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Testing a Bioswale to Treat and Reduce Parking Lot Runoff

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Abstract

A bioswale integrating Davis Soil (a mixture of Lava Rock and regular soils) and trees was installed in a parking lot on the University of California Davis's campus to evaluate the system's effectiveness on reducing storm runoff and pollutant loading from the parking lot and supporting tree growth. The control and treatment (best management practices or BMP) sites each had 8 parking spaces. These two sites were adjacent to one another and identical with the exception being that there was no Davis soil bioswale retrofit for the control site. A tree was planted at both sites. Storm runoff, pollutant loading, and tree growth were measured and monitored during February 2007 thru October 2008. There were 50 total storm events with a total precipitation of 563.8 mm (22.2 in) during this period. Compared with the runoff from the control site, the BMP site reduced amount of surface runoff by 88.8%. The loading reduction for nutrients, metals, organic carbon, and solids were 95.3%, 86.7%, 95.5%, and 95.5%, respectively. The total loading reduction was 95.4%. Petroleum hydrocarbons (i.e., gas, diesel, and motor oil) from both sites were below the laboratory detectable limit. The nature of Davis soil proved a better aeration and drainage system for tree roots during high moisture season. The performance of this BMP demonstrated its potential use for reducing runoff from parking lot and supporting tree growth.

Introduction

Increasing urbanization has resulted in the construction of more roads and parking lots, significantly increasing the amount of impervious land cover in our towns and cities. (Arnold and Gibbons, 1996). Impervious land cover alters surface runoff in both quantity and quality because of the effects on surface retention storage, rainfall interception, and infiltration. Large volumes of excess storm water runoff from urbanized areas cause flooding, water pollution, groundwater recharge deficits, destroyed habitat, beach closures, and toxicity to aquatic organisms (Greenstein et al., 2004; USEPA, 2005). Runoff from parking lots has unique flushing effects (Black, 1980). Best Management Practices (BMPs) have been developed to reduce parking lot runoff and pollutant loading. These BMPs include low-impact parking lot designs (Rushton, 2002; Rushton, 2001) as alternatives to traditional parking lots. The BMPs are decrease runoff and pollutant loads and include onsite treatments such as sand filters (USEPA, 1999), permeable pavement (Booth and Leavitt, 1999), and other types of treatment systems (Sonstrom et al., 2002). Vegetation has been used and recommended by US-EPA as one of the BMPs to clean pollutants and thus improve water quality (Barrett et al., 1998; Cheng, 2003; Liu et al., 2007; Matteo et al., 2006; US-EPA, 2004; Vyslouzilova et al., 2003). Vegetation reduces surface runoff by canopy interception (Xiao et al., 2000a) and improves infiltration of compacted subsoil (Bartens et al., 2008). Some of the intercepted rainwater will never reach the ground surface to produce surface runoff. Research also reports that rainfall interception may exceed 59% for old growth forests (Baldwin, 1938). Increasing canopy cover is one solution to reducing surface runoff. Indeed, there are stormwater fee credit programs in many US cities and trees are being used as a BMP for reducing stormwater runoff (Austin, 2007; BES, 2008; City of San Jose, 2007; Greensboro, 1996; Herrera Environmental Consultants, 2008)

Impervious land cover not only causes environmental problems downstream but also creates many problems that affecting our daily quality of life. Urban heat islands (Simpson et al., 1993; Swaid and Hoffman, 1989; Taha et al., 1991) and air quality problems (McPherson et al., 2000; Nowak et al.; Scott et al., 1999; Simpson et al., 1999; Smith, 1978) are directly caused by impervious land cover and the lack of vegetation cover. Tree planting programs have been established in many cities across the United States (such as Los Angeles, CA, Sacramento, CA, Denver, CO, and New York, NY etc.) to improve urban air quality and reduce the urban heat island (Hickenlooper, 2008; McPherson et al., 2008; STF, 2008). Many cities in California have established parking lot ordinances that require 50% canopy shading and treatment of storm runoff on site for storms with up to 10-year return frequencies (McPherson, 2001). However, tree growth and shading are often less than required due to problems such as inadequate soil volume, drainage, and aeration of these packed subsoils. Polluted urban soils due to lack of vegetation have caused environmental problems, including groundwater contamination (Mikkelsen et al., 1997) and the growing risk of heavy metal uptake by humans and livestock (Camobreco et al., 1996; Moller et al., 2005).

More recently, green infrastructure technology (Day and Dickinson, 2008) has integrated engineered soil and vegetation to treat and store parking lot surface runoff. Engineered soils, a mixture of stones and regular soils, are friendly to trees in urban environments and have higher porosity as compared with regular urban soil (Costello and Jones, 2003; Smiley et al., 2006). The larger volume of pore space provided by the highly porous, engineered soil provides more space for temporarily storing surface runoff (Day and Dickinson, 2008; Xiao and McPherson, 2008) and supports larger growing trees by providing pore space for water and air that promotes deep rooting. This also reduces the heaving of sidewalks, curbs and gutters by tree roots (Grabosky and Bassuk, 1995; Grabosky and Bassuk, 1996; Smiley et al., 2006).

Davis soil offers several advantages over other engineered soils. It is made of natural materials (75% lava rock and 25% loam soil) that are readily and inexpensively available in California. Because the main structural element is lava rock, the soil is very porous, so it stores more stormwater and makes more water available to the trees. The lava rock also has a very high surface area to volume ratio and, therefore, more nooks and crannies to trap pollutants (Xiao and McPherson, 2008). Reducing surface runoff reduces pollutants traveling downstream into the receiving water body. Laboratory experiments had indicated the potential to use Davis soil and vegetation as BMPs in runoff management (Xiao and McPherson, 2008). However, it is unclear how effective this system will be when used in everyday practice.

In this study a bioswale with Davis soil and a tree was constructed in an existing parking lot, and its performance was compared with an adjacent control in terms of pollutant removal rates, storm-runoff reduction capacity, and its ability to support tree growth.

Methods

Study Site

The study site was located at the University of California Davis's parking lot 47A at the corner of La Rue Drive and Dairy Road (Figure 1a). The micro-topography of the parking lot was elevated and evenly sloped toward north and south sides. The runoff from the north side flowed to a turf grass area. Runoff from the south side drained into the peripheral landscape along La Rue Drive. The overflow from the peripheral landscape drained into the street. A treatment site and a control site sat side by side at the southwest corner of the parking lot (Figure 1b). The treatment and the control sites had exactly the same dimensions.

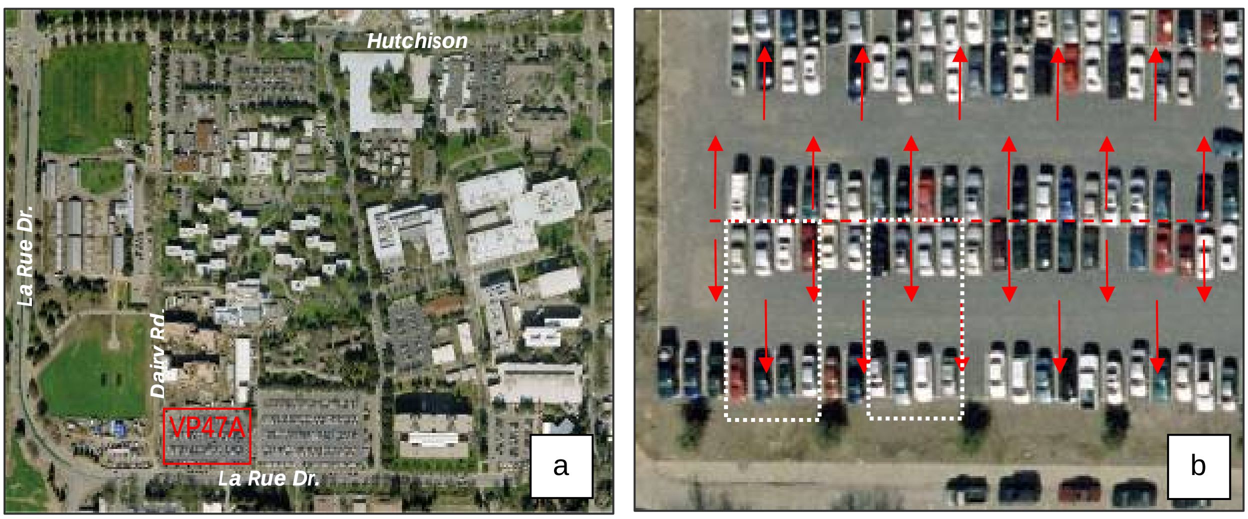

Figure 1. Study site: a). Parking lot 47A was located in the southwest region of this imagery. b). Detailed surface drainage (the line with arrows) of the southwest corner of the parking lot where the experiment was conducted. The study sites are outlined in both images.

The parking lot study site was used as a regular parking lot for a dormitory during 2007. Beginning in June 2008 it was used as a staging area for a nearby campus construction project.

Experiment Setup

A treatment site (34.0 ft (10.4 m) x 57.0 ft (17.4 m)) included eight parking spaces and a buffer strip (2.0 ft (0.6 m) x 34.0 ft (10.4 m)) between the parking spaces and the bioswale. The bioswale was 34.0 ft (10.4 m) long, 8.0 ft (2.4 m) wide, and 3.0 ft (0.9 m) deep. Two pieces of (57.0 ft (17.4 m) long, 0.4 in (1.0 cm)) diameter ropes were placed on the east and west edges of the parking lot to form the two edges of the treatment site. To contain runoff on the parking lot, the ropes were covered by tar 7.0 in (17.8 cm) wide and 0.8 in (1.9 cm) deep. Around 1,000.0 ft^3 (28.3 m^3) of soil in the planting strip was replaced with Davis soil to form the base of the bioswale. A fine graded geotextile (filter fabric Mirafi 180N) was placed at the bottom, sides, and top of the engineered soil. The geotextile prevented fine soil/sediment, which can reduce the the system's porosity, from entering the system. During soil replacement, Davis soil was packed by a tamping rammer (Mikasa MT-65H). Three redwood boards (2.0 in (5.1 cm) x 10.0 in (25.4 cm)) were buried on the west, south, and east edges of the bioswale. These boards were set 1.0 in (2.54 cm) above ground surface. The three boards and the two rope/tar strips defined the boundaries of the treatment and control sites. A 5.0 gallon (19.0 l) Bloodgood London Plane (*Platanus x acerifolia 'Bloodgood'*) tree was planted in the center of the bioswale. The control site had an identical setup as the treatment site except there was no soil replacement (Figure 2). The finished landscape of both control and treatment sites followed the UCD parking

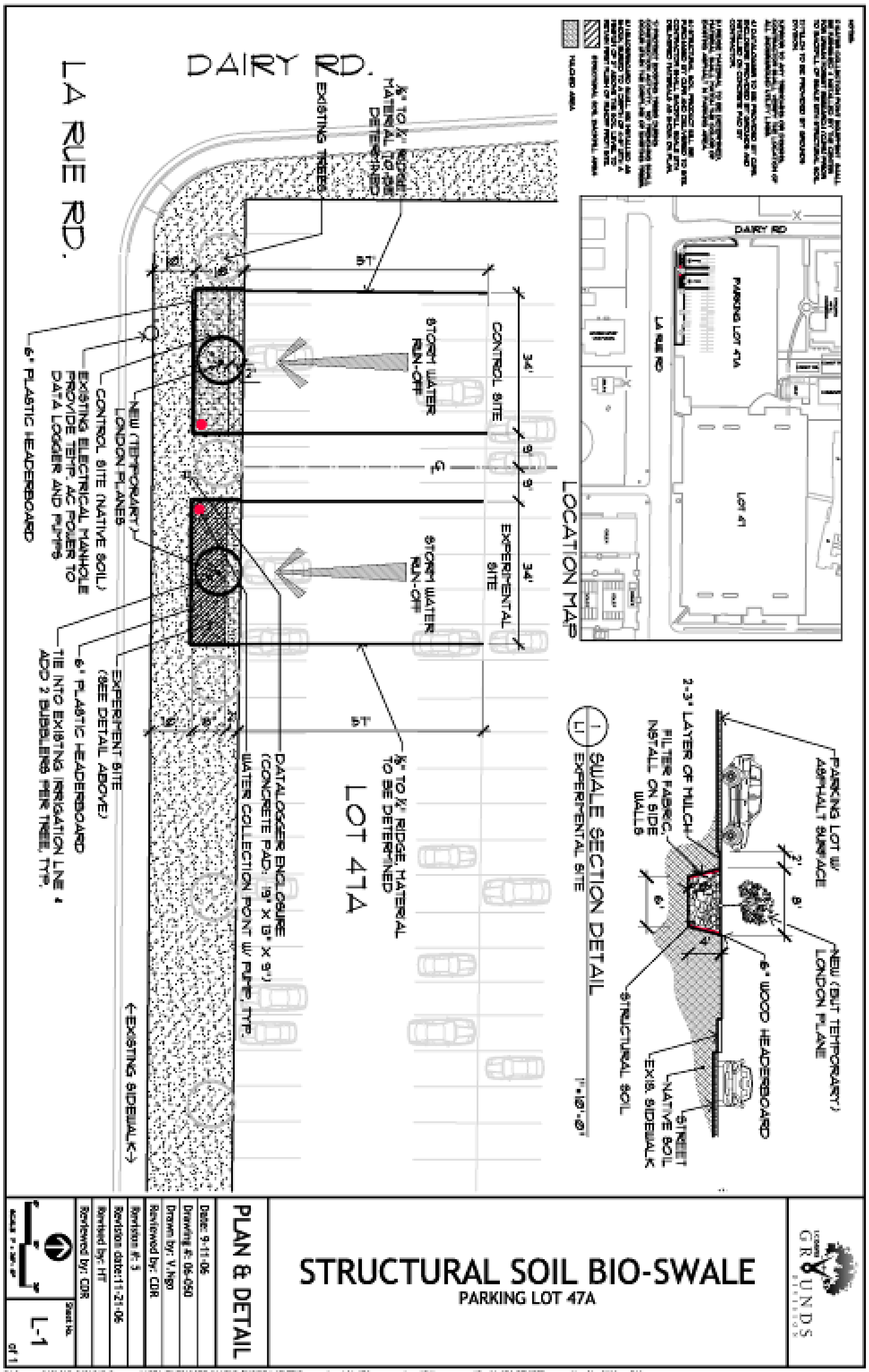

Figure 2: Detail field experiment setup design

lot standard. Mulch (i.e., wood chips) (1.0 in (2.54 cm) deep) was uniformly spread over the entire planting strip. Figure 3 shows the landscape before, during, and after the system installation. This bioswale was designed to eliminate runoff from a 10-year storm event (3.1 in (7.9 cm) rainfall) or 97% of all annual rainfall events (based on rainfall analysis of Davis' 2000 precipitation data), as per local development requirements.

Figure 3. Field installation: a). Before GIT installation; b). Excavation; c). Fill in Davis soil; d). Compact the soil; e). Leveled the pit; f) Tested the soil settlement; g). Added tree to the system; h) Finished site; i) Both control and treatment sites were coved with mulch to match the surrounding land cover.

The system was tested for landscape stability from artificial runoff right after the bioswale was installed. Potable water was brought to the site by water truck and water was spread on the parking lot to simulate stormwater runoff. During the test, more than 4,000.0 gallons (15.1 m^3) of water were stored and infiltrated by the bioswale system. There was no settling of the Davis soil.

Runoff Measurement System

Because of the relatively flat landscape between the parking lot and the street, surface runoff measurements were conducted through a surface-subsurface water collection and measurement system. Surface runoff flowed out off each test area via a 2.0 in (5.1 cm) PVC pipe. One end of this PVC pipe was located at the corner of the test area (i.e., the outlet point of the test area) at ground surface level and the other end was connected to an underground water storage tank (50.0 gallon (189.0 liter)) which was located near the corner (i.e., test site's outlet) (Figure 4). A submergible utility waste water pump (EF33, Grundfos Pumps Corporation) was located inside the water storage tank to pump out the runoff from the tank to street. The water level in the water storage tank was controlled by a float switch. The pump's working status was monitored by a current transformer (CS10-L, Campbell Scientific, Inc.) and automatically logged to a data logger (CR10, Campbell Scientific, Inc.). A flow-proportional drainage water sampling method (de Vos, 2001) was used in this study to collect water samples for water quality analysis. A flow controller was installed in the pump's outlet pipe to divide the outflow from the pump to the street and to a 5.0 gallon (19.0 liter) water sample container. The flow ratio between the runoff to street and runoff to the water sample container was set at 600:1 so that there was

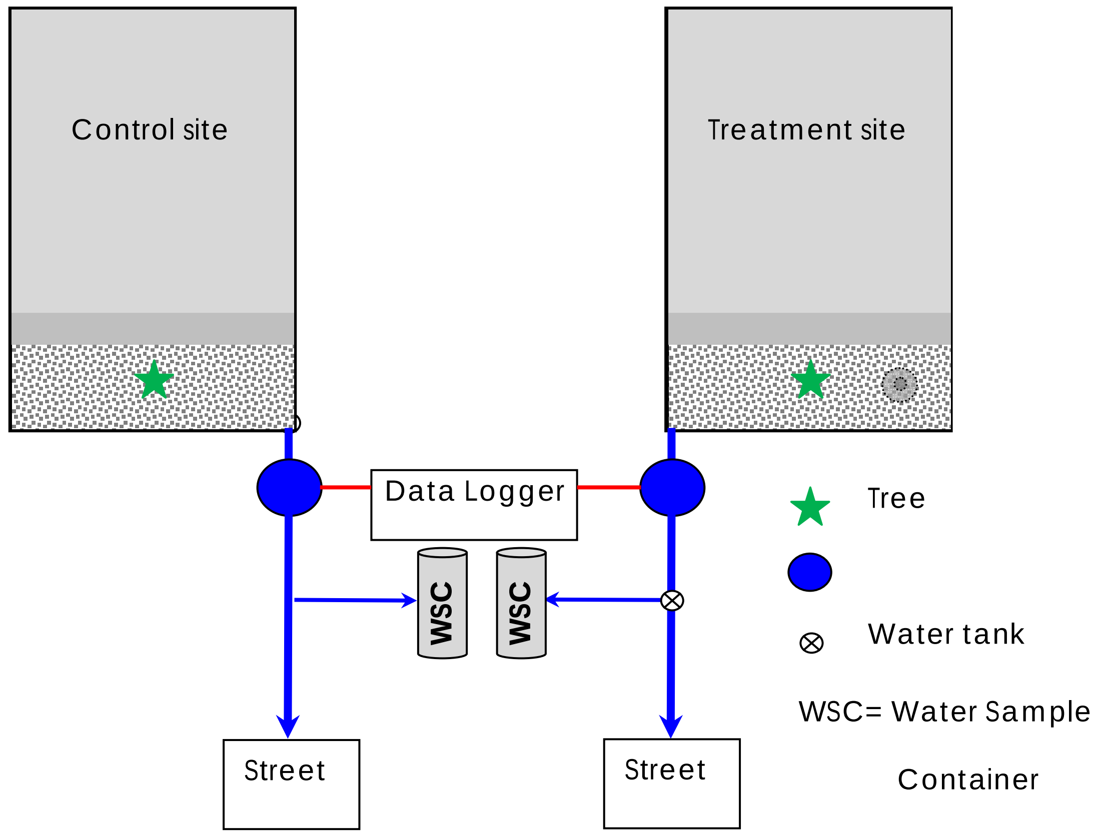

Figure 4. Measurement and water sample collection system

enough water sample collected from small storm events (0.13 in (3.3 mm) rainfall) and the container did not overflow during large storm events (10 years storm, 3.1 in (7.9 cm) rainfall). An 11.0 in (27.9 cm) diameter and 6.0 in (16.0 cm) deep plastic basin was placed at the bottom of the bioswale system. This basin received runoff from infiltration and provided water samples for water quality analysis of infiltrated runoff. Water samples (750.0 ml) were collected from the containers for water quality analysis after each storm event.

Measurement System Calibration

The measurement system was calibrated to obtain the relationship between the pump's operation time and the amount of water pumped from the system. Potable water was brought to the site in a 300 gallon (1,135.5 liter) water tank and a precision water meter (GPI TM100N, Great Plains Industries, Inc) was used to measure the amount of water added to the runoff storage tank (Figure 5).

Figure 5. System calibration. Water flowed by gravity from the portable water tank (left photo) to the underground water storage tank. A secured inlet in the underground tank (right photo) was used to allow water to flow directly into the tank.

Water Quality Analysis

Storm runoff quality analyses focused on standard pollutant parameters (US-EPA, 1983). The measured chemical constituents included nutrients (i.e., Total Kjehldahl Nitrogen (TKN), ammonia (NH_4), nitrate (NO_3), and Phosphorus (P)), metals (zinc (Zn), copper (Cu), iron (Fe), chromium (Cr), lead (Pb), nickel (Ni), mercury (Hg), and cadmium (Cd)), Total Organic Carbon (TOC), Dissolved organic carbon (DOC)), and Total Petroleum Hydrocarbons (TPH) (i.e., gas, diesel, and motor oil). The quality analyses also contain conventional physical properties such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), and Total Suspended Solids (TSS), since they are of primary concern in runoff water quality.

The majority of these water quality parameters were analyzed at the Division of Agriculture and Natural Resources (ANR) Analytical Laboratory, University of California. The ANR Analytical Laboratory performs water quality analyses for these selected chemical constituents with EPA recommended or standard analytical methods. The Method Detection Limit (MDL) for nutrients was 0.05 mg/L except TKN, for which the MDL was 0.10 mg/L. For metals, the MDL was 0.1 mg/L for copper, 0.02 mg/L for zinc, and 0.05 mg/L for both nickel and lead. For chromium and cadmium, the MDL was 0.005 mg/L, and selenium and mercury had an MDL of 1.0 µg/L. The organic carbon and hydrocarbons analyses were conducted by California Laboratory Services (CLS Labs). CLS is an EPA certified full service environmental chemistry laboratory. MDL were 1.0 mg/L for TOC and DOC and 0.05 mg/L for TPH.

The nature of the pollutant concentrations measured for each storm event represented the Event Mean Concentration (EMC) because the water samples were flow-proportional.

Results and Discussion

Storm runoff measurements were conducted from February 2007 through October 2008. There were 50 storm events with a total precipitation of 563.8 mm (22.2 in) during this time period (Table 1). Storm events were separated based on a 24-hour rainless period (Xiao et al., 2000b). Storm size ranged from 0.1 mm to 88.9 mm (3.5 in). Rainfall averaged 11.28 mm (0.44 in) per storm. Most storms were small, with 70% of the storm events less than 6.35 mm (0.25 in). In contrast, six storms accounted for more than half (53%) of the total precipitation.

Table 1. Storm Events

Event Number	Date	Precipitation mm	Precipitation in	Event Number	Date	Precipitation mm	Precipitation in
1	2/8/07	50.20	1.98	26	11/11/07	20.00	0.79
2	2/13/07	3.90	0.15	27	11/18/07	0.30	0.01
3	2/23/07	5.20	0.20	28	11/20/07	0.10	0.00
4	2/25/07	22.90	0.90	29	12/5/07	3.40	0.13
5	3/9/07	0.10	0.00	30	12/7/07	39.80	1.57
6	3/21/07	2.10	0.08	31	12/17/07	24.70	0.97
7	3/23/07	0.10	0.00	32	12/28/07	5.30	0.21
8	3/27/07	1.00	0.04	33	1/4/08	66.10	2.60
9	4/11/07	5.00	0.20	34	1/22/08	88.90	3.50
10	4/18/07	0.10	0.00	35	1/28/08	5.08	0.20
11	4/22/07	11.80	0.46	36	1/30/08	3.90	0.15
12	5/3/07	3.30	0.13	37	2/1/08	10.10	0.40
13	5/4/07	2.90	0.11	38	2/3/08	10.50	0.41
14	5/12/07	3.20	0.13	39	2/9/08	0.10	0.00
15	6/5/07	0.10	0.00	40	2/12/08	0.10	0.00
16	6/12/07	0.10	0.00	41	2/14/08	0.10	0.00
17	9/23/07	0.10	0.00	42	2/20/08	8.00	0.31
18	10/2/07	0.50	0.02	43	2/22/08	38.80	1.53
19	10/6/07	0.20	0.01	44	2/27/08	0.10	0.00
20	10/10/07	19.10	0.75	45	3/28/08	0.80	0.03
21	10/12/07	0.10	0.00	46	3/29/08	0.30	0.01
22	10/13/07	9.00	0.35	47	4/22/08	31.50	1.24
23	10/17/07	3.20	0.13	48	10/4/08	2.00	0.08
24	10/30/07	0.30	0.01	49	10/31/08	54.10	2.13

Storm Runoff Reduction

Of the 50 total storm events, only 20 storms generated surface runoff from the control site and 11 storms generated runoff from the treatment site. Runoff coefficients for these storms ranged from 0 to 76% for the control site and from 0 to 6% for the treatment site. Runoff from the control site accounted for 50% of total precipitation. In contrast, only 3% of rainfall falling on the treatment site contributed to surface runoff flowing off the site (Table 2). No runoff

Table 2. Runoff and runoff coefficient by storm event*

Event Number	Precipitation (mm)	Control Site			Treatment Site		
		Liter	Gallon	RC**	Liter	Gallon	RC
1	50.2	4,425.4	1,169.1	0.41			
2	3.9	126.7	33.5	0.15			
3	5.2	271.5	71.7	0.25			
4	22.9	2,027.2	535.5	0.42			
12	3.3	208.2	55.0	0.30			
20	19.1	2,140.4	565.4	0.53	178.7	47.2	0.04
22	9.0	1,049.8	277.3	0.55	89.4	23.6	0.05
26	20.0	1,601.6	423.1	0.38	175.7	46.4	0.04
30	39.8	5,211.2	1,376.6	0.62	364.0	96.2	0.04
31	24.7	2,216.6	585.6	0.42	89.0	23.5	0.02
33	66.1	10,653.8	2,814.4	0.76	654.9	173.0	0.05
34	88.9	14,103.8	3,725.8	0.75	1,128.1	298.0	0.06
35	5.1	330.3	87.2	0.31			
36	3.9	250.5	66.2	0.30			
37	10.1	1,465.0	387.0	0.68	93.5	24.7	0.04
38	10.5	1,575.1	416.1	0.71	94.1	24.9	0.04
42	8.0	766.6	202.5	0.45			
43	38.8	4,706.4	1,243.3	0.57	273.0	72.1	0.03
49	54.1	5,666.5	1,496.9	0.49	633.0	167.2	0.06
50	5.1	576.9	152.4	0.53			

*Only storms that had runoff flow off the system are listed in this table. The gray areas are storms with no runoff flow out the system.
**RC: Runoff coefficient.

flowed to the street from either site when precipitation was less than 0.13 in (3.3 mm) or 50% of the storm events. From the treatment site, there was no runoff flow to street for all storms less than 0.35 in (9.0 mm) or 70% of the total storm events. Storm runoff in the treatment site was significantly reduced. The runoff from the treatment site was 94% less than runoff from the control site.

Initially, the system was designed to retain and treat storm runoff from a 10-year event. However, the system size was reduced by 25% during field installation to avoid any potential damage to utility and communication cables that were underground. This explained why runoff was observed for less than 10-year storm events.

Pollutant Reduction

There were 21 chemical constituents analyzed in this project. All detectable water quality constituents' concentrations from the control site were consistently higher than those measured from the treatment site except for iron and pH which were consistently lower than the control site. However, there was no statistically significant difference between the runoff's pollutant concentrations between the two sites at a 0.05 significance level. Only Zn and Fe were detected from both treatment and control sites. The other metal elements (i.e., Cu, Cd, Cr, Pb, Ni, and Hg) were below the laboratory's MDL. This may be due to relatively clean runoff from this lot (Xiao et al., 2006) compared with runoff data from EPA (US-EPA, 1983). Diesel and Motor Oil were not detected from runoff samples collected from these sites. This may be due to filtering by the mulch applied on top of the planting strip. Hong et al (Hong et al., 2006) found that a thin layer of mulch on the surface of a bio-retention facility can effectively reduce oil and grease from urban stormwater runoff.

Loading Reduction

The bioswale installed in the treatment site not only reduced the amount of runoff but also reduced runoff pollutant concentrations. Thus, pollutant-loading that contributed to downstream runoff were different for the two sites. Table 3 listed pollutant loading from each storm event. This bioswale system reduced nutrients by 95.3%, metals by 86.7%, organic carbon by 95.5%, and solids by 95.5%. The average loading reduction of this system was 95.4%. Total loading from the control and from the treatment sites were 14,147.3 g (31.2 lb) and 675.1 g (1.4 lb), respectively. Solids (i.e., TDS and TSS) accounted for the majority of the loading (more than 72%), followed by organic carbon (i.e., TOC and DOC) which accounted for more than 23% of the total loading. Nutrients (i.e., nitrogen (TKN, ammonia, and ammonium)) and phosphorus (total and dissolved)) accounted for 3% of the total loading. The total amount of metals (i.e., Zn and Fe) from the treatment site was much smaller than from the control site (8.6 g vs. 64.3 g). However, 1.3% of loading from the treatment site were metals compared to 0.5% metals from the control site. The Davis soil was an integration of lava rock and regular soil. The lava rock could be a source of iron, accounting for the higher iron concentration found in the water samples collected from the treatment site. TPH from both sites were below the laboratory detectable limit.

The pH measured in the water samples from the treatment site was consistently higher than measured from the control site. At a confidence level of 0.05, there was no significant difference in pH measured in the runoff samples from the two sites. However, the pH value was 4% higher in the runoff from the treatment site (average pH = 7.53) than from the control site (average pH = 7.25). Similar changes of pH in engineered soils were observed by Day et al.

Table 3. Pollutant Loading by Storm Events*

Event	Control Site											Treatment Site										
Number	PT**	PS***	TKN	NO_3	NH_4	Fe	Zn	TOC	DOC	TDS	TSS	PT	PS	TKN	NO_3	NH_4	Fe	Zn	TOC	DOC	TDS	TSS
1	11.1	9.7	35.8	26.0	4.6	2.4	0.9	154.9	336.3	1,261.1	112.8											
2	0.3	0.3	1.0	0.7	0.1	0.1	0.0	4.4	9.6	36.1	3.2											
3	0.7	0.6	2.2	1.6	0.3	0.1	0.1	9.5	20.6	77.4	6.9											
4	5.1	4.4	16.4	11.9	2.1	1.1	0.4	70.9	154.0	577.7	51.7											
12	0.5	0.5	1.7	1.2	0.2	0.1	0.0	7.3	15.8	59.3	5.3											
20	5.4	4.7	17.3	12.6	2.2	1.2	0.4	74.9	162.7	609.9	54.6	0.3	0.3	1.5	0.6	0.1	0.2	0.0	3.8	13.0	39.3	3.5
22	2.2	2.0	4.6	13.9	0.1	0.4	0.1	36.7	56.7	320.1	12.6	0.0	0.0	0.1	0.5	0.0	0.2	0.0	1.9	1.7	23.2	0.5
26	3.3	3.1	7.0	21.2	0.1	0.6	0.1	56.1	86.5	488.5	19.2	0.0	0.0	0.3	0.9	0.0	0.4	0.0	3.7	3.3	45.7	1.1
30	2.6	1.6	7.3	2.5	0.8	2.6	0.3	57.3	125.1	469.0	52.1	0.2	0.1	0.9	0.1	0.0	0.7	0.0	4.4	6.2	29.1	10.2
31	0.9	0.6	3.4	0.7	0.1	1.2	0.4	53.2	22.2	199.5	42.1	0.0	0.0	0.1	0.0	0.0	0.3	0.0	2.2	0.7	6.2	0.8
33	2.1	1.8	12.3	1.8	1.2	25.0	0.5	213.1	106.5	852.2	245.0	0.1	0.1	0.6	0.0	0.0	1.4	0.0	12.4	4.9	52.4	5.9
34	1.4	1.1	7.8	1.0	0.4	9.9	0.7	169.2	141.0	1,198.7	401.9	0.3	0.2	1.1	0.1	0.0	3.8	0.1	8.8	8.5	39.5	11.3
35	0.0	0.0	0.2	0.0	0.0	0.2	0.0	4.0	3.3	28.1	9.4											
36	0.1	0.0	0.2	0.0	0.0	0.4	0.0	2.8	2.8	25.0	2.9											
37	0.3	0.2	1.2	0.2	0.0	2.1	0.1	16.1	16.1	146.5	16.8	0.0	0.0	0.1	0.0	0.0	0.2	0.0	1.1	1.1	4.7	1.6
38	0.6	0.5	3.2	1.3	0.2	1.7	0.1	55.1	50.4	189.0	26.1	0.1	0.0	0.2	0.2	0.0	0.2	0.0	2.0	1.8	8.9	1.4
42	0.3	0.2	1.6	0.6	0.1	0.8	0.0	26.8	24.5	92.0	12.7											
43	1.9	1.4	9.6	3.9	0.7	5.2	0.2	164.7	150.6	564.7	78.1	0.2	0.1	0.6	0.5	0.0	0.4	0.0	5.7	5.2	25.9	4.1
49	14.2	12.4	45.9	33.2	5.8	3.1	1.1	198.3	430.6	1,614.8	144.5	1.2	1.0	5.2	2.1	0.4	0.5	0.0	13.3	46.2	139.2	12.3
50	1.4	1.3	4.7	3.4	0.6	0.3	0.1	20.2	43.8	164.4	14.7											
Total	54.3	46.5	183.5	137.8	19.7	58.7	5.6	1,395.5	1,959.1	8,973.9	1,312.7	2.6	1.9	10.6	5.1	0.7	8.3	0.3	59.3	92.6	414.2	52.7

*Only storms that had runoff flow off the system are listed in this table. The gray areas are storms with no runoff flow off the system.

**PT: Total Phosphorus.

**PS: Dissolved Phosphorus.

(Day and Dickinson, 2008). The pH changes in the treatment site were caused by the materials used for making the Davis engineered soil (i.e., the lava rock). Changes of pH should be considered when selecting trees because some species may be sensitive to these pH changes.

Tree growth

During this one-year study period, trees planted at the treatment and control sites did not reach their mature size. The trees grew well at both sites. Figure 6 shows tree conditions during the 2008 growth season. For each picture, a Tetherball (Mikasa, T8000) was used to reference the tree dimensions. There was a slight visual difference between these two trees. The tree growth at the treatment site was slightly better than the tree growth at the control site. The Davis soil provided better aeration and drainage for the trees during the high moisture season due to the large amount of pore space existing in the lava rock. However, during the dry summer, the tree planted in the Davis soil required more frequent irrigation due to its drainage characteristics. Special tree care (i.e., more frequently irrigation) is needed for trees planted in engineered soil while tree roots are getting established.

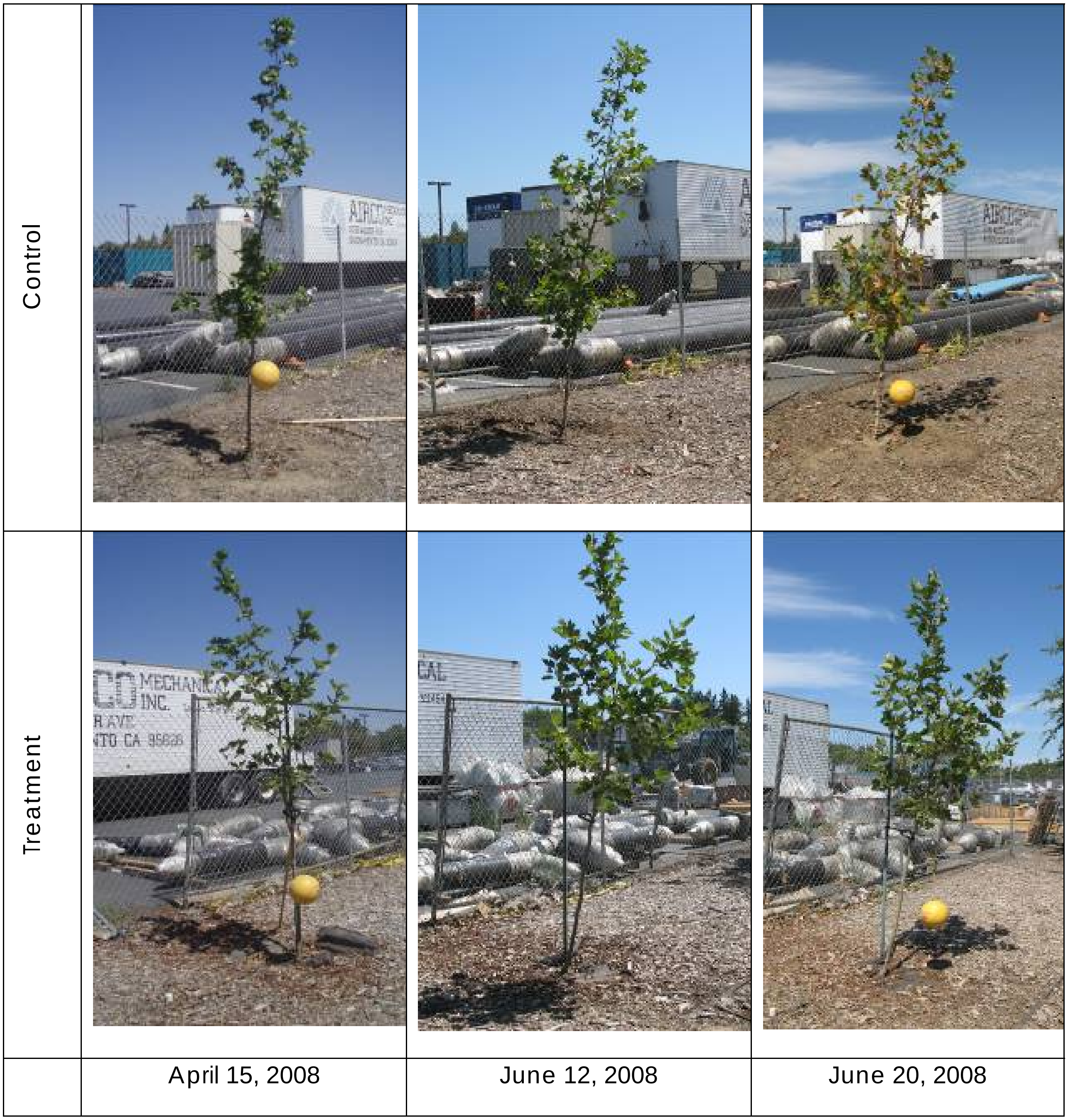

Figure 6. Visual observation of tree growth in the control and the treatment sites. During 2008 growth season, this parking lot was used as a staging station and only construction vehicles were permitted to park in this lot.

Conclusion

Results from the field experiment indicate that the bioswale effectively reduced the amount of storm runoff and pollutant (i.e., nutrients, metals, organic carbons, hydrocarbons, and solids) loading from the parking lot. The bioswale reduced runoff by 88.8% and the total loading by 95.4%. Individual water quality constituent reduction rates ranged from 86% for iron to 97% for nitrogen. Pollutant removal rates for nutrients, metals, organic carbon, and solids were 95%, 87%, 95%, and 95%, respectively. In the treatment site, the high porosity of the Davis soil provided more space to store runoff and better aeration to the tree root system compared with the compacted clay loam soil at the control site.

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