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Hydrologic Impacts of Bioswale Porous Media on Parking Lot Drainage

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Abstract: **Bioswales are stormwater control structures designed stormwater runoff volume and filter stormwater solids and pollutant from surface runoff. Bioswale generally consists of sloped surface ground with native wetland plants to lead stormwater percolation and infiltration, porous media to allow for stormwater retention and stormwater contaminant filtration, and stormwater drain conduit under the porous media. In this study, we monitored the bioswale evaluation factors of stormwater total volume reduction, peak flow rate reduction, and peak time attenuation. It is concluded that, based on a total of 29 monitoring of storm events, pumice is a hydrologically best performing material for the bioswale porous media for all three evaluation factors. Recycled crushed glass was also a competitive material for all the criteria except peaktime attenuation. It shows 32% peaktime attenuation than non-bioswale parking lot, but it is less than half of the pumice materials performance (64%). To evaluate a local availability, a cost analysis of the bioswale material and construction cost is recommended. Retail prices of the bioswale materials from the local areas as well as a value of parking space, which can be obtained by reducing stormwater retention pond size caused by the bioswale system, should be included in the cost analysis.**

Keywords: **Low impact development, stormwater best management, parking lot bioswale, surface runoff.**

I. INTRODUCTION

Bioswale is a landscape elements designed to reduce stormwater runoff volume and remove stormwater solids and pollutant from surface runoff. It represents a sustainable and cost effective retrofit method to decrease the volume of water that flows into rivers and streams from impervious areas during storm events. United States Environmental Protection Agency (USEPA) states that bioswale is an appropriate application of Low Impact Development (LID) principles of preserving and recreating natural landscape features and appealing on-site drainage [8]. These decentralized Best Management Practices (BMPs) used sources control approaches with potential to reduce significantly urban stormwater runoff quantity. Bioswale generally consists of sloped surface ground with native wetland plants to lead stormwater percolation and infiltration, porous media to allow for stormwater retention and filtration of contaminant occurs during the first flush of storm event, and stormwater drain conduit under the porous media. It is recommended that the top layer needs to be a material absorbs the runoff from the parking lot surface to drain effectively the parking lot, while the second layer should be a porous material with high water retention capacity to release stormwater slowly to the drain conduit to delay the peak flow time. As part of surface runoff flow path, it is designed to maximize the time water spends in the swale, which aids the trapping of pollutants [8]. NRCS (Natural Resources Conservation Service, USDA) recommends that bioswale should be sized to convey at least a 10-year frequency storm or about 109.2 cm precipitation in 24 hours [7]. However, there are many different designs and porous materials to improve hydrologic performance for various types of stormwater drainage structure and impervious areas. In addition, due to the use of local vegetation for the top layers and situ soil for the porous media, local geometric and ecological conditions are important considerations in bioswale design

[1]. The City of Houston, Texas recommends that 0.76 m of permeable soil with 0.15 m of gravel as parking lot bioswale porous media to keep at least 6.9 mm of soil filtration rate [2]. The City of Austin, Texas recommends 70%-80% concrete sand and decomposed granite sand with 20%-30% screened bulk topsoil for the bioswale filtration mixture to keep 1.1 m/day of conductivity [3]. Native situ soils (80%) and compost (20%) with gravels for the top layer are suggested by the City of McAllen located in south Texas. However, medium sand mixture is also recommended to increase hydraulic conductivity of the porous media in south Texas, since loamy silt is a major soil type of the Lower Rio Grande Valley basin [4]. The determination of bioswale porous materials can be merely based on the local availability.

The Lower Rio Grande Valley (LRGV) in South Texas has actively adopted bioswale system as a LID application to reduce stormwater peak flow rate and to retain stormwater volume and to filter stormwater pollution and solids. Numerous bioswales exist currently in LRGV and more are expected to be built in parking lots and driveways due to the leadership and support from city and county drainage district and collaborations with the state and federal agencies. The purpose of this project is to examine hydrologic performances of the bioswale system with the decision parameters of stormwater runoff volume reduction, peak flow rate reduction, and peak time attenuation by testing prototype bioswale in newly constructed parking lots in the University of Texas Rio Grande Valley (UTRGV) campus in Edinburg, Texas. Figure 1 shows the specific locations and layout of the study parking lots and sampling sites.

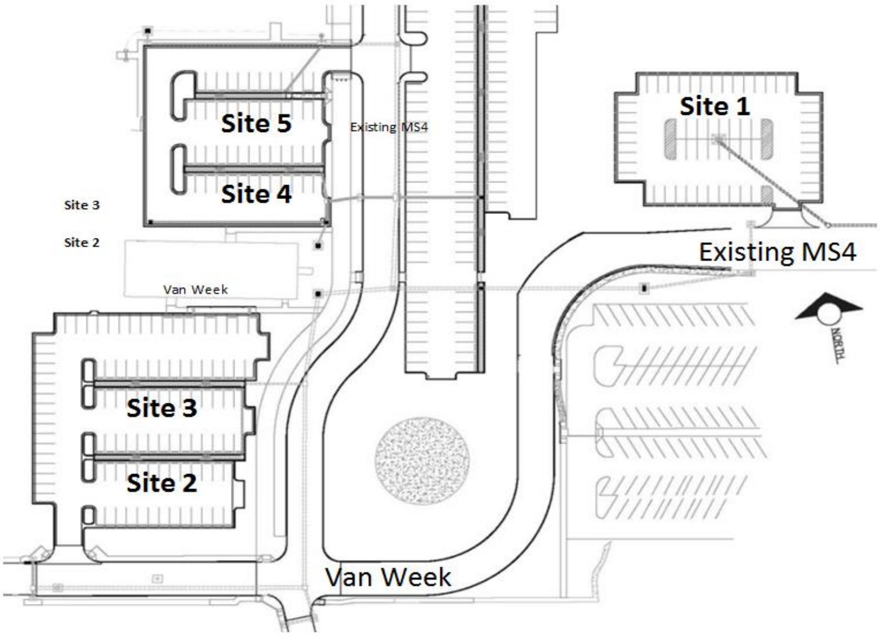

Fig. 1 Bioswale parking lots located North of Van Week Street in UTRGV campus

II. METHODS

A. Sampling Plan and Setup:

The bioswale porous media, sampling locations, and the parking lot drainage size to be tested in this study are listed in Table I. Each drainage area was delineated by parking lot surface grade, which contributes to the each bioswale and the existing MS4 (Municipal Separate Storm Sewer System). The bioswale porous media materials are selected based on the previous studies related to bioswale materials [4]. They examined seven different materials of manufactured sand, natural sand, pumice, rubber mulch, lava rocks, UTRGV campus situ-soil, and fine recycled crushed glass. They found that the pumice demonstrated superior stormwater volume retention and solids filtration capacity and concluded that manufactured sand and pumice can constitute the ideal bioswale porous media materials. In this project, manufactured sand, natural sand, and pumice were tested due to their proven performance in the previous study. Recycled crushed glass also was tested because of its availability and advantage of the sustainable materials. The objectives of this study was to monitor hydrologic parameters of the UTRGV campus parking lots which are equipped four different porous media bioswale systems and conventional no bioswale system to evaluate the bioswale parking lot hydrologic performance. This study will provide a practical guideline for equipping the border communities with cost effective stormwater drainage system that will ultimately result in cleaner and safer water to the communities.

TABLE I: Bioswale porous media materials and parking lot catchment size

Sites	Bioswale	Porous Materials	Locations	Catchment Size (m^2)
Site 1	No bioswale	No bioswale	26°18'32.46"N 98°10'21.31"W	959.1
Site 2	Bioswale 1	Pumice	26°18'30.76"N 98°10'26.91"W	874.1
Site 3	Bioswale 2	Manufactured sand	26°18'31.40"N 98°10'26.72"W	882.2
Site 4	Bioswale 3	Recycled crushed glass	26°18'33.38"N 98°10'25.83"W	845.8
Site 5	Bioswale 4	Natural sand	26°18'34.22"N 98°10'25.76"W	833.7

We monitored time dependent volumetric flow at the outlet of the bioswale system, which connects to the existing campus MS4 using a level-velocity data logger. We used Stingray level-velocity logger, which monitors and saves flow level, velocity, and temperature in open/closed conduit. It is a battery operated devise storing the data up to about 2 months with one-minute monitoring/logging time internal. We used two data loggers at both the conventional parking lot (Site 1) and one of the bioswale parking lots (Sites 2, 3, 4, or 5) to measure parking lot runoff. One data logger was relocated to other sites by turn to achieve all four sites. Thirty-nine storm events were monitored during the project period and 29 events were used for the hydrologic performance analysis. The level-velocity sensor and the data logger were anchored on the bottom of the drainage pipe and the drainage box wall to avoid possible water damage, respectively. The device is maintained weekly basis. Sediment/solid depositions on the sensor was cleaned to ensure accurate data monitoring and the batteries were replaced. The logged data was retrieved in the sites by connecting a mobile computer. Figure 2 shows the data logger installations at the site 1 and the data retrieving at the site 3.

Fig. 2 Stingray data logger installation at the site 1 conventional no-bioswale parking lot and the data retrieving at the site 3 manufactured sand material bioswale parking lot.

Grab type of surface water sampling was adopted in this monitoring. About 300 ml of parking lot runoff was sampled at the influence and effluence of the bioswale system immediately after storm events to collect the first flush. Figure 3 shows the stormwater runoff sampling at the effluence of the site 4. Sampling rod could reach to the bioswale drainpipe through the monitoring hatch, which is located at the most downstream of the bioswale strip. The samples were delivered to the lab for the filtration analysis.

Fig. 3 Stormwater runoff sampling at the site 4 recycled crushed glass parking lot

B. Data Analysis and Hydrologic Performance Criteria:

The precipitation peak time (t_{pk}) was observed from the surface runoff measured data by selecting the time monitoring time at the highest runoff volume. The time to peak (t_{peak}) was defined as a time interval from the beginning of the precipitation (t_{pd}) to the peak precipitation time (t_{pk}). It was calculated in the unit of minutes. Runoff hydrograph (Q_r) is the time dependent parking lot runoff discharge measured at the outlet of the each parking lot by the velocity-level data logger (flow meter). Runoff volume (V_r) is the volumetric runoff in the unit of cubic feet by multiplying the runoff (ft^3/s) by the time interval (seconds) of the hydrograph. Peak discharge (Q_p in the unit of ft^3/s) and peak time (t_p in the unit of minute) were observed from the flow meter monitored data.

The hydrologic performance decision parameters were estimated by comparisons of the field measurements of between the bioswale parking lot and the non-bioswale parking lot. Field staffs visited sites immediately following rainfall events to collect samples and download flow data, while there will be a routine visit to maintain equipment. Site identification, sampling date, time, personnel, and any field comments concerning conditions at the site were noted in the field logbook. Samples collected at the site were labelled for transportation to the laboratory. The analysed runoff samples were disposed through UTRGV laboratory sewer system immediately.

III. RESULTS

A. Monitoring Events:

The daily precipitation during the project period of the December 2014 to December 2016 is plotted in Figure 4. The maximum daily precipitation depth was 2.91 inches and the median value was 0.41 inches. The flow meter recorded thirty-nine storm runoff events for the period, while 29 events out of the record were used for the hydrologic performance analysis. Table II lists the data acquisition dates per site and the number of monitored date and storm events. We had very limited storm events for 7 months from November 2015 to June 2016. Six storm events were monitored in the period for the site 3. Not all precipitation events were used in the study, since the runoff occurrence is dependent on mainly rainfall intensity and moisture contents of the porous media. Only effective rainfall can be transformed the runoff, which can be monitored by the data logger.

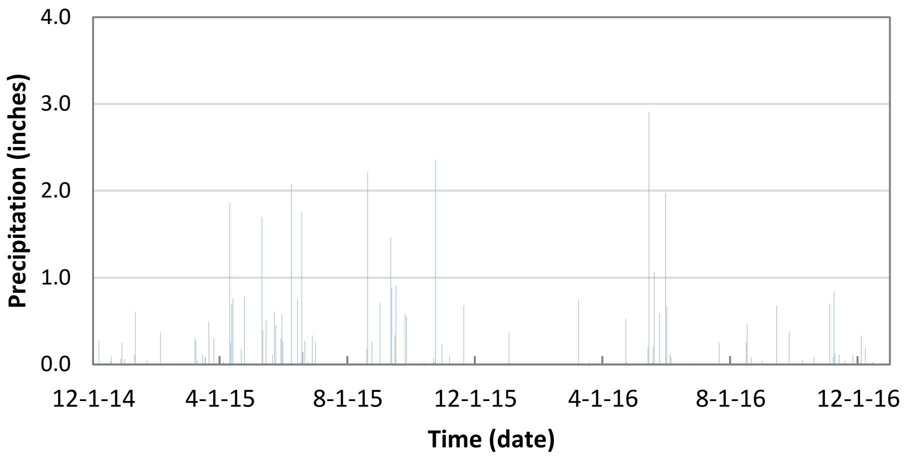

Fig. 4 Daily precipitation depth during the project period: December 2014 to December 2016

TABLE II: NUMBER OF STORM EVENTS MONITORED FOR BIOSWALE PARKING LOTS

Sampling Sites	Porous Materials	Number of Storm Events Monitored	Data Acquisition Date		Number of days Monitored
			Starting	Ending	
Site 1	No bioswale	29	4/10/15	11/13/16	448
Site 2	Pumice	7	6/19/15	10/30/15	136
Site 3	Manufactured sand	6	11/20/15	6/21/16	215
Site 4	Recycled crushed glass	8	4/10/15	6/8/15	60
Site 5	Natural sand	8	8/16/16	11/13/16	39

B. Hydrologic Performance of Bioswale Parking Lots:

The conventional non-bioswale parking lot (Site 1) runoff hydrograph were compared with the bioswale parking lots (Sites 2, 3, 4, and 5) as shown in Figures 5 to 8. The grey bar plot represents an hyetograph of the rainfall during the monitoring event. Red and blue color lines indicate the monitored runoff at the bioswale parking lot and non-bioswaled parking lot, respectively. Volume reduction (%), peak flow reduction (%) and peak time attenuation (%) are clearly displayed in the hydrographs. Figure 5 shows the excellent hydrologic performance of the parking lot 2, which uses pumice porous materials, 81% of volume reduction, 82% of peak flowrate reduction, and 67% of time attenuation than the conventional parking lot (site 1).

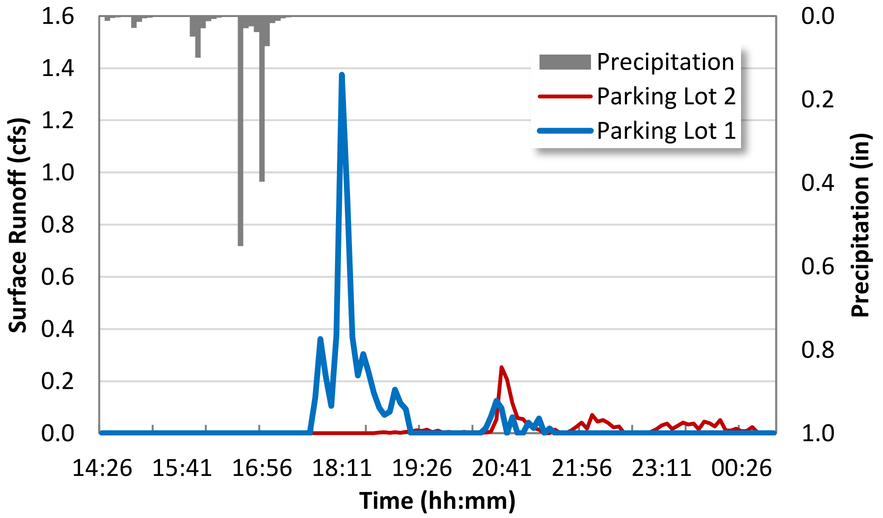

Fig. 5 Site 2 pumice material bioswale parking lot hydrologic performance by comparing Site 1 non-bioswale parking lot, June 19, 2016

Figure 6 shows the manufactured sand material performance of 81% volume reduction, 69% peak flowrate reduction, and 44% peak time attenuation. The runoff pattern follows the precipitation and shows very similar tendency of the non-bioswale parking lot 1 runoff hydrograph.

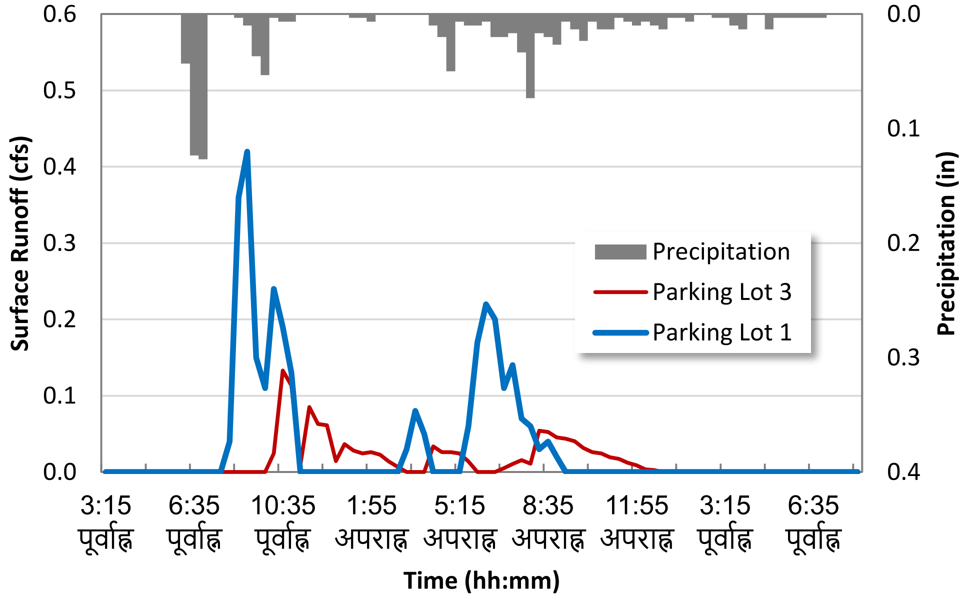

Fig. 6 Site 3 manufactured sand material bioswale parking lot hydrologic performance by comparing Site 1 non-bioswale parking lot, March 9, 2016

Crushed recycled glass material bioswale as shown in Figure 7 produces lower number of time attenuation (22%) than other materials. It means that the material release the runoff faster than other materials tested in this study. Volume and peak flowrate reduction were 54% and 57%, respectively. Shorter runoff duration was observed in the event than the non-bioswale parking lot runoff period. Figure 8 shows the natural sand material media hydrologic performance: 51% volume reduction; 38% peak flowrate reduction; and 29% time attenuation in comparison of the non-bioswale parking lot. Short precipitation duration led short and simpler runoff hydrographs.

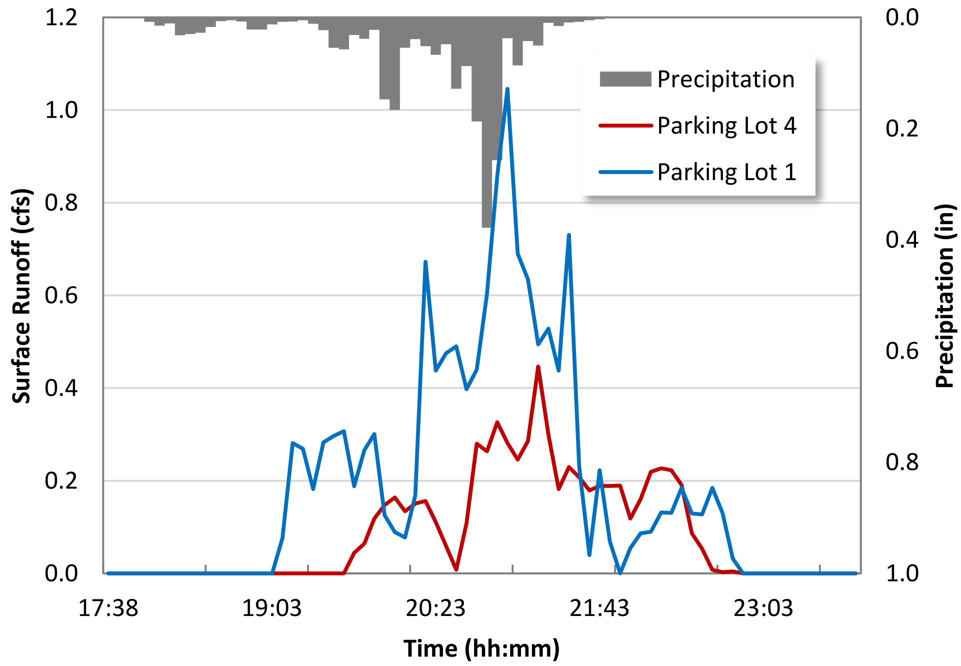

Fig. 7 Site 4 crushed recycled glass material bioswale parking lot hydrologic performance by comparing Site 1 non-bioswale parking lot, June 8, 2015

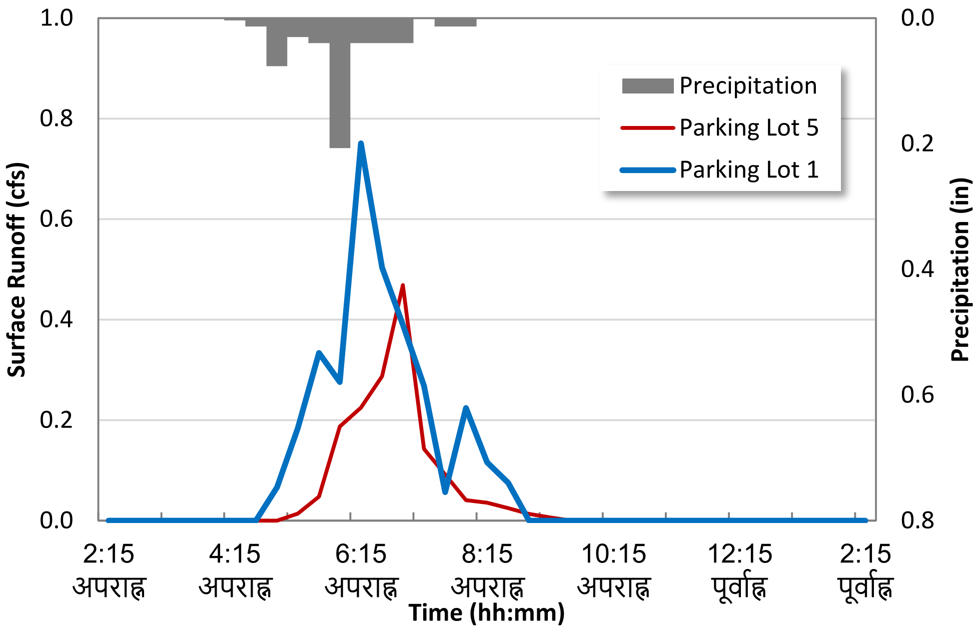

Fig. 8 Site 5 natural sand material bioswale parking lot hydrologic performance by comparing Site 1 non-bioswale parking lot, August 30, 2016

IV. CONCLUSION

The project goal is to examine hydrologic performances of the four different parking lot bioswale porous materials of pumice, manufactured sand, recycled crushed glass, and natural sand. Pumice material showed best hydrologic performance in all decision criteria of runoff volume reduction, peak flowrate reduction, and peaktime attenuation. Pumice is volcano rock has an average porosity of 90% and initially floats on water [9]. This high porosity per volume can hold the parking lot runoff volume and release slowly than other materials tested in this study. Manufactured sand material showed very similar performances with natural sand material among the volume reduction, peak flowrate reduction, and peaktime attenuation. Their difference is not exceeding 5.5%. Pumice is an ideal material for the bioswale porous media than the others. Volcano rock is known to be a very successful material for bioswale system and is widely used including California State [10]. Recycled crushed glass was also a competitive material for all the criteria except peaktime attenuation. It shows 32% peaktime attenuation than non-bioswale parking lot, but it is less than half of the pumice materials performance (64%). To evaluate a local availability, a cost analysis of the bioswale material and construction cost should be followed. The cost analysis should include not only materials and construction cost, but also a value of parking space, which can be obtained by reducing stormwater retention pond size caused by the bioswale system. Interview and technical survey with stormwater LID designers and managers regarding bioswale material preferences will be helpful for the ideal material determination.

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