INNOVATIVE CONSERVATION PROGRAM
Metropolitan Water District of Southern California

DISCLAIMER

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THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION

CAP CENTRAL ARIZONA PROJECT

Southern Nevada Water Authority

Rain Gardens: Water-Wise Investments in our Future

Prepared by The Bay Foundation for the Metropolitan Water District of Southern California

July 2016

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"We're in a new era. The idea of your nice little green grass getting lots of water every day, that's going to be a thing of the past" – Gov. Jerry Brown (April 2015)

Introduction

Rainwater harvesting is the process of intercepting rainwater from a roof, lawn, or other surface and utilizing it for beneficial purposes. By implementing rainwater harvesting techniques, residents gain access to an extra supply of water while reducing the pressure on limited potable water supplies. Many residential and commercial properties are fitted with downspouts; when it rains, water runs off roofs through these downspouts, and often onto an impervious surface, such as a sidewalk, driveway, or parking lot. Rainwater harvesting helps increase local water resources by redirecting the flow of runoff to pervious surfaces where it can percolate into the soil and promote groundwater recharge. Rain barrels and rain gardens are two common methods of rainwater harvesting.

A rainwater harvesting program provides many benefits to the participants, local and regional communities, municipalities, water agencies, the environment, and many others. These benefits include protecting our bays and ocean, reducing energy use, conserving water, and recharging groundwater.

- **Protection of Our Bays and Ocean**: Rainwater flowing from a downspout onto sidewalks, driveways, and streets collects a variety of pollutants before reaching the nearby storm drain system. By capturing rainwater, residents can reduce the amount of runoff and pollution reaching the Santa Monica Bay, thus aiding in improving the quality of our local water bodies.

- **Reduction of Energy Demands**: The State of California Energy Commission reported that water-related energy consumption in California accounts for nearly 20% of the State's electricity, 30% of its natural gas, and requires about 88 billion gallons of diesel fuel every year (CEC 2006). One inch of rain falling on a one thousand foot rooftop produces more than 600 gallons of water. Energy consumption in the State would be greatly reduced if homeowners substituted potable water with captured rainwater.

- **Water Conservation**: California has entered an era of increasing water scarcity, coupled with projections of increased temperatures of up to 10 degrees Fahrenheit by the end of the century. Using rainwater to water plants helps conserve dwindling drinking water supplies. The USEPA estimates up to 60% of water use in the Southwest is used outdoors; USEPA also estimates that nearly 50% of outdoor water use is wasted by inefficient application methods and systems (USEPA 2016). Rainwater harvesting can replace outdoor potable water use, especially when combined with lawn and sprinkler replacement that occurs when installing a rain garden.

- **Recharge of Groundwater Supplies**: Approximately 40% of southern California's drinking water comes from groundwater (Mathany and Belitz 2015). Harvesting rainwater and allowing it to infiltrate into the ground will help replenish groundwater supplies.

Project Description

Outdoor water use reduction represents the greatest opportunity for water savings in the United States. This project implemented a cost effective alternative for inefficient and intensive outdoor water use by eliminating the need altogether. The gathered knowledge will contribute to additional and far reaching water savings as the lessons learned are adopted widely and the information is utilized to replace irrigation systems and fill a data gap for our region.

The primary goals of this project included:

1) Installing rain gardens on four residential properties;
2) Conducting pre- and post-monitoring for potable water savings and infiltration potential;
3) Conducting pre- and post-monitoring of polluted runoff volume reductions; and
4) Analyzing cost-effectiveness.

This project also had objectives that included increasing potable water savings and reducing or eliminating stormwater runoff and associated pollutants at the four properties. Additionally, the project was targeted to identify effective strategies for rainwater harvesting in coastal and fine-grained sediment regions and provide recommendations. The substantial monitoring components of this project provided a much needed analyses of rainwater harvesting benefits and allowed for a comparative analysis of multiple parameters and water saving measures. For this project, the target audience was intended to be residential properties and large-scale commercial developments and their surrounding neighborhoods. Additional outreach was coordinated through websites, social media, news articles, and reports.

Replacing grass lawns with rainwater harvesting measures such as rain gardens is an effective method to reduce potable water consumption while simultaneously replenishing groundwater reserves and reducing surface water pollution. This project builds on the award-winning Culver City Rainwater Harvesting Program, which began to evaluate cost-effective strategies and developed outreach and implementation strategies for the residential installation of hundreds of rain barrels. This project supplemented those successes in a more thorough evaluation of rain gardens, while providing new components to the analyses, such as quantifiably tracking potable water savings and runoff reductions.

Project Implementation Strategies

A double-impact approach to water savings and conservation was implemented. Specifically, water saving strategies included removing irrigation lines, sprinkler systems, and restricting or removing outdoor water use altogether which promoted potable water conservation. The second approach installed rain gardens with drought-tolerant native species and infiltration basins that reduced water use and redirected and virtually eliminated dry- and wet-weather runoff. Roof runoff from some of the downspouts were redirected and connected to both a rain barrel and then directly into the rain garden.

The lack of available data in the southern California area has been a hindrance to project implementation in some circumstances. Moving forward into the future of sustainable water use, the data collected by this project will help fill a data gap in our region. Data collection strategies included, but were not limited to: sub-metering of the irrigation system prior to its removal to quantify potable outdoor water use, measurements of stormwater runoff before and after implementation of the rain gardens, calculating infiltration and analyzing soil type, conducting a cost-effectiveness evaluation, and estimating pollutant load reductions.

Community Benefits

This project directly benefit the community in multiple ways, including economic benefits to individuals such as energy savings, environmental benefits to the region such as pollution reduction and potable water use reductions, and educational benefits to participants and through outreach such as increased public awareness of water issues. Education and outreach to the local community was a strong component of the implementation of this project and a matching project conducted simultaneously through a grant from the Los Angeles Department of Water and Power to conduct water and energy conservation outreach to the broader Los Angeles community.

Surrounding communities and the region also benefit as more rainwater is recharged to supplement groundwater supplies and less polluted water reaches the Bay, resulting in the improvement of water quality at local beaches and the ocean. Lastly, the construction of native planted rain gardens will create more local neighborhood green spaces (Figure 1).

Figure 1. Spring blooms at Site 2 (1 April 2016).

Methods

A key component of this project was to collect and analyze data to support the evaluation of the effectiveness of implementing rainwater harvesting strategies in coastal regions. Data collection for this project included pre- and post-implementation potable water monitoring, pre- and post-installation stormwater monitoring, soil characteristics, and cost-effectiveness. Stormwater monitoring included evaluations of both stormwater runoff and pollution reduction using calculations from each individual property, or site. Four sites were evaluated as part of this project and are referred to as Sites 1-4. Address locations are kept confidential for the purposes of the homeowners.

Pre-Installation Potable Water Monitoring

Irrigation systems at all residential properties were outfitted with sub-meters to quantify the volume of water being used on their grass lawns for a minimum of six months (Figure 2 and Table 1). Residents were asked to retain their existing lawn watering and maintenance schedule to allow for accurate pre-installation water use estimates. These meters helped compare potable water use volumes prior to and after the implementation of rainwater harvesting strategies. Pre-implementation monitoring included analyzing water use tracked by sub-meter deployment to calculate a total annual average outdoor lawn water use for each residence, based on the length of time deployed (ranging from 180 to 277 days) (Table 1). Sub-meters were checked monthly.

Figure 2. Photo of sub-meters installed at a residential property.

Table 1. Pre-installation potable water monitoring information.

	Site 1	Site 2	Site 3	Site 4
Pre-Installation Monitoring Date Range	8/18/2014 – 3/21/2015	8/18/2014 – 5/22/2015	12/16/2014 – 6/14/2015	1/3/2015 – 7/14/2015
Total # of Pre-Installation Monitoring Days	215	277	180	192

Pre-Installation Stormwater Monitoring

To assess stormwater runoff volumes, a range of design options and materials were researched and considered to implement a mobile, customizable, and repeatable method for calculating stormwater runoff volumes, including the use of weirs, digital water meters, mobile dams, and water diverters. Due to the small topographical slope and elevation gradients across most of the residential properties, the use of weirs was dismissed as it was infeasible to enclose enough water for the weirs to be effective without losing runoff. A slight slope was necessary to attempt any of the on-site stormwater monitoring methods; thus, the chosen design was first attempted at the site with the highest slope (Figure 3, left).

After testing several diversion methods, the final design chosen involved diverting all stormwater running off a property using inexpensive mobile dams to direct stormwater runoff towards the lowest corner of the property in elevation. In this corner, a small hole was dug containing a five gallon bucket. A small pump was placed in the bucket which pumped water through a hose equipped with a digital water meter on the end to calculate water volumes. The necessary equipment and final design setup are shown in Figure 3, right. A rain gauge was also installed on site to allow stormwater runoff volumes to be associated with actual, *in situ* precipitation depths. The innovative design was highly mobile, inexpensive, and easily customizable for a variety of residential property settings.

Figure 3. Equipment needed for residential stormwater runoff volume monitoring (left). Final design setup for stormwater runoff volume monitoring at a trial residential property (right).

Rain Garden Installations

After pre-installation monitoring was completed, rain gardens complete with native vegetation were constructed at four sites and integrated with an existing rain barrel if available. One site was completed each month from April to July 2015 taking 4 to 5 days to complete. Rain gardens reduce polluted runoff and recharge groundwater by allowing infiltration of several thousand gallons of rainwater per storm event. This rainwater harvesting technique is designed to capture and infiltrate stormwater runoff before entering storm drains via a bermed water retention basin (also known as a bioswale).

Property Selection

In an attempt to assess as many residential properties as possible and have several options to choose from, a varied solicitation and outreach strategy was implemented. Solicitation primarily occurred electronically, through The Bay Foundation's email listserv and posted to TBF's website and multiple social media platforms (www.santamonicabay.org). Additionally, calls with local Neighborhood Council members occurred, the notice was included in an e-newsletter, and sent to electronic listservs of several partners such as the Mar Vista Green Committee Announcements list. The notices included information regarding participation, property pre-requisites (both for monitoring and rain garden implementation), and the selection process. The response generated was overwhelming and made for a very competitive selection process.

Ninety interested property owners responded to request more information about the project. More than half of the respondents followed up to provide specific required property information. Interested applicants provided general information (e.g. lawn size, roof catchment area) and photos of their property. All of the respondents who submitted property information were thoroughly reviewed and evaluated, and fourteen were selected for site visits. Site visits were conducted, and four were selected for participation in the project based on yard size, roof catchment size, location of downspouts, visibility, and ease of implementation and monitoring (Figure 4).

Figure 4. Photographs of the final, selected property sites: (A) Site 1; (B) Site 2; (C) Site 3; (D) Site 4)

Rain Garden Construction

Project planning involved coordinating with project area municipality employees to identify and obtain the necessary permits required for project implementation. Permits were required for parkway modifications and the procurement and placement of a green waste dumpster.

Volunteers were coordinated and solicited through the joint-internship program of TBF and Loyola Marymount University's Center for Urban Resilience. Notices were posted on the TBF website, Santa Monica College's Sustainable Works Program, UCLA Institute of the Environment and Sustainability, UCLA landscape design program, through social media (Facebook and Twitter), via listservs, and through partnership word-of-mouth to request volunteer participation.

Construction of each rain garden spanned a date range from a Wednesday or Thursday through Sunday where staff and select interns participated Wednesday, Thursday, and Friday and prepared the project sites for the large-scale volunteer work events held on Saturdays and Sundays. In addition to assisting with project implementation, volunteer participants gained educational experience by learning the value of water conservation and the basic steps to install similar drought tolerant landscapes at their own homes. The goal was to have from 10 to 30 volunteers participate on each day of each event.

The following list summarizes the construction date range for each site:

Site 1: April 23 – 26 (4 days)
Site 2: May 21 – 24 (4 days)
Site 3: June 10 – 14 (5 days)
Site 4: July 15 – 19 (5 days)

At each property the following steps were taken:

1. Sod, non-native plants, and irrigation pipes were removed. A sodcutter was used for removal, when necessary (Figure 5, right).
2. Soils were aerated and moved using a tiller, and low quality soils were amended with compost (Figure 5, left).

3. Project sites were contoured to create rainwater-capture bioswales and infiltration galleries were drilled using an auger to drill holes in the depressional area of the bioswale (Figure 5, right).
4. Large boulders and bioswale stones were placed to add depth to the landscape, for aesthetic purposes at the homeowner's request, and slow water movement through the bioswale during a storm event to increase infiltration potential.
5. Native California, drought-tolerant plants (up to 30 species and 400 individual plants per site) were placed and planted. An auger was used to expedite the process of drilling holes for plants.
6. Biodegradable weed-suppression paper with holes cut for individual plants was placed along the top of the swale, and four inches of mulch was subsequently applied on top throughout the site.
7. Downspouts were retrofitted to flow into a rain barrel and then the bioswales, and subsequently tested.

Figure 5. Photographs of larger rain garden installation equipment: tiller (left), auger (center), and sodcutter (right). Images courtesy asrentall.com and HomeDepot.com.

The heart of a rain garden is the bioswale. Also known as a diversion swale, stormwater that is normally lost is captured and redirected into a drought-tolerant native garden. Its bermed, sloped edges gently guide water into a rocked-lined channel that allows water to pond and eventually soak into the soil which recharges groundwater, filters pollutants, and waters plants (Figure 6) (Lancaster 2013).

Native, California, drought-tolerant plants were selected to correspond with specific locations within the rain garden. For example, plants with a high tolerance for inundation [e.g. Mexican rush (*Juncus mexicanus*), common rush (*Juncus patens*), and Yerba mansa (*Anemopsis californica*)] were planted in the lower swale designed to pool water during a rain event. Less inundation tolerant plants [e.g. mugwort (*Artemisia douglasiana*), and hummingbird sage (*Salvia spathacea*)] were planted on the upper berms and upland areas. Native plants also provide habitat for wildlife, and will attract native birds and butterflies to the rain gardens. A complete list of the native plants installed in the rain gardens can be found in Appendix A.

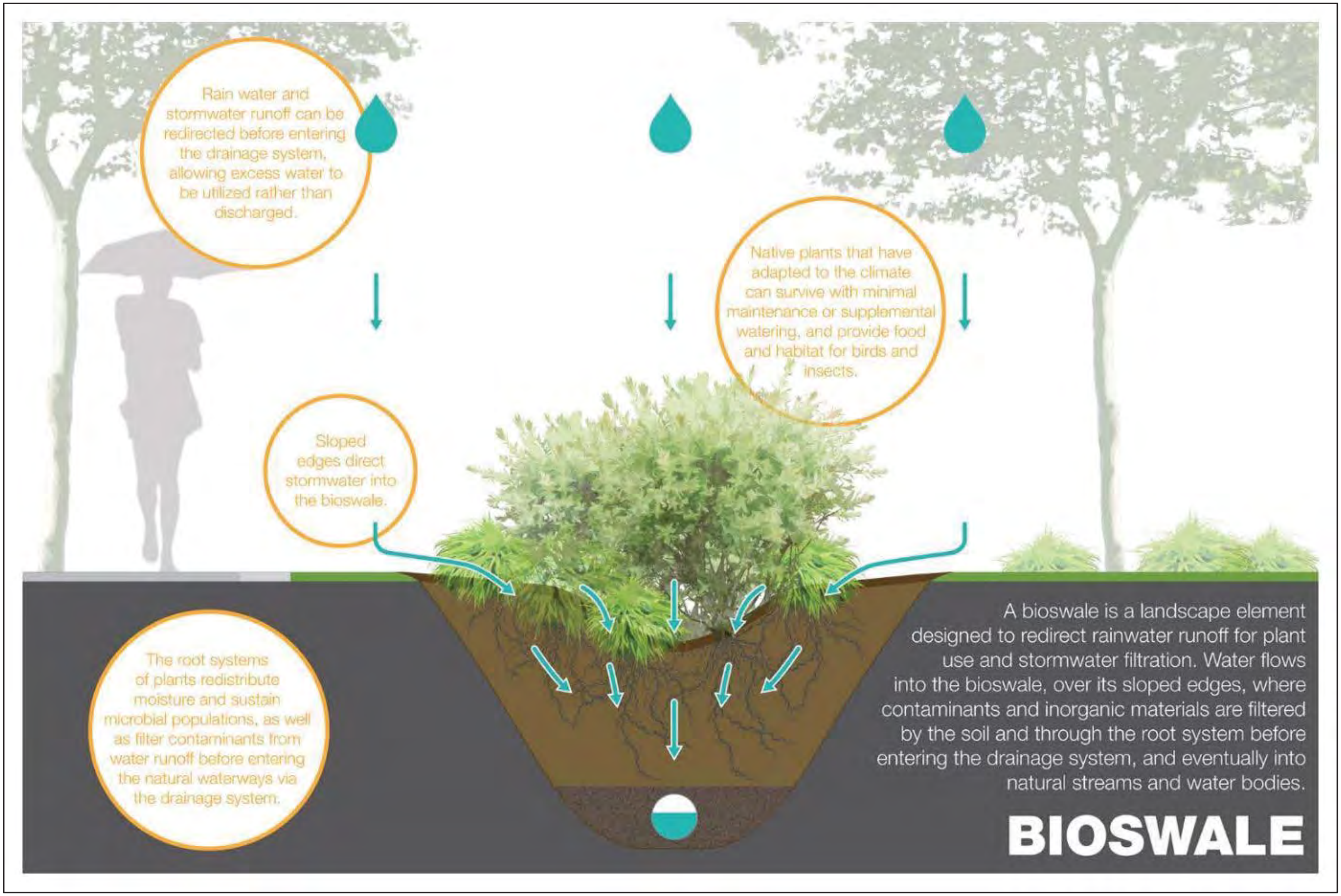


Figure 6. Bioswale graphic replicated from [Upstream Matters](#).

Roof Catchment Runoff Calculation

Prior to rain garden installation, roof catchment calculations were made to determine the amount of stormwater runoff a typical storm would produce. A well designed rain garden integrated with rain barrels and/or cisterns can capture hundreds (or thousands) of gallons of water. Each garden in this project was designed to infiltrate runoff from a rainfall event equal to or greater than one inch.

Roof area was calculated for each site by measuring the length and width of each section of the roof, either onsite or through an online aerial map, and multiplying to get square footage (Figure 7). Each roof section area was then added together to derive a total roof area. Since only half of the downspouts were being diverted (2 per site) in either rain barrels or the bioswale, we divided the total roof area by 2 to estimate the amount of roof runoff that could be captured (the blue arrows in Figure 7 indicate this flow). By adjusting the rainfall variable in the equation we were able to calculate roof catchment runoff under various scenarios. The coefficient in the roof catchment runoff calculation is the average percentage (expressed as a decimal value) of water that runs off a given surface material, such as lawns, roofs, or roads. The higher the number, the more quickly the water moves and runs off. Roof coefficients are high, and range from 0.75 to 0.95 depending on the roof slope and material. A coefficient of 0.95 was an appropriate choice for the roof catchment runoff calculation associated with chosen sites (SWRCB 2013).

The following equation was applied to determine roof catchment runoff in gallons:

Roof Catchment Area (sq ft)	x	Rainfall (in.)	x	Coefficient	x	0.623 (converts square inches into gallons)	=	Roof Catchment Runoff (gallons)

Figure 7. Google Earth view of Site 4. Using the map measurement tool, the approximate area was determined.

Lawn Runoff Calculation

Despite appearances to the contrary, stormwater also flows off of lawns and is lost to storm drains. The same formula used to calculate roof catchment runoff described above, was applied to calculate stormwater runoff from the yard. A different coefficient (0.35) should be substituted:

Lawn Catchment Area (sq ft)	x	Rainfall (in.)	x	Coefficient	x	0.623 (converts square inches into gallons)	=	Lawn Runoff (gallons)

Soil Characteristics

Soil characteristics are an important component in rain garden installations and can affect the water retention, stormwater infiltration, and vegetation growth on site. Soil texture refers to the size of the particles that make up the soil, often a combination of clay, silt, and sand, all of which have various water infiltration properties. The highest water infiltration rates are seen in sand-dominant soils, while clay-dominant soils often have poor water infiltration rates. Soil texture was estimated using two different techniques: soil texture by feel and soil texture by measurement. The following flowchart was used to determine soil texture by feel and involved reviewing a series of questions while physically manipulating a soil sample with ones hands (Whiting et al. 2015, Figure 8).

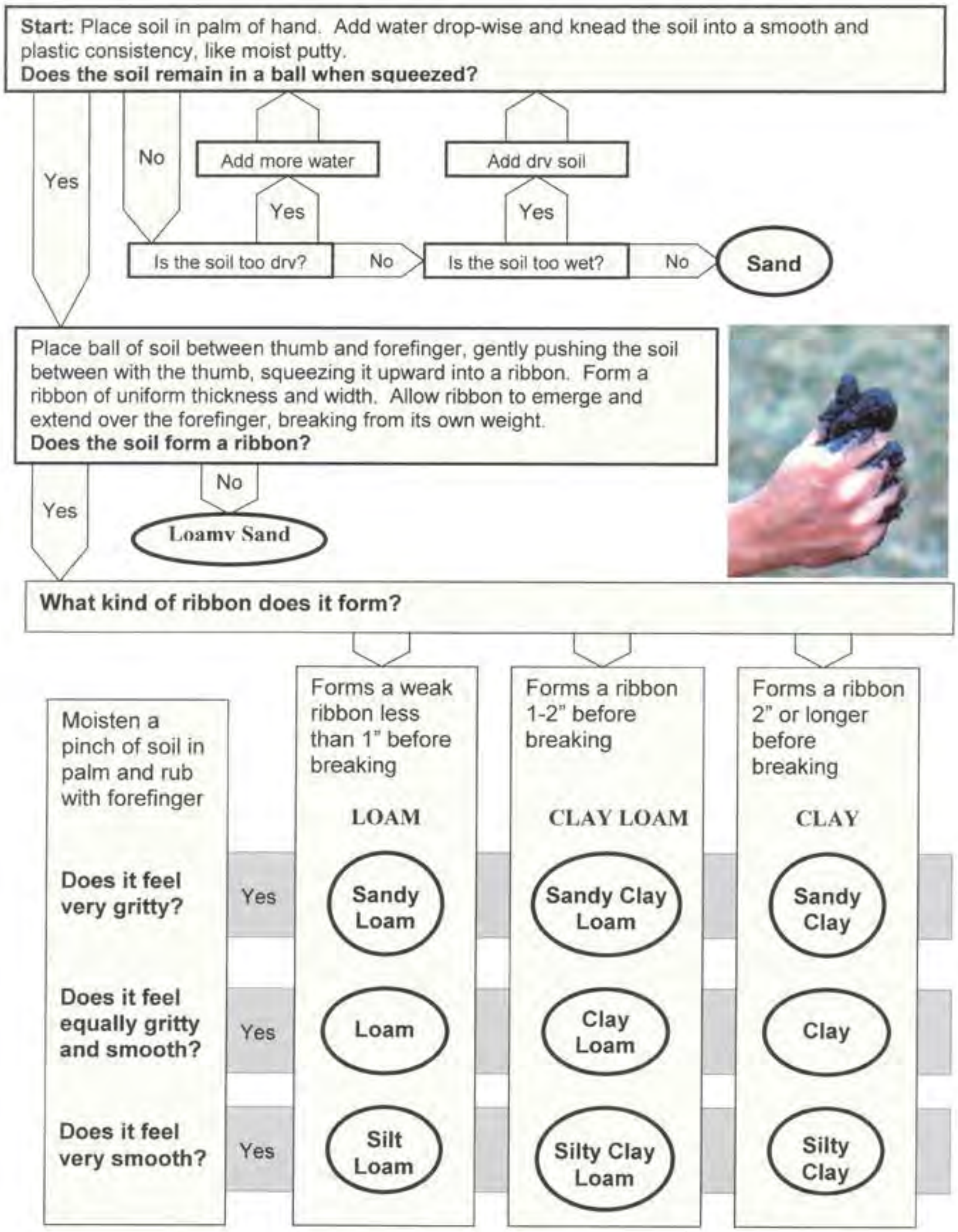


Figure 8. Soil texture by feel flowchart protocol (Whiting et al. 2015).

A more quantitative soil texture measure was conducted by analyzing rain garden soil samples in a laboratory setting. Soil samples were dried, cleaned by removing all rocks and debris, and pulverized to remove clumps. Soil samples, along with clean water, were placed inside graduated cylinders, and shaken to break apart soil aggregates and separate the soil into mineral particles. The thickness of various soil particles, including sand, silt, and clay, were measured over the course of several days as the sediment settled in the cylinder. The percent composition of soil from each rain garden site was calculated and the soil type estimated from the following soil texture triangle (USDA 2016, Whiting et al. 2015; Figure 9).

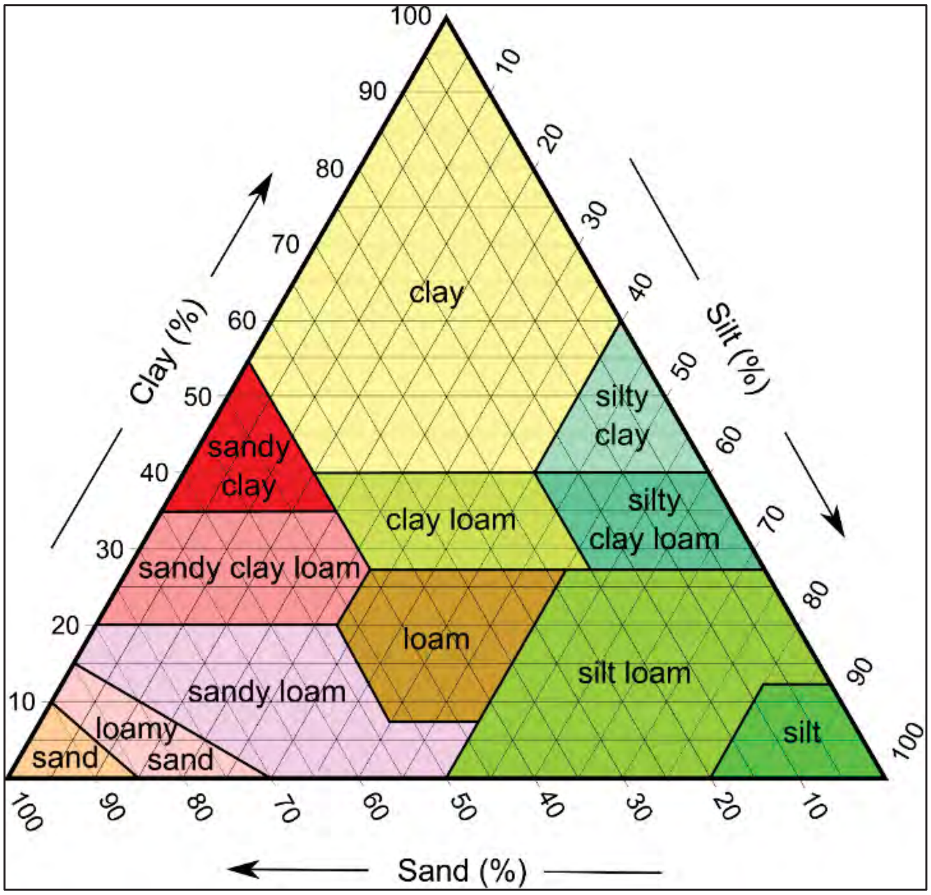


Figure 9. Soil texture triangle using percent composition of clay, silt, and sand (USDA 2016).

Estimates of soil infiltration rates were determined by referencing USDA soil information for each type of soil texture found at each site. The soil texture type and estimated percent slope at each rain garden site were used to determine infiltration rate.

Post-Installation Potable Water Monitoring

To compare and quantify pre-implementation versus post-implementation potable water use at each site, sub-meters were installed on garden hoses (post-implementation) at each of the four sites (Figure 10). TBF conducted between 222 and 381 days of post-implementation monitoring at each site (Table 2). Pre-installation potable water use by year was compared to post-installation portable water use by year and percent reduction in water use was calculated. Additionally, monthly use was graphed to determine if seasonal trends in water use were apparent.

Figure 10. Sub-meter attached to hose for post-implementation watering.

Table 2. Number of Days of Post-Implementation Monitoring per Site

	Site 1	Site 2	Site 3	Site 4
Post-Installation Monitoring Date Range	5/18/2015 – 6/2/2016	5/28/2015 – 1/5/2015	6/15/2015 – 6/2/2016	7/21/2015 – 5/4/2016
Post-Installation Monitoring Days	381	222	336	277

Post-Installation Stormwater Monitoring

Estimating stored and infiltrated stormwater is a useful measure to analyze the direct environmental benefits provided by the installation of the rainwater harvesting methods. Post-implementation stormwater monitoring consisted of a bioswale capacity assessment during a 1.49-inch storm (January

6-7, 2016), calculating average annual stormwater capture, and projection pollution reduction calculations.

During the first week of January 2016, the National Weather Service predicted a large storm system moving into the area. The rain garden at Site 2 was selected since observations from an earlier storm (>0.25 inch) showed it was only one to significantly pond.

Stormwater Runoff Calculations

Two values were calculated in determining total average stormwater runoff: roof catchment area and yard size. Each were calculated by multiplying catchment area (square feet), rainfall (inches), coefficient, and 0.623 (to convert square inches into gallons).

The following equation calculates the average annual runoff per downspout or lawn with appropriate coefficient

Area of Roof or Lawn (Catchment Area) (sq ft)	x	Rainfall (in.)	x	Coefficient	x	0.623 (converts square inches into gallons)	=	Runoff (gallons)

Computing roof areas and dividing by half since only approximately half of the roof runoff will be captured via two downspouts, we get runoff values ranging from 525 to 1050 gallons. Likewise, for each yard we get values ranging from 226 to 317 gallons.

Collectively, a 1-inch storm will yield about 1858 gallons of roof runoff and nearly 1094 gallons of yard runoff for a combined total of 2952 gallons (Table 3).

Table 3. Roof and lawn stormwater catchment area and for runoff potential for all project sites.

	Site 1	Site 2	Site 3	Site 4	All Sites
Rainfall (inches)	1	1	1	1	1
Roof Catchment Area (sq ft)	525	815	1050	750	--
Roof Runoff (gallons)	311	482	621	444	1858
Yard Size (sq ft)	1373	1036	1454	1155	--
Yard Runoff (gallons)	299	226	317	252	1094
Total Runoff (gallons)	610	708	938	696	2952

Pollution Reduction

Capturing and infiltrating stormwater also reduces the amount of pollutants entering waterways and the ocean. Pollutant reductions were calculated by multiplying residential stormwater pollutant load constants found in the National Stormwater Quality Database by the estimated number of gallons captured annually (Pitt et al. 2004; Table 4). All pollutant reductions were converted from milligrams per liter to ounces per gallon.

The following equation estimates pollutant reductions achieved through stormwater captured:

Pollutant reductions	**=**	**(Stormwater captured**	**x**	**3.785)**	**x**	**(Pollutant load constant**	**÷**	**1000)**	**x**	**0.1335**
oz/gal	=	gallons	x	gallons to liters	x	mg/L	÷	convert mg/L to g/L	x	convert g/L to oz/ gal

Table 4. Pollutant reduction constants by constituent.

Constituent	Constant (mg/L)
Nitrite + Nitrate	0.6
Oil and Grease	3.9
Total Phosphorous	0.3
*E. coli**	700
Arsenic	0.0030
Cadmium	0.0005
Copper	0.0120
Lead	0.0120

* *E. coli* measured as Most Probable Number

Cost-Effectiveness

To evaluate cost-effectiveness, the expenses were calculated for labor and supplies for each site and added together to assess the total cost of rain garden installation per site. Supplies and materials included renting equipment to create the bioswale, purchasing native plants, and additional required supplies such as mulch, boulders, weed abatement paper, etc. The area of each yard was calculated by multiplying length by width for each area and then added together for each site. Cost per square foot was determined by dividing the total cost of each site by the total number of square feet of lawn that was replaced. The number of volunteer hours was multiplied by the 2015 California volunteer rate ($27.59), as estimated by Independent Sector, to estimate potential additional cost (https://www.independentsector.org/volunteer_time). Lastly, potable water savings estimates were calculated based on the total number of gallons saved per year and using the current water rates (per HCF) from Los Angeles Department of Water and Power (www.ladwp.com).

Results

Saving water, whether through conservation or by stormwater capture, can be accomplished with something as simple and as elegant as a rain garden. Across all sites, potable water use plummeted, stormwater was diverted, and native plants blossomed and bloomed giving sustenance and support to birds, bugs, and animals alike.

Pre-Installation Potable Water Monitoring

For a period of at least six months, each site was monitored to determine how much water individual front lawns received. The calculated annual pre-implementation water consumption rates ranged from 11,715 gallons per year (Site 4) up to 28,540 gallons per year (Site 2) (Table 5). It should be noted, that the homeowners chosen already had a conservative approach to water use – their lawns were not very green; however, they were eager to do more. Homeowners with more typical potable water use, will see greater savings.

Table 5. Pre-implementation potable use per site.

	Site 1	Site 2	Site 3	Site 4
Pre-Implementation Monitoring Date Range	8/18/2014 – 3/21/2015	8/18/2014 – 5/22/2015	12/16/2014 – 6/14/2015	1/3/2015 – 7/14/2015
Monitoring Days	215	277	180	192
Gallons (total sub-meter reading)	8,405	5,808	4,977	2,641
Number of Sprinkler Heads Included	6 out of 12	9 out of 22	7 out of 15	6 out of 14
Total Gallons *	16,810	14,197	10,665	6,162
Yearly Extrapolation **	28,538	18,707	21,626	11,714

*Total gallons = gallons x (total sprinklers / # sprinklers monitored)

**Yearly extrapolation = total gallons / (days monitored / 365)

Pre-Installation Stormwater Monitoring

To determine stormwater runoff during a storm, an innovative diversion method was designed that was highly mobile, inexpensive, and easily customizable for a variety of residential property settings. However, California experienced an historic drought during the project period (roughly June 2014 – June 2016), and the lack of rainfall significantly impacted the ability to monitor and survey storm events during the wet seasons. Only two rainfall events exceeded 0.15 inches after the final sampling design was developed, and only two properties were surveyed using the design. The slope of the yard and lawn was not sufficient to redirect stormwater from either property, and the final design was found to be ineffective. In lieu of *in situ* monitoring, standardized calculations and equations were applied to take advantage of known coefficients using drainage area, lawn size, roof catchment, and runoff volumes. Rainfall for the pre-installation period was estimated at 8 inches total and the roof catchment runoff and lawn runoff equations were used to estimate total pre-installation stormwater runoff (Table 6). As can be seen, over 23,560 gallons were lost to that storm season. Detailed equations are described in the "Post-Installation Stormwater Monitoring" methods section, below.

Table 6. Estimated stormwater water runoff from roofs and lawns at all sites.

	Site 1	Site 2	Site 3	Site 4	Total Gallons
Rainfall (inches)	8	8	8	8	8
Roof Catchment Area (two downspouts) (sq ft)	525	815	1,050	750	--
Roof Runoff (gal)	2480	3849	4959	3542	14830
Lawn Size (sq ft)	1373	1036	1454	1155	--
Lawn Runoff (gal)	2388	1802	2530	2010	8730
Total Runoff (gal)	4868	5651	7489	5552	23560

Rain Garden Installations

Roof Catchment Runoff Calculation

Roof catchment area was determined for each site by calculating the total roof area and dividing by two. Each site had two out of the four downspouts directed towards either installed rain barrels or the rain garden bioswale. Using the roof catchment runoff equation, total runoff in gallons, was calculated for all four sites under a 1-inch storm scenario and a historic yearly precipitation average scenario. Under a 1-inch storm scenario, the total roof runoff potential for all sites was 1,858 gallons. Applied to a historic yearly precipitation average of 13.4 in/year for the region, the total roof runoff potential for all sites was 24,897 gallons. Roof catchment areas and stormwater runoff potential for each site are listed in Table 7.

Table 7. Roof catchment areas and stormwater runoff estimates by site.

	Site 1	Site 2	Site 3	Site 4	Total Gallons
Roof Catchment Area (sq ft)	525	815	1050	750	--
1-inch Storm (gal)	311	482	621	444	1858
Historic Yearly Precipitation Average (13.4 in.) (gal)	4167	6458	8321	5949	24897

Lawn Runoff Calculation

Using the lawn runoff equation, total runoff in gallons, was calculated for all four sites under a 1-inch storm scenario and a historic yearly precipitation average scenario. Table 8, shows a significant amount of water is lost to runoff, lacking time to infiltrate into saturated soils. Under a 1-inch storm scenario an estimated 1,094 gallons runoff all sites combined. Under a yearly precipitation average of 13.4 in/yr for the region, the total lawn runoff potential for all sites was 14,659 gallons.

Table 8. Lawn areas and stormwater runoff estimates by site.

	Site 1	Site 2	Site 3	Site 4	Total Gallons
Lawn Area (sq ft)	1373	1036	1454	1155	--
1-inch Storm (gal)	299	226	317	252	1094
Historic Yearly Precipitation Average (13.4 in.) (gal)	4010	3026	4248	3375	14659

Bioswales

Bioswales were customized, in terms of design and function, specifically for each site. Contour and flow were dictated by downspout locations, existing walkways, and aesthetic considerations. From a flat lawn, bioswales were dug (up to 2-feet deep) and bermed several inches to maximize capacity. Bioswales comprised about 25 to 30% of the area; the rest functioning as uplands (Table 9).

Table 9. Estimated area of bioswale per yard.

	Site 1	Site 2	Site 3	Site 4
Roof Catchment Area	525	815	1050	750
Yard Size (sq ft)	1373	1036	1454	1155
Bioswale Area (sq ft)	412	311	436	347

Plants

The number and type of plant each site received depended on the size of the front yard and bioswale design. Regardless of these specifics, the plant palette included drought-tolerant native plants suited to the Los Angeles region. In total, over 1,500 plants were planted including common yarrow (*Achillea millefolium*), Santa Barbara sedge (*Carex barbarae*), clustered field sedge (*Carex praegracilis*), hummingbird sage (*Salvia spathacea*), and beardless wild rye (*Leymus triticoides*) (Appendix A; Figure 11). The total number of plants installed ranged from 315 (Site 4) to 480 (Site 1).

Recorded post-implementation potable water use was used exclusively for plant establishment. Potable use continued to drop as plants required less and less water over time. Eventually the plants will not require any supplemental watering, and use should drop to virtually zero.

Figure 11. Plants in spring bloom at Site 2 (April 2016).

Volunteers

Hundreds of volunteers played a significant role in the rain garden installations. They assisted in most phases of the work from start to finish. Volunteers included the homeowners, neighbors, students from Loyola Marymount University, University of California Los Angeles, University of Southern California, Santa Monica College, and local high schools (Table 10; Figure 12).

Table 10. Number of volunteers and volunteer hours.

	Site 1	Site 2	Site 3	Site 4	All Sites
# Volunteers	22	37	22	21	102
# Hours	160	213	119	248	740


Figure 12. Volunteers helping install a rain garden: preparing the bioswale (left); plant vegetation (right) (May 2016).

Rain Garden

Site 1

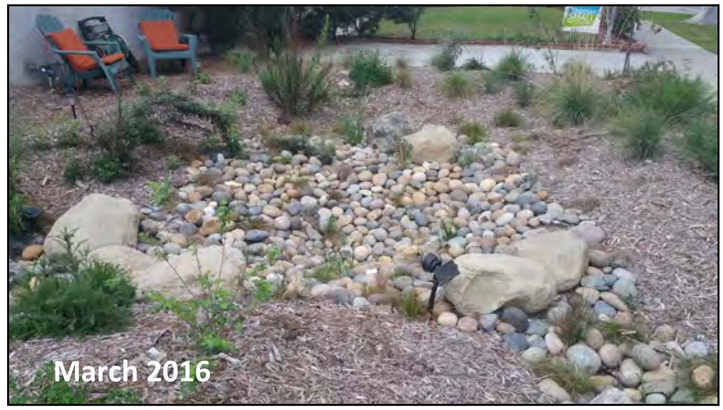

June, 27, 2014


April, 26, 2015


April, 27, 2015

Site 1

January 2016



March 2016

May 2016

July 2016

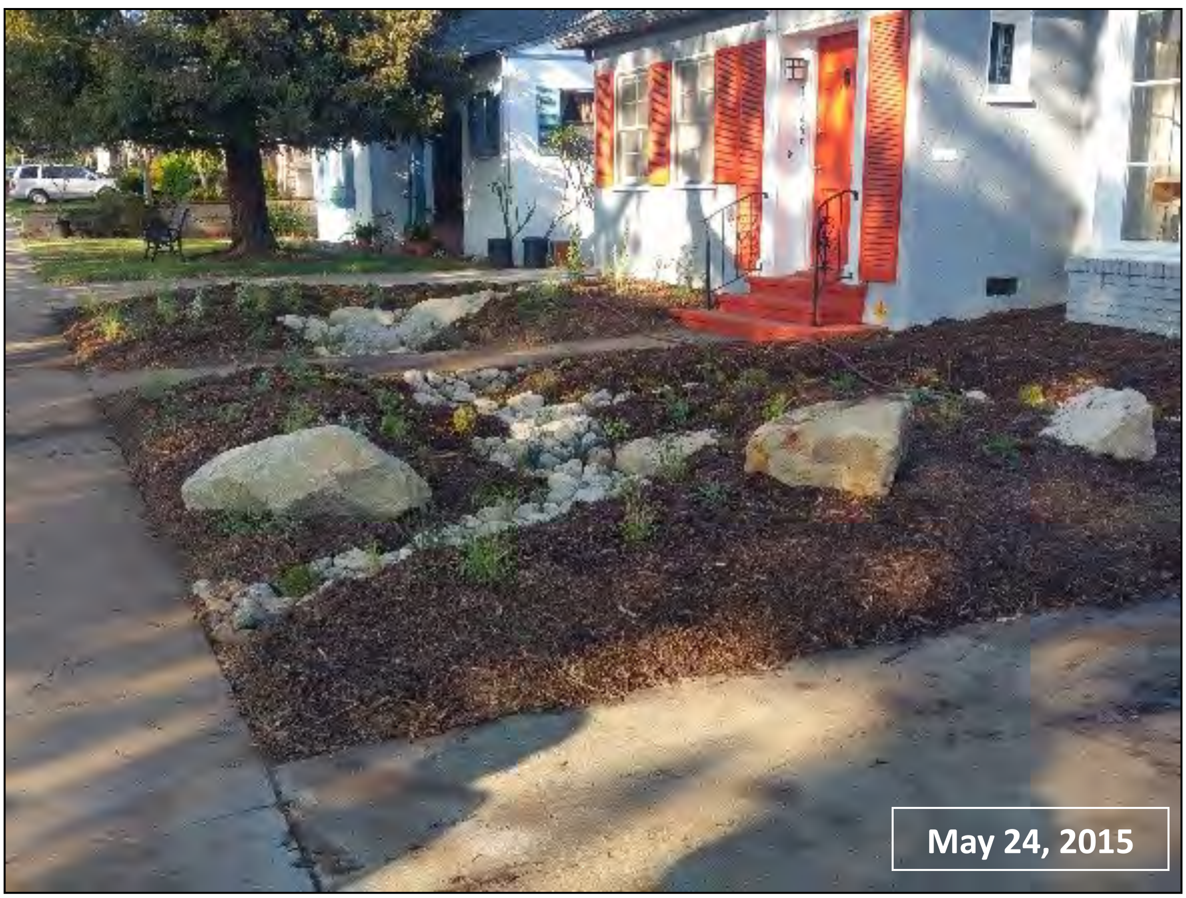
July 2016

Rain Garden

Site 2


April, 27, 2015

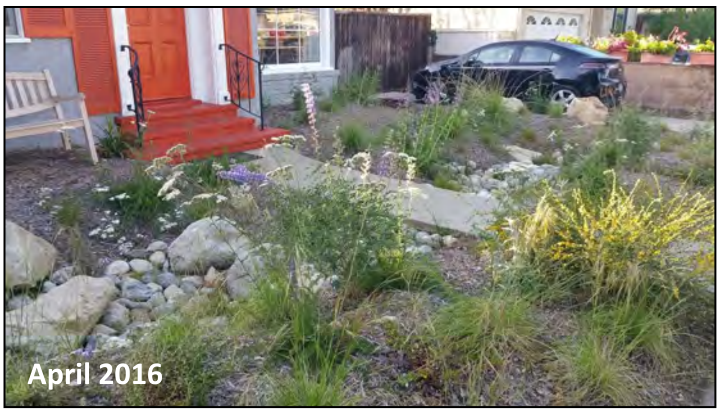

May, 23, 2015


May 24, 2015

Site 2


January 2016


March 2016

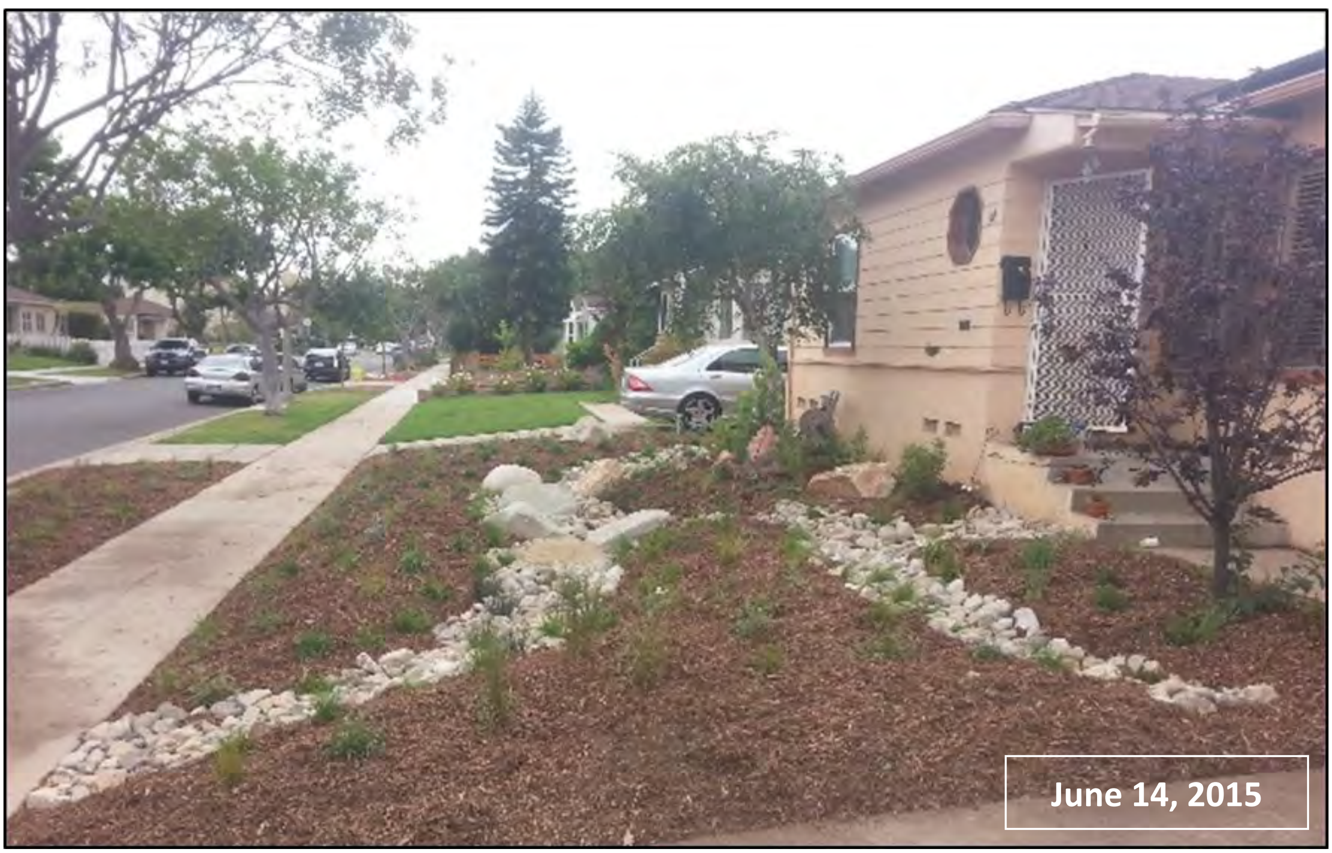

April 2016


July 2016


July 2016

Rain Garden

Site 3



Site 3


January 2016


March 2016


April2016


July 2016


July 2016

Rain Garden

Site 4


November 2014


July 30, 2015

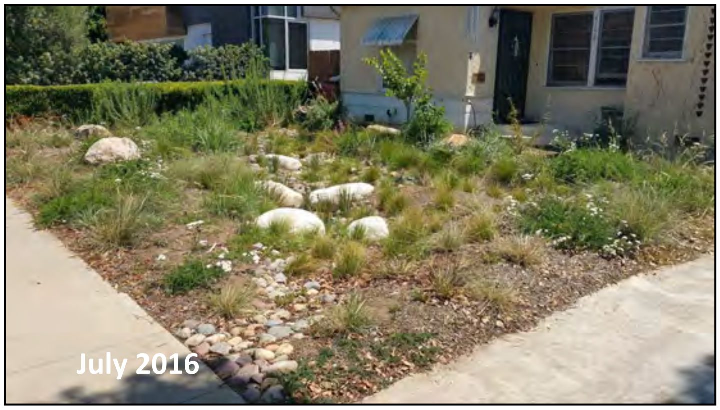

September 15, 2015

Site 4

January 2016

March 2016

April2016



July 2016

July 2016

Soil Characteristics

Soil samples from each site were analyzed to determine texture and type. First, a basic soil texture by feel protocol was performed on each sample. Results from this test are shown in Table 11, with Site 1 soil identified as clay, Sites 2 and 3 as silty clay loam, and Site 4 as silty clay. A quantitative soil texture analysis followed, resulting in the data shown in Table 12 and Figure 13. Site 1 soil was identified as clay, Site 2 soil was identified as silty clay loam, and soil from Sites 3 and 4 was identified as silty clay. All sites showed a strong clay component, ranging from 45.2% at Site 2 to 78.0% at Site 1.

Table 11. Soil texture by feel for each site.

Site	Soil Type
1	Clay
2	Silty Clay Loam
3	Silty Clay Loam
4	Silty Clay

Table 12. Soil texture by measurement for each site.

Site	Sand (%)	Silt (%)	Clay (%)	Soil Type
1	16.0	6.0	78.0	Clay
2	15.6	38.7	45.2	Silty Clay Loam
3	7.4	42.6	50.0	Silty Clay
4	11.1	42.2	46.7	Silty Clay

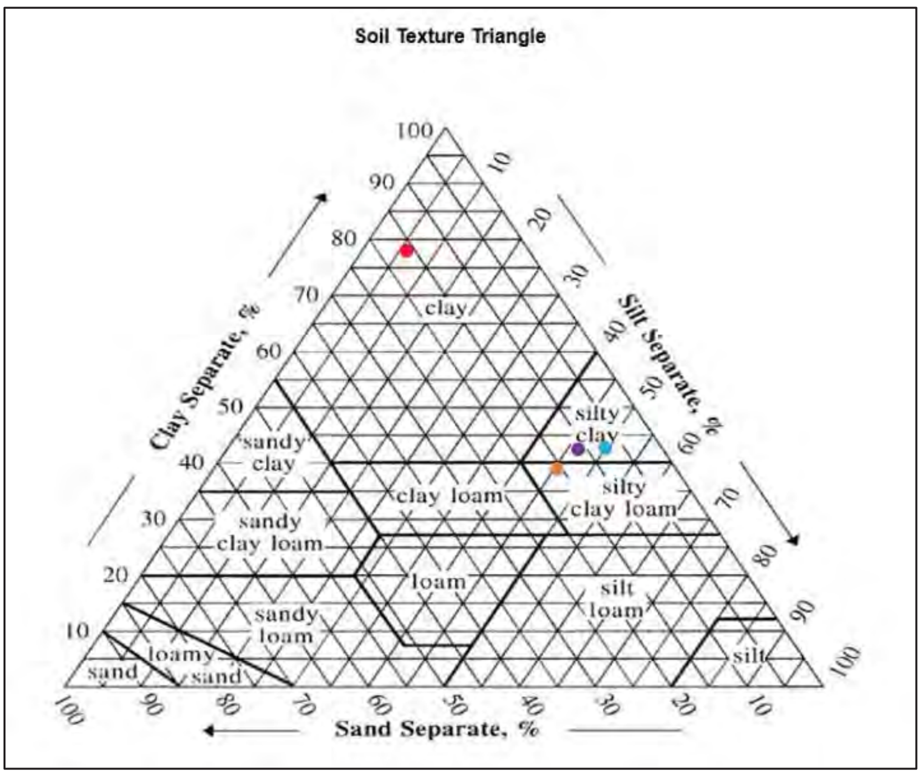


Figure 13. Soil texture by measurement results for each site overlaid onto the Soil Texture Triangle (USDA 2016).

Figure 14. Lab measurement of soil texture from individual rain garden sites.

Compared to previous grassy lawns that were relatively flat, the installation of rain gardens and bioswales created a variation of topography onsite, specifically designed to capture and infiltrate stormwater runoff. Percent elevation at each rain garden varied from 0-4% in flat areas planted with upland vegetation to over 16% in the bioswale regions. The range of infiltration, categorized by slope, per rain garden site are shown in Table 14 and Figure 15. Soil texture at Site 1 was predominantly clay, which had the lowest infiltration rates, ranging from 0.03-0.13 inches per hour. Site 2, with soil categorized as silty clay loam had the highest infiltration rates, ranging from 0.06-0.22 inches per hour. Sites 3 and 4 had soil categorized as silty clay, with infiltration rates ranging from 0.05-0.19 inches per hour (Table 13).

Table 13. Infiltration Rate (inches/hr) per soil type found at each site (USDA 1990).

		Infiltration Rate (in/hr)				
Site	Soil Type	0-4% Slope	5-8% slope	8-12% slope	12-16% slope	>16% slope
1	Clay	0.13	0.10	0.08	0.05	0.03
2	Silty Clay Loam	0.22	0.15	0.13	0.09	0.06
3	Silty Clay	0.19	0.15	0.11	0.08	0.05
4	Silty Clay	0.19	0.15	0.11	0.08	0.05

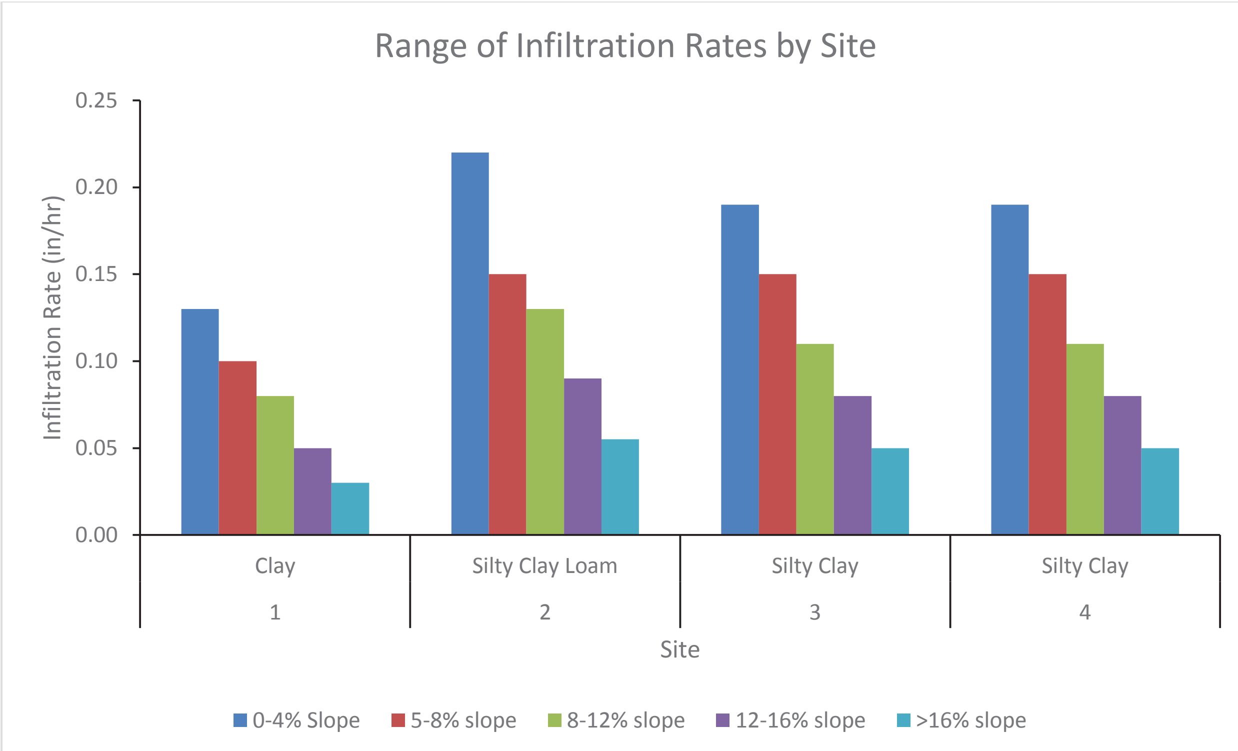


Figure 15. Range of infiltration rates by site (USDA 1990).

Post-Installation Potable Water Monitoring

Water used for the establishment of native plants (post-implementation) was compared to pre-implementation sod irrigation potable water use values (Table 14). Over the course of the monitoring period, post-implementation sub-meter data consistently showed a substantial decrease in potable water use at each site (Tables 15-19). Site 1 reduced pre-installation annual potable water use from 28,540 gallons to 1,845 gallons post-installation; Site 2 went from 18,708 gallons down to 4,311 gallons; Site 3 went from 21,626 gallons to 2,519 gallons; Site 4 used 11,715 gallons and ended at 3,548 gallons. Extrapolating the overall trend shows a substantial decrease over time, with additional consistent water use reduction since September 2015.

100% of the post-implementation potable water was retained in the gardens on-site at each location; thus, dry weather lawn runoff was reduced to zero at all sites. All sites showed significant total water use reductions ranging from 70% (11,715 gal vs 3,548 gallon) to 94% (28,540 gal vs 1,845 gal) compared to pre-implementation values (Table 14). Additionally, Sites 1 and 3 which used the most pre-implementation potable water had the lowest overall post-implementation potable water use. Site had the lowest pre-implementation water use (11,715 gal), but had the highest post-implementation usage because of over watering by her gardener.

Although sub-meters were an effective means of monitoring portable water use, on three occasions they failed. On July 30, 2015 a gardener broke one of the sub-meters, and it was replaced two days later. On January 7, 2016, another sub-meter stopped recording, likely from storm debris. Despite troubleshooting and technical support assistance, the meter was not able to be repaired. Lastly, in early May 2016, another sub-meter was broken at Site 4. Because of sub-meter cost, it was determined that sufficient data had been taken and general trends noted that the extra expense was not justified.

Table 14. Summary of post-implementation stormwater data and percent reductions per site.

	Site 1	Site 2	Site 3	Site 4
Post-Implementation Monitoring Date Range	5/18/2015 – 6/2/2016	5/28/2015 – 1/5/2015	6/15/2015 – 6/2/2016	7/21/2015 – 5/4/2016
Monitoring Days	381	222	336	277
Gallons (total sub-meter reading; one hose per site)	1,925	2610 (1)	2,319 (2)	2,693 (3,4)
Yearly Extrapolation *	1,845	4,311	2,519	3,548
Annual Extrapolated Percent Change **	- 94%	- 77%	- 88%	- 70%

** yearly extrapolation = total gallons / (days monitored / 365)*

*** annual extrapolated percent change = (pre-implementation yearly - post-implementation yearly) / pre-implementation yearly * 100*

Table 15. Potable water use reduction pre- and post-implementation (as of June 2, 2016).

Site	Pre-Implementation (gal/yr)	Overall Post-Implementation (gal/yr)	Total Water Use Reduction (%)
1	28,540	1,845	94%
2	18,708	4,311	77%
3	21,626	2,519	88%
4	11,715	3,548	70%

Table 16. Detailed pre- and post-implementation savings by accomplishment period for Site 1, Lafayette.

	TOTAL (gal)	Gallons/Year	% Reduction
Pre-Implementation	8,406	28,540	----
9/29/2015	1,049	2,858	90%
12/18/2015	1,278	2,180	92%
3/4/2016	1,290	1,618	94%
6/2/2016	1,925	1,845	94%

Table 17. Detailed pre- and post-implementation savings by accomplishment period for Site 2, Wagner.

	TOTAL (gal)	Gallons/Year	% Reduction
Pre-Implementation	5,808	18,708	----
9/24/2015	2,020	6,197	67%
12/18/2015	2,601	4,654	75%
*1/4/2016	2,610	4,311	77%

**Sub-meter stopped recording.*

Table 18. Detailed pre- and post-implementation savings by accomplishment period for Site 3, Jasmine.

	TOTAL (gal)	Gallons/Year	% Reduction
Pre-Implementation	4,977	21,626	----
9/27/2015	915	3,840	82%
12/18/2015	1,435	3,098	86%
3/4/2016	1,695	2,514	88%
6/2/2016	2,319	2,519	88%

Table 19. Detailed pre- and post-implementation savings by accomplishment period for Site 4, Kenyon.

	TOTAL (gal)	Gallons/Year	% Reduction
Pre-Implementation	2,641	11,715	----
9/25/2015	1,099	7,294	38%
12/18/2015	1,522	3,997	66%
3/4/2016	1,904	3,217	73%
6/2/2016	2,693	3,548	70%

Seasonal Variation

The average daily rate of potable water usage by site, after the rain gardens were installed, varied by month and site (Figure 16). Site 1 is the best representation of the expected pattern of water use, which included an initial phase of higher water usage immediately post-installation of the garden to acclimate the plants, little to no water use in the 'rainy season' (typically October through March or April), and with potable water use ramping back up slightly in the warmer, spring months, but to a lesser extent than the first spring/summer of installation. Site 1 seemed to also loosely follow the pattern of rainfall by month also illustrated in Figure 16, with less average water used in the months with higher rainfall (e.g. January, February, and March).

Site 2 and Site 4 both had a gardener and are good examples of inconsistent water usage due to a lack of understanding of the gardener of native plant systems. The spike of almost 49 gallons per day (average) seen at Site 2 in September was due to a significant amount of yard work and the hose being used on both the front and back yards. This suggests two things: (1) the Site 2 potable water calculation estimates were actually quite conservative, and may be more accurately reflective of about half of the estimates of readings from the sub-meter, and (2) effective communication about native landscaping is vital to conserving outdoor water.

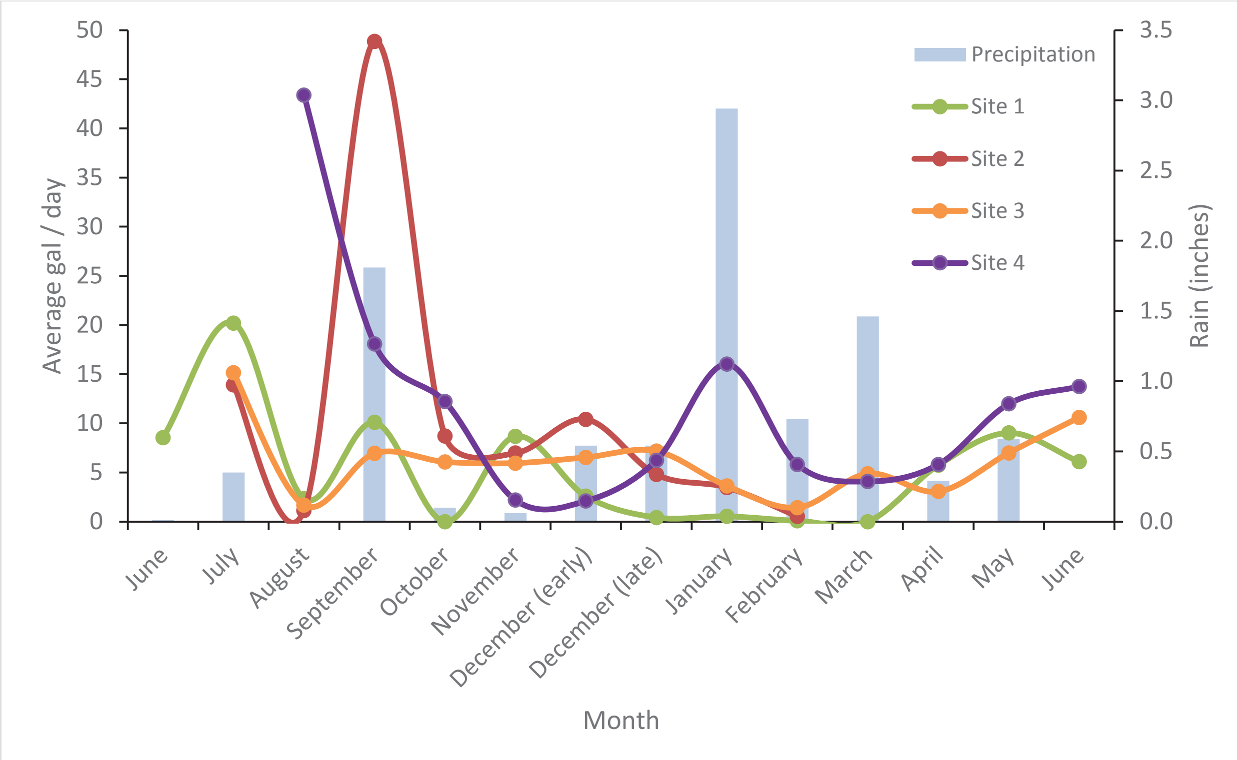


Figure 16. Average daily water use rates for each site (gallons / day).

Post-Installation Stormwater Monitoring

Despite the stormwater monitoring occurring during an El Niño year, Southern California received less than average precipitation during the 2015/16 wet season. The 2015 post-monitoring period only received 2.47 inches of rain, while 2016 received 5.21 inches. With the prediction of a >1-inch storm during the first week of January 2016, monitoring equipment was set up at Site 2 on January 4, 2016.

A 5-gallon bucket equipped with a pump, hose, and digital water meter were installed at the overflow portion of the bioswale at Site 2 (Figure 17A and 17B). The bucket sub-meter showed that the bioswale did reach capacity after the peak of a 1.49 inch storm event, but only 3.0 gallons of stormwater from the entire storm did not infiltrate (Figure 17C and 17D). It should be noted, the National Weather Service reported 1.49 inches, while an on-site rain gauge measured approximately 1.8 inches (Figure 17E). Complete post-storm infiltration was achieved by 08:00, January 6, 2016 (Figure 17F). This is a conservative estimate for all the other gardens, because after post-storm site visits, Site 2 is the only site to pond. The other three rain gardens had no post-storm ponding despite the 1.49 inch storm (photos on file). The original plan was to monitor each rain garden for overfilling, but since none of the sites ponded, it was deemed unnecessary.

Figure 17. Post-implementation stormwater monitoring (Site 2, Wagner). Pre-storm installation (1/4/2016): (A) 5-gallon bucket installed at bioswale overflow; (B) automated pump, hose, and water meter to assess installed. Post-storm assessment: (C) Bioswale overflow monitoring post-storm (1/5/2016); (D) bioswale ponding (1/5/2016); (E) on-site rain gauge (1/5/2016); (F) complete bioswale infiltration (1/6/2016).

Runoff Calculations

Roof and lawn runoff was calculated using the formula:

Area of Roof or Lawn (Catchment Area) (sq ft)	x	Rainfall (in.)	x	Coefficient	x	0.623 (converts square inches into gallons)	=	Runoff (gallons)

The average catchment area for each downspout ranged from 311 to 1050 square feet (sq ft), and for each year area from 252 to 317 gallons. As can be seen from Table 20, for just a 1-inch storm each property captured an average of 2952 gallons of stormwater that would have been destined for the storm drains. Even with drought conditions, collectively nearly 23,560 gallons of storm water was saved with nearly 8-inches of rain (Table 21). Finally, given the historical average of 13.2 inches of rain and assuming it will hold over time, each rain garden would save on average 10,000 gallons yearly or over 41,000 gallons combined (Table 22).

Table 20. Roof and lawn runoff estimates from a 1-inch storm.

	Site 1	Site 2	Site 3	Site 4	All Sites
Rainfall (inches)	1	1	1	1	1
Roof Area (sq ft)	525	815	1050	750	--
Roof Catchment Runoff (gal)	311	482	621	444	1858
Yard Size (sq ft)	1,373	1,036	1,454	1,155	--
Yard Runoff (gal)	299	226	317	252	1,094
Total Runoff (gallons)	610	708	938	696	2952

Table 21. Roof and lawn runoff estimates for post-implementation period (July 2015-May 2016).

	Site 1	Site 2	Site 3	Site 4	All Sites
Rainfall (inches)	8	8	8	8	8
Roof Area (sq ft)	525	815	1,050	750	--
Roof Catchment Runoff (gal)	2,480	3,849	4,959	3,542	14,830
Yard Size (sq ft)	1,373	1,036	1,454	1,155	--
Yard Runoff (gal)	2,388	1,802	2,530	2,010	8,730
Total Runoff	4,868	5,651	7,489	5,552	23,560

Table 22. Roof and lawn runoff estimates for average rainfall (approx. 13.4 inches).

	Site 1	Site 2	Site 3	Site 4	All Sites
Rainfall (inches)	13.4	13.4	13.4	13.4	13.4
Roof Area (sq ft)	525	815	1050	750	--
Roof Catchment Runoff (gal)	4,164	6,464	8,327	5,948	24,903
Yard Size (sq ft)	1,373	1,036	1,454	1,155	--
Yard Runoff (gal)	4,010	3,026	4,248	3,375	14,659
Total Runoff (gal)	8,174	9,489	12,576	9,323	39,562

Pollutant Reduction Calculations

Pollutant reductions were calculated by multiplying residential stormwater pollutant load constants found in the National Stormwater Quality Database by the estimated number of gallons captured annually (Pitt et al. 2004). All pollutant reductions were converted from milligrams per liter to ounces per gallon. Based on the runoff estimates given above (Tables 20-22), pollution load reductions were calculated for a 1-inch storm, post-implementation period (July 2015-May 2016), and the historical average (Tables 23-25).

Based on annual rain fall and bioswale capacity, Table X shows the estimated pollutant load reduction achieved per property and combined for all properties.

Table 23. Pollution load reduction from a 1-inch storm.

	Site 1	Site 2	Site 3	Site 4	All Sites
Pollutant (Load Constant)	Pollutant Load Reduction (oz or MPN)				
Nitrite + Nitrate (0.6)	0.216	0.194	0.222	0.202	0.90
Oil and Grease (3.9)	1.406	1.261	1.441	1.313	5.82
Total Phosphorous (0.3)	0.108	0.097	0.111	0.101	0.45
E. coli (700)*	252	226	259	236	1,044
Arsenic (0.003)	0.001	0.001	0.001	0.001	0.00
Cadmium (0.0005)	0.000	0.000	0.000	0.000	0.00
Copper (0.012)	0.004	0.004	0.004	0.004	0.02
Lead (0.012)	0.004	0.004	0.004	0.004	0.02

* *E. coli* measured as Most Probable Number.

Table 24. Pollution load reduction during post-implementation period (July 2015-May 2016).

	Site 1	Site 2	Site 3	Site 4	All Sites
Pollutant (Load Constant)	Pollutant Load Reduction (oz)				
Nitrite + Nitrate (0.6)	1.726	1.549	1.769	1.612	7.14
Oil and Grease (3.9)	11.221	10.066	11.501	10.476	46.43
Total Phosphorous (0.3)	0.863	0.774	0.885	0.806	3.57
E. coli (700)*	2,014	1,807	2,064	1,880	8,333
Arsenic (0.003)	0.009	0.008	0.009	0.008	0.04
Cadmium (0.0005)	0.001	0.001	0.001	0.001	0.01
Copper (0.012)	0.035	0.031	0.035	0.032	0.14
Lead (0.012)	0.035	0.031	0.035	0.032	0.14

* *E. coli* measured as Most Probable Number.

Table 25. Pollution load reduction given the historical average rainfall of 13.4 inches.

	Site 1	Site 2	Site 3	Site 4	All Sites
Pollutant (Load Constant)	Pollutant Load Reduction (oz)				
Nitrite + Nitrate (0.6)	2.899	2.600	2.971	2.706	11.99
Oil and Grease (3.9)	18.843	16.903	19.312	17.591	77.96
Total Phosphorous (0.3)	1.449	1.300	1.486	1.353	6.00
E. coli (700)*	3,382	3,034	3,466	3,157	13,993
Arsenic (0.003)	0.014	0.013	0.015	0.014	0.06
Cadmium (0.0005)	0.002	0.002	0.002	0.002	0.01
Copper (0.012)	0.058	0.052	0.059	0.054	0.24
Lead (0.012)	0.058	0.052	0.059	0.054	0.24

* *E. coli* measured as Most Probable Number.

Cost Effectiveness

The total cost to install each rain garden was estimated to vary between $8,000 to $11,000, with a $3,000 range between the cheapest garden and the most expensive (Table 26). The cost per square foot varied between $6.63 and $9.11 (Table 26). The average cost per square foot was $7.74. Interestingly, the cheapest cost per square foot was not associated with the largest site (Site 3), but instead was associated with Site 1, largely due to a varied implementation strategy, soil quality, and plant list for each site. At the time of the installation of the gardens, a $3.00 per square foot rebate was being offered for lawn replacement with drought tolerant species. Therefore, the average cost of per square foot with the rebate included was $4.74.

The cost per square foot was also estimated using only the cost of supplies, without including labor, and was found to vary between $3.36 and $4.02 per square foot. This would be a more representative cost for a "do-it-yourself" homeowner. The average cost per square foot of supplies only was $3.63, or $0.63 per square foot with the rebate included. Therefore, for an average Los Angeles lawn of approximately 1,000 square feet, the cost to the homeowner would be less than $650. This is a significant cost savings when compared to landscape company estimates which range from $10-30 per square foot for residential lawn replacement.

Table 26. Actual costs for labor, supplies, and evaluated per square foot for each property.

	Site 1	Site 2	Site 3	Site 4	Total
Area (sq ft)	1,373	1,036	1,454	1,155	5,018
Labor	$ 4,495.92	$ 4,215.58	$ 6,031.48	$ 5,874.00	$ 20,616.98
Supplies	$ 4,606.72	$ 3,878.40	$ 5,068.42	$ 4,646.02	$ 18,199.56
Total Cost per Site	**$ 9,102.64**	**$ 8,093.98**	**$ 11,099.90**	**$ 10,520.02**	**$ 38,816.54**
Cost / sq ft	**$ 6.63**	**$ 7.81**	**$ 7.63**	**$ 9.11**	**$ 7.74**
Cost / sq ft (no Labor)	$ 3.36	$ 3.74	$ 3.49	$ 4.02	$ 3.63

Using volunteers and helpful neighbors dramatically reduced the potential cost of rain garden installation. Without volunteers, the average cost of the garden would have risen by approximately 35%, or between approximately $3,000 and $7,000 (Table 27). The total cost to implement all four gardens would have risen to almost $60,000.

Table 27. Potential cost savings of volunteer assistance.

	Site 1	Site 2	Site 3	Site 4	Total
Volunteer Hours	160	213	119	252	744
Volunteer Match (Savings)	$ 4,414.40	$ 5,876.67	$ 3,283.21	$ 6,952.68	$ 20,526.96
Total Cost (with Volunteers)	**$ 13,517.04**	**$ 13,970.65**	**$ 14,383.11**	**$ 17,472.70**	**$ 59,343.50**

Annual water bill savings were estimated to vary between $65 and $200, conservatively, by site, or approximately 85% of each water bill (Table 28). Those savings will increase as the gardens become more established, water use continues to drop off, and as rates increase over time. Estimates do not include cost of electricity savings. If a homeowner chose the "do-it-yourself" option discussed above, and submitted a rebate, the water bill savings alone would cover the cost of rain garden installation in a few years. Additionally, if homeowners allow the native gardens to 'go wild' with minimal maintenance, they could save between $500-$1,000 annually through reducing or eliminating efforts of gardeners.

Table 28. Estimated annual water savings for each property.

	Site 1	Site 2	Site 3	Site 4	Total
Potable Water Use (Pre) (gal)	28,540	18,708	21,626	11,715	80,589
Potable Water Use (Post) (gal)	1,845	4,311	2,519	3,548	12,223
Total Potable Water Savings (gal)	26,695	14,397	19,107	8,167	68,366
Estimated Annual Savings	**$ 200.00**	**$ 110.00**	**$ 150.00**	**$ 65.00**	**$ 525.00**

The number of gallons saved per dollar spent at each property was found to be very close to the predicted average of 2 gal/dollar and varied between 0.78 at the low end to a maximum of 2.93 gal/dollar at Site 1 (Table 29).

Table 29. Gallons of potable water saved divided by cost of each site.

	Site 1	Site 2	Site 3	Site 4	Average
Gallon(s) saved per dollar spent	2.93	1.78	1.72	0.78	1.80

Outreach

To highlight and promote the Metro-ICP project, a "How-to" video was created featuring the rain garden construction at Site 1 which can be found on TBF's YouTube page (Figure 18). The homeowner of Site 1 also produced two videos, one made shortly after the rain garden was installed (April 2015; Video 1) and the other a year after rain garden completion (April 2016; Video 2).

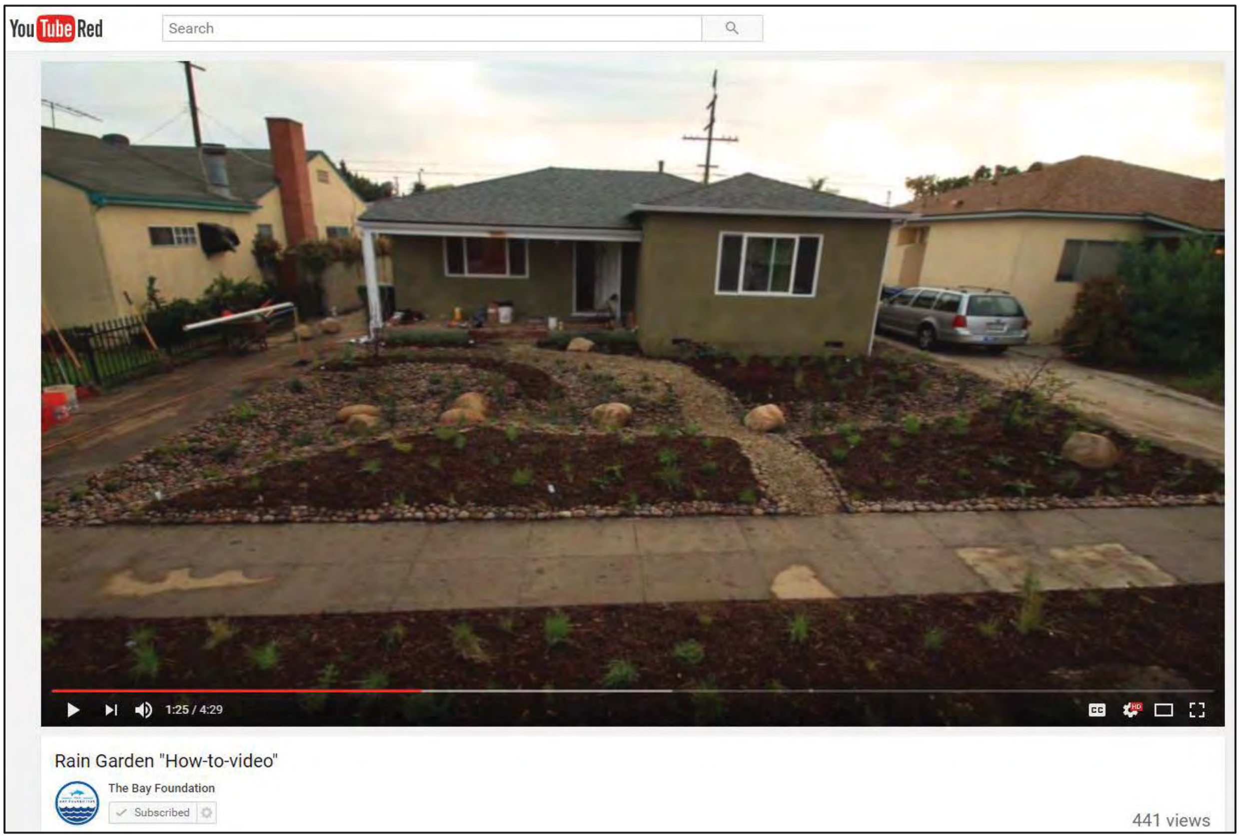


Figure 18. Screenshot of TBF's 'Rain Garden "How-to-video"' https://youtu.be/yG94TuZWUDw.

Overcoming Challenges and Lessons Learned

Several challenges were encountered during the grant period, which loosely fall into two categories, including: monitoring implementation and rain garden installation. These challenges were overcome in a variety of ways, and may be important for organizations or individuals looking to install or monitor rain gardens and implement other rainwater harvesting strategies.

Monitoring Implementation

Several challenges were overcome during the pre- and post-installation potable water and stormwater monitoring periods, including: (1) drought (lack of rainfall for stormwater monitoring); (2) installation of stormwater monitoring equipment; and (3) failure of potable water monitoring equipment.

Due to the lack of appropriate rainfall events (i.e. minimum duration of several hours and minimum rainfall of 0.25 inches), only two properties were monitored for stormwater runoff volume during the pre-installation monitoring phase. Unfortunately, the time span included the driest January ever recorded in California's history. Even lengthening the initial stormwater monitoring time frame was not enough to capture any significant storm events. This may present an ongoing challenge to other organizations and individuals hoping to collect stormwater data as a component of their projects or programs.

During each of the two stormwater monitoring events the preferred monitoring system (mobile dam and bucket/pump system) was deployed. Due to the lack of appropriate rainfall events (minimum of 0.15") following the identification of the final sampling design, only two properties were monitored for stormwater runoff volume. Unfortunately, the sampling was scheduled over a time span which included the driest month ever recorded in California's history (January). This wet season has had a complete dearth of acceptably-sized storm events, and has therefore reduced our ability to successfully sample stormwater runoff at all locations. As an alternate solution to this problem and to adequately calculate stormwater runoff volumes, equations which take advantage of known runoff coefficients can be used. Drainage area was measured for each project site and coefficients were used to calculate runoff volumes from the roof and yard with the proper infiltration coefficient applied to each land use type and slope (see Pre-Implementation Stormwater Monitoring in methods above). This method is an acceptable alternative to approximate the volume of stormwater precipitating on the project site and the runoff leaving the property.

Additionally, three of the sub-meters for potable water monitoring stopped working partway through the post-installation potable water savings monitoring period. The first one broke at Site 4 on July 30, 2015 after the gardener dropped it. It was replaced on August 1, 2015 with the sub-meter designated for post-implementation stormwater monitoring. A replacement was ordered. The second meter stopped working on January 5, 2015 during stormwater monitoring at Site 2, possibly from sediment. The meter was cleaned, technical support consulted, but without solution. A replacement was not ordered. The third sub-meter broke at Site 4 sometime at the end of May 2016.

The sub-meter malfunctions increased in frequency and duration as the post-installation potable water monitoring progressed. While an additional back-up sub-meter was purchased to rectify the issue, towards the end of the grant period several more failed. On-site troubleshooting could not resolve the problem. Because of sub-meter expense, working with the manufacture to resolve problem was attempted before investing in a replacement. Unfortunately, funds were not located before the completion of the monitoring period.

Another challenge was the difficulty one homeowner had in getting the gardener to cut back potable water use. While other sites achieved dramatic post-implementation reduction, often close to their peak, Site 4's reduction was more gradual. It was only once the gardener adapted a more sustainable watering practice that Site 4's potable water usage decreased.

Rain Garden Installation

The four residential rain gardens matured beautifully and performed their functions of stormwater capture and potable water savings; however, the project was not without its challenges.

Site Selection

The first challenge encountered in the grant period was a lack of interest from commercial property owners in installing rain gardens on their properties. TBF's original proposal was to attempt two commercial rain gardens and two private rain gardens, all of comparable size for the purposes of data collection. However, reaching agreements with commercial property owners proved to be too difficult due to the structure and management of the eight properties that were evaluated as part of this project. Often there were too many management levels including individual on-site personnel, maintenance staff, site managers, owners, etc. It was not possible to draft a Memorandum of Understanding for any of the potential project areas where ongoing maintenance of the site after the installation of the gardens would be taken on by the owners. Also, site restrictions such as inaccessible downspouts, no recent potable water use history, and/or inadequate lawn size further made commercial property difficult. These set-back is valuable information to implement future projects of this scale. Additional resources may be needed when attempting to implement rainwater harvesting strategies on larger properties, and a higher level of understanding and commitment is needed.

Soils

As part of the project, attempts were made to focus efforts on choosing residential properties that had clay soils or soils that had very little natural infiltration. These types of soils made the implementation of the rain garden a bit more difficult, such as in contouring and digging the bioswale to depth and boring several infiltration galleries for added capacity. However, the success of each of the gardens to infiltrate a significant storm event (i.e. > 1in) shows that this strategy of rainwater harvesting and capture can be an effective tool even in clay soils with low infiltration rates.

Invasive Plants

Although rain gardens need far less maintenance than convention lawns, during establishment period where native plants need time to mature, routine weeding might be required. During the installation process, reasonable care is made to extricate all non-native vegetation and roots; however, some might have been missed or blown in. Homeowners have communicated that routine weed management has been necessary.

Conclusions and Recommendations

Rainwater harvesting is the process of intercepting rainwater from a roof, lawn, or other surface and utilizing it for beneficial purposes. By implementing rainwater harvesting techniques, residents gain access to an extra supply of water while reducing the pressure on limited potable water supplies. A rainwater harvesting program provides many benefits to the participants, local and regional communities, municipalities, water agencies, the environment, and many others. These benefits include protecting our bays and ocean from stormwater runoff and pollution, conserving water, reducing energy use, and recharging groundwater.

Through a grant from the Metropolitan Water District's Innovative Conservation Program, this project explored the effectiveness of rain gardens as a rainwater harvesting strategy, also evaluating their implementation as a potential cost-effective technique. The methods and structure developed as part of this project are replicable by individual homeowners, businesses, or larger commercial properties.

Many advantages of rain gardens were effectively highlighted as part of this project, including flood protection, stormwater capture and pollutant reduction, water infiltration, lowering maintenance needs and landscaping costs, and lowering potable water and energy bills. Additional advantages not evaluated by this project include factors like aesthetic benefits, sediment capture, and a healthier outdoor space through native California plants (over lawn grasses), which provide habitat for birds, butterflies, and other beneficial insects and wildlife. Disadvantages associated with this particular rainwater harvesting technique are often tied to costs associated with implementing any significant change in an outdoor space or yard; however, this project explored ways to reduce those costs.

The cost per square foot of rain garden installation was found to be highly variable and dependent on the individual conditions of each site. Cost-effectiveness was not found to scale up with increase in the size of an individual rain garden, but instead, appeared to be tied to specific characteristics of the individual sites. Recommendations associated with cost savings include "do-it-yourself" options that would negate the cost of labor for installation, solicitation of helpful neighbors and volunteers, and a rebate submission (if available) from your water provider. Additionally, a conservative approach to yard watering will always be a more cost-effective option than a perpetually green lawn, and native plants will serve to significantly decrease potable water costs and increase potable water and energy savings.

Homeowners who were approached for this project in 2014 were already starting to implement drought-adaptability and water conservation measures and restrictions on their lawns such as watering limits by time and day; thus, savings for this project may be understated, if scaled to a city-wide or region-wide level. If all residents were evaluated with the ability to change their water use behaviors, these results would likely still be significantly underestimated for the greater Los Angeles region (depending on individual water use).

Soil characteristics were an important component of the evaluation of rainwater harvesting techniques and rain garden design. Fine, clay-based soils infiltrated less stormwater than sand- and silt-based soils. However, this project demonstrated that, contrary to popular belief, poor infiltration rates normally associated with predominantly clay soils will still successfully and functionally capture stormwater. Proper design of rain garden components including bioswale placement, vegetation spacing, soil aeration, infiltration galleries, and soil amendments, will all increase the infiltration of clay-based soils to produce a fully functioning rain garden.

At the level of four rain gardens, stormwater infiltration, while significant by site, had lower inputs of pollutant load reduction than if implemented on a region-wide scale. However, applying the calculator for stormwater pollutant load reduction techniques city-wide would have a significant positive impact on water quality and public health. Additional rainwater harvesting strategies are recommended, such as bioswales along easements with curb cuts to allow stormflow to be diverted and taken off the street. Stormwater and pollutant reduction data from this project may serve to inform climate change efforts in the Los Angeles region.

Outreach and availability of online resources, rebates, and application strategy websites seem to be a potentially limiting factor in the broad-scale implementation of rainwater harvesting strategies. We recommend the development of a submission form on agency websites where interested residential or commercial property owners could apply to be on a list for future projects. This may populate a listserv database to more easily target large residential and commercial property owners, and the recommendation would solve one of the more significant early challenges of this project. Even in a drought, rainwater harvesting strategies reduce potable water consumption and provide the opportunity for the implementation of additional rainwater harvesting strategies. We also encourage interested residents to review our online materials, such as the rain garden YouTube videos.

If rain garden projects are implemented on a larger residential or commercial scale, it is likely that the benefits would scale up in a correlated manner, e.g. additional stormwater pollution reduction, higher infiltration rates, etc. To achieve more significant programmatic capabilities, additional agency funding for rain garden programs would be beneficial. As all new projects can't necessarily be innovative, it's important to secure a long-term funding source to supplement efforts by homeowners and commercial property owners to retrofit their outdoor spaces to be better equipped to face climate change, drought, increasing frequency/intensity of storm events, etc. Inclusion of more partners would subsequently reduce potential program costs for an individual agency. Additional potential partners could include sanitation districts, stormwater or groundwater management agencies, flood control districts, resource agencies, and environmental or community organizations. Diversifying responsibilities and funding among multiple entities will help ensure the long-term viability of the program.

Since 1988, the mission of The Bay Foundation has been to improve water quality, conserve and rehabilitate natural resources, and protect the Santa Monica Bay and surrounding watershed's benefits and values. The work on this grant has strengthened this mission creating the opportunities to develop new strategies to continue and enhance these goals. We look forward to working with the Metropolitan Water District to further our common goals.

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Appendix A: Plant List

Plant	Common Name	Site 1	Site 2	Site 3	Site 4
Achillea millefolium	Common yarrow	X	X	X	X
Artemisia douglasiana	California mugwort	X	X	X	-
Carex barbarae	Santa barbara sedge	X	X	X	-
Carex praegracilis	Clustered field sedge	X	X	X	X
Carex spissa	San diego sedge	X	X	X	X
Cercis occidentalis	Redbud	X	-	X	-
Eriogonum parvifolium	Sea cliff buckwheat	X	X	X	X
Isocoma menziesii	Menzies' goldenbush	-	-	X	X
Juncus balticus	Baltic rush	-	-	-	X
Juncus mexicanus	Mexican rush	X	X	X	-
Juncus patens	Common rush	X	X	X	X
Juncus xiphioides	Iris leave rush	X	-	-	-
Leymus condensatus	Giant wild rye	X	-	-	-
Leymus triticoides	Beardless wild rye	X	X	X	X
Lotus scoparius	Deerweed	X	X	X	X
Lupinus albifrons	Silver lupine	-	-	X	X
Lupinus longifolius	Long leaf bush lupine	X	X	X	-
Mimulus aurantiacus	Sticky monkeyflower	X	X	X	X
Mimulus cardinalis	Cardinal monkey flower	X	X	X	X
Muhlenbergia rigens	Deergrass	X	X	X	X
Penstemon centranthifolius	Scarlet bugler	-	-	X	X
Penstemon spectabilis	Showy penstemon	X	X	X	X
Rosa californica	California wild rose	X	X	X	-
Salvia leucophylla	San luis purple sage	-	X	X	X
Salvia spathacea	Hummingbird sage	X	-	X	X
Sambucus mexicana	Blue elderberry	-	-	X	-
Satureja douglasii	Yerba buena	-	-	X	-
Sisyrinchium bellum	Western blue eyed grass	X	X	X	X
Stipa pulchra	Purple needle grass	X	X	X	X
Zauschneria californica	Hummingbird trumpet	X	X	X	X
	Total # Plants by Site	**408**	**387**	**372**	**315**