Technical Note

Assessment of Car Wash Runoff Treatment Using Bioretention Mesocosms

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Abstract: Car wash runoff is known to be a pollution source to surface water bodies. Many groups hold car-washing fundraisers unaware of pollution issues associated with car wash runoff. This preliminary study investigated whether rain gardens are an appropriate management practice for reducing car wash pollutants, specifically surfactants. The concentrations of total phosphorus (TP), total suspended solids (TSS), and surfactants were measured in car wash runoff before and after treatment in three rain garden mesocosms. Mean TSS and surfactant effluent concentrations were significantly lower than the car wash runoff with TSS reductions ranging from 84 to 95% and surfactant reductions ranging from 89 to 96%. The removal efficiencies for surfactants were not enough to reduce concentrations below literature-based values for aquatic toxicity. Mean TP effluent concentrations were higher than the car wash runoff with increases ranging from 197 to 388%, although the increase was not statistically significant. This project demonstrates the potential for using bioretention to reduce pollutants associated with car wash runoff and using car wash events to educate the public about watershed protection. **DOI:** 10.1061/(ASCE)EE.1943-7870.0000719.

CE Database subject headings: Biological processes; Surface-active agents; Runoff.

Author keywords: Bioretention; Rain gardens; Surfactants.

Introduction

Non-point-source pollution is a major issue that affects water resources as development alters the hydrology of an area. As natural areas become developed, non-point-source pollution volumes and peak flows are increased, causing flooding and degrading local water quality. Non-point-source pollution and associated runoff are major contributors to New Jersey's water pollution problems [New Jersey Department of Environmental Protection (NJDEP) 2011a] and may have a negative impact on aquatic life, contaminate reservoirs, increase the cost of treating drinking water and wastewater, and degrade groundwater supplies.

Recent investigations have shown that significant quantities of non-point-source pollutants are generated from residential car washing (Smith and Shilley 2009). Car wash runoff was shown to be a source of petroleum hydrocarbons, heavy metals, phosphorus, nitrogen, ammonia, total suspended solids (TSS), and surfactants from car wash soap. In New Jersey, as well as the nation as a whole, many groups hold car-washing fundraisers unaware of the pollution issues associated with car wash runoff. Residential car washing and organized car wash events are currently exempt from the federal stormwater regulation program—the National Pollutant Discharge Elimination System Program. The most common pollution prevention strategies for car washing involve public education, partnering with commercial car washes for fundraiser events, use of storm drain inserts to collect wash water, and encouraging washing cars on lawns and other pervious surfaces. Little information exists on the effectiveness of using bioretention systems to reduce pollutants associated with car wash runoff.

Bioretention systems are often installed to reduce surface runoff and non-point-source pollution in developed areas. These systems, also called rain gardens, provide water quality treatment by utilizing physical, chemical, and biological processes in the vegetation and growing medium. Rain gardens are estimated to reduce total nitrogen by 30–97%, total phosphorus (TP) by 28–85%, and TSS by up to 99% (Dietz 2007; Davis et al. 2009; Roy-Poirier et al. 2010). Rain gardens have also been shown to be effective at treating metals (Glass and Bissouma 2005), polycyclic aromatic hydrocarbons (DiBlasi et al. 2009), and pathogens and bacteria (Hunt et al. 2008; Rusciano and Obropta 2007).

Most studies investigating pollutant removal capabilites of rain gardens have focused on nutrients, sediment, and heavy metals from stormwater (Dietz 2007; Davis et al. 2009; Roy-Poirier et al. 2010) with no peer-reviewed studies investigating the benefits of using bioretention to reduce pollutants from car wash runoff, specifically in treating surfactants. Extensive research and review have been conducted on surfactant behavior, fate, and ecotoxicity in both aquatic and terrestrial environments (Scott and Jones 2000; Venhuis and Mehrvar 2004; Ying 2006; Mungray and Kumar 2009). Synthetic, anionic surfactants, such as linear alkylbenzene sulphonates (LAS), are widely used commercially (Scott and Jones 2000). In the aquatic environment, LAS concentrations as low as 0.02 mg/L have been shown to be toxic to aquatic life (Venhuis and Mehrvar 2004; Ying 2006).

In light of this evidence, there exists a need to conduct studies investigating pollutants associated with car wash runoff and the potential to use bioretention for car wash pollution. The goals of this

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Note. This manuscript was submitted on July 6, 2012; approved on April 10, 2013; published online on April 12, 2013. Discussion period open until January 1, 2014; separate discussions must be submitted for individual papers. This technical note is part of the ***Journal of Environmental Engineering***, Vol. 139, No. 8, August 1, 2013. © ASCE, ISSN 0733-9372/2013/8-1132-1136/$25.00.

J. Environ. Eng. 2013.139:1132-1136.

study are (1) to estimate pollutant loads from one community car wash event and (2) to use experimental rain garden mesocosms to determine removal efficiencies of car wash pollutants, including surfactants. Although it is expected that bioretention will be successful as a treatment option for car wash runoff, the extent of this success is unknown for surfactants and will be investigated in this study.

This study complements an existing installation of a car wash at a high school in Clark, New Jersey, to be used by students for frequent fundraiser events. This "green" car wash utilizes green infrastructure practices including a bioretention basin and above ground cistern capturing water from an adjacent building. The dirty car wash runoff is diverted to the rain garden instead of entering the storm drain system. In the future, field investigations of this rain garden will be compared to our controlled mesocosm study.

Methods

Experimental Setup

Experiments were conducted in October 2011 at Rutgers University's Environmental and Natural Resource Sciences Building in New Brunswick, New Jersey, using four bioretention mesocosms. Rain garden mesocosms were used to ensure a more controlled study to reduce complicating factors that might influence water quality results. The bioretention mesocosms were constructed in June 2011 using four 71.9-L "rope tub" containers, 56.5 cm in diameter and 41.9 cm high. A drainage system of four PVC ball valves was placed squarely in the bottom of each mesocosm and sealed with waterproof caulk to prevent leakage. Each mesocosm was elevated on a rack system created from cement blocks and metal rails (Fig. 1).

Design criteria for the mesocosms followed those used by Rutgers in its demonstration rain garden program (Obropta et al. 2008). Approximately 10.0 cm of washed ¾-in. gravel was placed in the bottom of each mesocosm to allow for sufficient drainage. Soil media used in the mesocosms follow bioretention guidelines established by the New Jersey Department of Environmental Protection (2009) for stormwater best management practices (BMPs). Soil media consisting of 82% sand and 18% humus/manure mix by volume, was hand-mixed on a tarp prior to installation in the mesocosms. Approximately 15.0 cm of soil media was added to each mesocosm.

Four plants from each of three species were planted, for a total of 12 plants in each mesocosm: soft rush (*Juncus effusus*), switchgrass (*Panicum virgatum*), and black-eyed susan (*Rudbeckia lacinata*). These plants are typical for rain gardens designed in New Jersey. A 5.0-cm layer of wood mulch was applied on top of the soil media leaving approximately 12.0 cm of ponding depth for each of the mesocosms. Mesocosms were visually inspected and checked as level to the ground on a daily basis prior to and during experimentation to ensure even distribution of infiltrated water in the soil media. Each mesocosm was watered with tap water on an as needed basis prior to running the experiment, which occurred when the mesocosms were approximately 4 months old. Every effort was made to make certain that each mesocosm was constructed and maintained in an identical manner to ensure proper comparison of results.

Fig. 1. View of experimental setup showing mesocosms after construction

Sample Collection and Analysis

The research project was designed to measure the concentration of TP, TSS, and surfactants [methylene blue active substances (MBAS) as LAS] in car wash runoff before and after treatment in rain garden mesocosms. These parameters were selected based on the known water quality impairments for the receiving water body of the installed green car wash in Clark, New Jersey, and the pollutants typically associated with car washes (Rutgers Cooperative Extension Water Resources Program 2005; Smith and Shilley 2009; NJDEP 2011a). This study focused on LAS surfactants since they are commonly found in detergents. Runoff was generated by conducting three car wash events on a vehicle selected from Rutgers University's Environmental Sciences Department so that one vehicle was washed per event. The vehicles had typically been used for field visits and meeting travel and had average dirt accumulation. No significant rain events occurred during October 2011 when the study was conducted, and the weather was dry during the wash events. Each vehicle was rinsed prior to washing, and a concentrated car wash soap (Blue Coral High Foam Car Wash Concentrate) was mixed with tap water according to manufacturer's instructions and then applied to vehicles using terry cloth towels. After washing, each vehicle was rinsed with tap water. Rinsing and washing occurred on an impermeable tarp capable of containing and collecting the runoff water. This prevented contaminants and particles deposited on the pavement from contributing to the runoff so that contaminants from the vehicle itself were quantified during this study. Each of the three vehicle wash events were conducted in as consistent a manner as possible. The tarp was thoroughly rinsed and allowed to completely dry between vehicle washing events.

Car wash runoff was collected in a 71.9-L "rope tub" container and divided into three equal volumes based upon how much runoff was generated from each event (approximately 45–60 L depending on the vehicle washing event). Each third of the runoff generated was applied to one of three mesocosms as influent. The fourth mesocosm had approximately 20 L of tap water (hereafter referred to as clean water influent) applied as a control for statistical comparison. The PVC ball valves on the bottom of all four mesocosms were kept closed. Effluent samples were collected approximately 24 h after addition to the mesocosms to allow for adequate treatment of the target contaminants (TP, TSS, and surfactants). The NJDEP design criteria require that bioretention systems have a permeability rate sufficient to convey the runoff passing through the soil planting bed (NJDEP 2009). Minimum design permeability rates in

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New Jersey for infiltrating stormwater are 0.5 in./h (1.25 cm/h) (NJDEP 2004). The 24-h sampling time corresponds to this permeability rate for the 30-cm media depth in the mesocosms. Samples for analysis were collected as grab samples while the effluent was flowing in appropriate containers by opening one of the four PVC ball valves located at the bottom of each mesocosm. Samples of the tap water used during the wash events and the runoff generated prior to treatment by the mesocosms were also collected to establish baseline data for the study. All samples were kept on ice after collection and until drop off for sample analyses. Samples were analyzed for TP, TSS, and surfactants by Accutest Laboratories (Dayton, New Jersey) and followed appropriate analytical and chain of custody procedures for TP (EPA Method 365.3), TSS (*Standard Methods*, 20th Ed. (SM20) Method 2540D), and surfactants (SM20 Method 5540C) (American Public Health Association 1998; United States Environmental Protection Agency 2012).

Pollutant removal was calculated as percent removal (%R) of the measured target contaminants (TC) in the runoff. All losses from the system through the various physical, chemical, and biological processes were lumped together, and the %R was calculated as

$$\%R = \frac{TC_{\mathrm{IN}} - TC_{\mathrm{OUT}}}{TC_{\mathrm{IN}}} \tag{1}$$

TC was based on the concentrations of TP, TSS, and surfactants applied to and collected from each mesocosm. Analysis of variance (ANOVA: single factor) was used to analyze differences between clean water influent and car wash runoff as well as percent removal between mesocosms. Paired sample t-tests were used to determine differences in influent and effluent pollutant concentrations. A significance level of $p < 0.05$ for all statistical tests was considered significant. Statistical analyses were conducted using the statistical software package in *Microsoft Excel*.

Results and Discussion

Car Wash Runoff Characterization

The mean pollutant concentrations from the car wash runoff exceeded New Jersey surface water quality standards for TSS and TP (Table 1; NJDEP 2011b). New Jersey does not have a numerical standard for surfactants. Surfactants are considered to be toxic substances (general) and "should not be present in such concentrations as to affect humans or be detrimental to the natural aquatic biota, produce undesirable aquatic life, or which would render the waters unsuitable for the designated uses." Varying toxicity levels have been reported in the literature for LAS (Venhuis and Mehrvar 2004). Lewis (1991) reported that chronic effects of LAS occurs at concentrations normally greater than 0.1 mg/L. Bjerregaard et al. (2001) reported that LAS concentrations in sewage effluent have a physiological impact on marine life when between 0.02 and 1.0 mg/L. Mean surfactant concentration for the car wash runoff was well above these thresholds at 9.20 mg/L.

Table 1. Mean Pollutant Concentrations in Car Wash Runoff and Estimated Pollutant Load per Car Wash Fundraiser Event

Parameter	Standards for fresh waters (mg/L)[a]	Car wash runoff (mg/L)	Load per car[b] (kg)	Load per car wash event[b] (kg)
TP	0.1	0.17 ±0.12	0.0000088	0.00088
TSS	40.0	114.67 ±27.57	0.0059	0.59
Surfactants	n/a	9.20 ±1.15	0.00048	0.048

Note: ± indicates standard deviation.
[a]NJDEP (2011b).
[b]Load is based on average volume applied to mesocosms (51.7 ± 3.9 L) and an estimate of 100 cars per car wash event.

Table 2. Comparison of Mean Pollutant Concentrations for Clean Influent and Car Wash Runoff ($n = 3$)

Parameter	Clean influent (mg/L)	Car wash runoff (mg/L)	p-value
TP	0.03 ±0	0.17 ±0.12	ns
TSS	2.67 ±1.15	114.67 ±27.57	$p < 0.05$
Surfactants	0.09 ±0.06	9.20 ±1.15	$p < 0.01$

Note: ± indicates standard deviation; ns = not significant.

Based on mean pollutant concentrations in the car wash runoff, an estimate of the potential pollutant loading from a typical car wash event can be determined (Table 1). Pollutant loading is estimated as the product of the average volume of car wash runoff discharged to the mesocosms during this study (51.7 ± 3.9 L) and an estimate of 100 vehicles washed per car wash event held at the high school in Clark, New Jersey (S. McCabe, personal communication, May 30, 2012). Calculating percent watershed loading for these pollutants is beyond the scope of this study, but based on these estimates there is the potential for car wash fundraiser events to contribute significant quantities of pollutants to receiving water bodies.

Results shown in Table 2 indicate that mean TP concentration was higher in the car wash runoff than the clean water influent (tap water), although this difference was not statistically significant. Since a phosphate-free car wash soap was used during the car wash events, it is possible that the dirt residue on the vehicles might have been a source of TP to the runoff. Both mean TSS and mean surfactant concentrations for the car wash runoff were significantly higher in comparison to the clean water influent (Table 2).

Rain Garden Pollutant Removal Efficiencies

Results showed no significant difference between mesocosm 1, 2, and 3 for mean pollutant effluent concentrations or percent removal. This indicates there was no difference in removal efficiencies between these mesocosms for individual pollutants. This was expected as the mesocosms were built to be identical. Table 3 shows that for all mesocosms mean TP effluent concentrations were higher than the influent, although the increase was not significant. The TP percent reductions for each mesocosm indicate that more TP was discharged from the mesocosms then entered, including the control mesocosm. It is most likely that the humus/manure mixture and mulch added to the media became a source of TP. Possible nutrient leaching of the soil media or plants can occur in bioretention BMPs (Davis et al. 2009). The TP concentrations in the effluent from the underdrains of two rain gardens in Haddam, Connecticut. increased in comparison to precipitation and inlet concentrations (Dietz and Clausen 2005). Monitoring of the rain gardens over a 2-y period showed that over time the inlet and outlet TP concentrations became similar. Researchers noted that soil disturbance at the start of the study might be the cause of the observed increase (Dietz and Clausen 2005). Long-term monitoring of the mesocosms in the current study is necessary to determine whether

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Table 3. Summary of Influent and Effluent Mean Pollutant Concentrations ($n = 3$)

Parameter	Influent (mg/L)	Effluent (mg/L)	Percent reduction (%)	*p*-value
Control Mesocosm				
TP	0.03 ±0	0.36 ±0.29	−1,323	ns
TSS	2.67 ±1.16	13.33 ±11.93	−400	ns
Surfactants	0.09 ±0.06	0.21 ±0.08	−146	ns
Mesocosm 1				
TP	0.17 ±0.12	0.50 ±0.42	−197	ns
TSS	114.67 ±27.57	5.00 ±3.00	96	$p < 0.05$
Surfactants	9.20 ±1.15	0.37 ±0.02	96	$p < 0.01$
Mesocosm 2				
TP	0.17 ±0.12	0.81 ±0.50	−388	ns
TSS	114.67 ±27.57	15.33 ±5.86	87	$p < 0.05$
Surfactants	9.20 ±1.15	0.57 ±0.14	94	$p < 0.01$
Mesocosm 3				
TP	0.17 ±0.12	0.52 ±0.46	−213	ns
TSS	114.67 ±27.57	18.33 ±16.65	84	$p < 0.01$
Surfactants	9.20 ±1.15	0.93 ±0.47	90	$p < 0.01$

Note: ± indicates standard deviation; ns = not significant.

TP effluent concentrations decrease over time. The authors recognize that a large fraction of the TP in the effluent may be dissolved P or orthophosphate, which was not investigated in this initial study. Future study will involve investigating what proportion of the exported TP observed is dissolved.

For mesocosms 1, 2, and 3, mean TSS effluent concentrations were significantly lower than the influent (Table 3). These results correspond well with other studies showing that bioretention basins effectively remove sediment from stormwater runoff (Davis et al. 2009; Hatt et al. 2009). Rain gardens would be an effective means of reducing TSS concentrations in car wash runoff.

Surfactant concentrations in the effluent were also significantly lower compared to the influent (Table 3), although the removals were not enough to reduce concentrations below aquatic toxicity ranges noted by researchers (Lewis 1991; Bjerregaard et al. 2001). Further research is needed to determine rain garden designs that sufficiently reduce effluent surfactant concentrations and whether surfactants effectively degrade within the rain garden media. Much of our knowledge of surfactant breakdown in soil comes from investigating sewage sludge applications to agricultural lands (Holt et al. 1989; Holt and Bernstein 1992; Mungray and Kumar 2009). Microbial breakdown of surfactants in the soil can be the primary mechanism for LAS removal (Holt et al. 1989). Removal occurs rapidly with half-life values for LAS observed between 7 and 22 days. Even in soils with little organic material and high sand content (between 77 and 96%), similar to rain garden designs for New Jersey, LAS concentrations rapidly degraded to below detection limits (Kuchler and Schnaak 1997). These results are important as they indicate that surfactants will most likely not accumulate in the rain garden nor will they be taken up by the plants themselves. Because aerobic activity is the primary mechanism for surfactant removal, it is essential for the rain garden to have proper drainage. Biodegradation of LAS under anaerobic conditions has not been demonstrated (Jensen 1999). Long-term monitoring of the mesocosms, as well as monitoring of the rain garden installed as part of the high school car wash, will be necessary to confirm that surfactants do not accumulate in the rain garden over time.

Conclusions, Summary, and Recommendations

This preliminary investigation demonstrates that rain gardens have the potential to effectively reduce some pollutants associated with car wash runoff, although the researchers acknowledge the small sample size ($n = 3$) on which the results are based. Surfactant concentrations were reduced by over 89%, although these removals were not enough to reduce concentrations below aquatic toxicity ranges. The TSS was reduced by over 80%, while TP concentrations were higher in the effluent than influent, indicating that the organic medium might initially leach nutrients. Based on loading estimates, this study corresponds with prior research indicating that car wash runoff contributes significant quantities of pollutants, specifically TSS and surfactants, to receiving water bodies (Smith and Shilley 2009). Additional research is underway investigating the treatment of hydrocarbons, the physical, chemical, and biological processes occurring to remove the target analytical parameters (TP, TSS, and surfactants), as well as the influence of age on removal efficiency.

In addition to providing stormwater and water quality benefits, rain gardens are often installed on school grounds to engage students in hands-on activities and provide watershed and non-point-source pollution education. Considering the popularity of car wash fundraisers for student activity clubs, an enormous potential exists to marry these two activities and use rain gardens to help reduce the negative impacts of car wash runoff contaminants. Car wash events could become an education and outreach opportunity not just for students but also for parents who help organize these activities and drivers who have their cars washed. Often car wash events happen in the same location. Thus, when planning rain garden installations, effort should be made to place the rain garden where it can effectively capture and treat car wash runoff.

Acknowledgments

The authors would like to thank the following Rutgers Bioenvironmental Engineering students for help during this study: Rich Padgitt, Kyle Gourley, and Nicole Del Monaco. They would also like to thank the Dept. of Environmental Sciences for providing the vehicles that were washed for this experiment.

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