the American Water Works Association 2015, 61–66.

Mini, C., Hogue, T., Pincetl, S., 2014a. Patterns and controlling factors of residential water use in Los Angeles, California. Water Policy 16, 1054–1069.

Mini, C., Hogue, T.S., Pincetl, S., 2014b. Estimation of residential outdoor water use in Los Angeles, California. Landscape and Urban Planning 127, 124–135. doi:10.1016/j.landurbplan.2014.04.007

Mitchell, D., Hanak, E., Baerenklau, K., Escriva-Bou, A., McCann, H., Perez-Urdiales, M., Schwabe, K., 2017. Building Drought Resilience in California's Cities and Suburbs. Public Policy Institute of California, San Francisco, CA.

Office of the Governor of California, 2016. Executive Order B37-16: Making Conservation a California Way of Life. Sacramento, CA.

Pincetl, S., Porse, E., Cheng, D., 2016. Fragmented Flows: Water Supply in Los Angeles County. Environmental Management. doi:10.1007/s00267-016-0707-1

Porse, E., Derenski, J., Gustafson, H., Elizabeth, Z., Pincetl, S., 2016. Structural, Geographic, and Social Factors in Urban Building Energy Use: Analysis of Aggregated Account-Level Consumption Data in a Megacity. Energy Policy 96, 179–192.

Porse, E., Mika, K.B., Litvak, E., Manago, K., Glickfeld, M., Hogue, T., Gold, M., Pataki, D., Pincetl, S., 2017. Systems Analysis and Optimization of Local Water Supplies in Los Angeles. Journal of Water Resources Planning and Management.

Sovocool, K., Morgan, M., Bennett, D., 2006. An In-Depth Investigation of Xeriscape as a Water Conservation Measure. Journal of the American Water Works Association 98, 82–93.

Tull, C., Schmitt, E., Atwater, P., 2016. How Much Water Does Turf Removal Save? Applying Bayesian Structural Time-Series to California Residential Water Demand. Presented at the KDD Workshop on Data Science for Food, Energy and Water, San Francisco, CA.

US Census, 2014. American Community Survey. U.S. Census Bureau, Washignton, D.C.: Government Printing Office.

Supplemental Data List

The below list of items is included as Supplemental Data in support of the report of findings.

1) *Turf Replacement Programs in LA County by Water Agency.* Data from survey of LA County retail water agencies regarding existing turf replacement programs.
2) *Parameters of Model Fit* for statistical models developed to assess correlation in aggregated turf replacement penetration rate with factors of socio-demographics, economics, and geography.
3) *List of 1,000 properties* used to assess landscape changes in front yards from turf replacement. The database includes assessed characteristics reported in findings.
4) *Images of 1,000 properties* surveyed to assess changes in landscapes for front yards.