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16. Abstract

The United States EPA (Environmental Protection Agency) MS4 (Municipal Separate Storm Water Sewer System) Program regulations require municipalities and government agencies including the Louisiana Department of Transportation and Development (LADOTD) to develop and implement stormwater best management practices (BMPs) for linear transportation systems to reduce the discharge of various pollutants, thereby protecting water quality. An efficient and cost-effective stormwater BMP is urgently needed for elevated linear transportation projects to comply with MS4 regulations. This report documents the development of a first flush-based stormwater treatment device, the first flush reactor, for use on elevated linear transportation projects/roadways for complying with MS4 regulations. A series of stormwater samples were collected from the I-10 elevated roadway section over City Park Lake in urban Baton Rouge. Stormwater treatment experiments were conducted using three laboratory columns filled with different combinations of filter medium layers. In terms of contaminant removal efficiency, the optimum filter medium combination was found to be (a) a mixture of Smart Sponge and Hydra CX2 in the top layer, (b) zerolite in the next layer, (c) sand, (d) sawdust, and (e) gravel in the bottom layer. Results of the laboratory experiments indicate that the first flush reactor with the optimized filter medium layers is able to remove over 85% of total suspended solids (TSS), 90% of total phosphorus, 99% of NO_2-N and NO_3-N, and 70% - 90% of fecal coliform bacteria. Tested heavy metals include Al, As, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Na, Ni, P, Pb, Si, and Zn. In general, removal rates of heavy metals through the recommended filter media are higher than 80%. The removal rates of three toxic heavy metals including cadmium (Cd), copper (Cu), and lead (Pb) are higher than 90%. Hydrocarbon levels in the stormwater samples were too low to be detected. Some unsolved problems in the current design of the first flush reactor include the low removal rate (15%-58%) of TKN (Total Kjeldahl Nitrogen) and the slight release (up to 20%) of toxic metal zinc (Zn) from the reactor. The problems may be resolved by conducting more column tests and possibly replacing the Hydra CX2 with other types of fiber mulch. Experimental results presented in this report may be used for further study of filter medium selection and for optimization of the first flush reactor.

Guidelines for design, field construction, operation, and maintenance of the first flush reactor are provided in this report to help environmental engineers and stormwater managers design and operate the first flush reactor properly and achieve the stormwater pollutant removal efficiency required in the MS4 program.

17. Key Words
First flush reactor, MS4, stormwater treatment.

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First Flush Reactor for Stormwater Treatment for Elevated Linear Transportation Projects

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ABSTRACT

The United States EPA (Environmental Protection Agency) MS4 (Municipal Separate Storm Water Sewer System) Program regulations require municipalities and government agencies including the Louisiana Department of Transportation and Development (LADOTD) to develop and implement stormwater best management practices (BMPs) for linear transportation systems to reduce the discharge of various pollutants, thereby protecting water quality. An efficient and cost-effective stormwater BMP is urgently needed for elevated linear transportation projects to comply with MS4 regulations. This report documents the development of a first flush-based stormwater treatment device, the first flush reactor, for use on elevated linear transportation projects/roadways for complying with MS4 regulations.

A series of stormwater samples were collected from the I-10 elevated roadway section over City Park Lake in urban Baton Rouge. Stormwater treatment experiments were conducted using three laboratory columns filled with different combinations of filter medium layers. In terms of contaminant removal efficiency, the optimum filter medium combination was found to be (a) a mixture of Smart Sponge and Hydra CX2 in the top layer, (b) zerolite in the next layer, (c) sand, (d) sawdust, and (e) gravel in the bottom layer. Results of the laboratory experiments indicate that the first flush reactor with the optimized filter medium layers is able to remove over 85% of total suspended solids (TSS), 90% of total phosphorus, 99% of NO_2-N and NO_3-N, and 70% - 90% of fecal coliform bacteria. Tested heavy metals include Al, As, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Na, Ni, P, Pb, Si, and Zn. In general, removal rates of heavy metals through the recommended filter media are higher than 80%. The removal rates of three toxic heavy metals including cadmium (Cd), copper (Cu), and lead (Pb) are higher than 90%. Hydrocarbon levels in the stormwater samples were too low to be detected. Some unsolved problems in the current design of the first flush reactor include the low removal rate (15%-58%) of TKN (Total Kjeldahl Nitrogen) and the slight release (up to 20%) of toxic metal zinc (Zn) from the reactor. The problems may be resolved by conducting more column tests and possibly replacing the Hydra CX2 with other types of fiber mulch. Experimental results presented in this report may be used for further study of filter medium selection and for optimization of the first flush reactor.

Guidelines for design, field construction, operation, and maintenance of the first flush reactor are provided in this report to help environmental engineers and stormwater managers design and operate the first flush reactor properly and achieve the stormwater pollutant removal efficiency required in the MS4 program.

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IMPLEMENTATION STATEMENT

Results of the first flush reactor may be implemented by the LADOTD following the US EPA and Louisiana Department of Environmental Quality (LDEQ) MS4 regulations. Guidelines for design, field construction, operation, and maintenance of the first flush reactor are provided in this report to help engineers and stormwater managers design and operate the first flush reactor properly and achieve the stormwater pollutant removal efficiency mentioned in this report. The author’s recommendation, based on this study, is that the LADOTD considers constructing and installing a pilot-scale first flush reactor at I-10 roadway section at City Park Lake in urban Baton Rouge for field monitoring and demonstration. The currently recommended design of the first flush reactor can be further improved by possibly replacing Hydra CX2 with other types of fiber mulch. The experimental results presented in this report may be used for the further study of filter medium selection and for optimization of the first flush reactor. The first flush reactor developed in this study will assist LADOTD in complying with the US EPA and LDEQ MS4 regulations.

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INTRODUCTION

The US EPA MS4 Program regulations require municipalities and government agencies including Louisiana Department of Environmental Quality (LDEQ) and LADOTD to develop and implement stormwater best management practices (BMPs) for linear transportation systems to reduce the discharge of pollutants, thereby protecting water quality. The BMPs commonly used for linear transportation systems include exfiltration trench devices, infiltration devices, vegetated bio-filter devices, and detention devices. While many of these BMPs have varying degrees of viability, none are applicable for the many sections of elevated roadways in Louisiana. The state of Louisiana has more elevated roadways than any other state in the US. In addition, most existing stormwater BMPs require high hydraulic conductivity topsoil for infiltration; however, the soils in coastal Louisiana are typically composed of clay and silt, which have low permeability and may result in the failure of infiltration-based BMPs.

Sansalone and Teng (2005 and 2004) improved a partial exfiltration reactor (PER) by using a bed of oxide-coated sand. The PER device is mainly designed to remove heavy metals. However, pollutants contained in storm water runoff from highways and roads include not only metals but also a broad range of other contaminants such as vehicle brake dust, oils, greases, fuels, bacteria, and oxygen-robbing nutrients (TRB 2006). The contaminants become transported into rivers, bayous, lakes, and coastal waters, causing impairment of receiving waterbodies. New Louisiana MS4 regulations require a reduction of at least 50 % of all contaminants. Therefore, an efficient and cost-effective stormwater treatment device is urgently needed for complying with the MS4 regulations.

OBJECTIVE

The primary objective is to design and test a first flush-based stormwater treatment device for elevated linear transportation projects/roadways that is capable of complying with MS4 regulations. The innovative idea behind the device is to combine a first flush collection device with layered reactive filter media to form a first flush reactor and, thereby, capture and treat the most polluted portion of runoff from a catchment site.

The “first flush” refers to the delivery of a disproportionately large load of pollutants during the early portion of a storm runoff event (Deng et al., 2005). The existence of this first flush of pollutants provides an opportunity for efficient treatment of stormwater runoff from elevated linear transportation pavements.

SCOPE

A series of laboratory column tests were conducted to select the effective filter media and determine the optimum combination of the filter media forming the core part of the first flush reactor. Natural stormwater samples were collected from the I-10 elevated roadway section over City Park Lake in urban Baton Rouge. The reactive filter media tested in the laboratory experiments include Spanish moss, mulch, woodchips, sawdust, sand, Smart Sponge, Hydra CX2, and zerolite. Contaminant removal efficiencies of various combinations of filter media were determined. The contaminants analyzed in the tests include TSS, nutrients [total phosphorus, NO_2-N, NO_3-N, Total Nitrogen (TN), and TKN], fecal coliform bacteria, heavy metals (Al, As, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Na, Ni, P, Pb, Si, and Zn), and hydrocarbons.

METHODOLOGY

This research was conducted by executing the three tasks listed below using advanced experimental and analytical facilities available in the Department of Civil and Environmental Engineering at LSU.

Task 1: Bench Scale Column Experiments with Continuous Influent

The research objective under this task was to test the performance of various filter media in removing different types of contaminants from linear transportation system runoff. To accomplish the objective, bench-scale column experiments were conducted under well-controlled laboratory conditions. Ten gallons of natural stormwater samples were collected using two coolers on September 14, 2008; November 5, 2008; December 9, 2008; January 24, 2009; March 16, 2009; and May 12, 2009, respectively, from the I-10 elevated roadway section over City Park Lake in urban Baton Rouge, as shown in Figure 1a. The average

Figure 1a
Stormwater sampling site at the I-10 roadway section at City Park Lake

annual daily traffic volume (ADT) for eastbound I-10 lanes is 70,400 vehicles. Mean annual precipitation at the site is 1460 mm/year.

Figure 1b shows the plan view of the experimental site. Runoff is generated from a 544-m^2 section of Portland cement concrete (PCC) pavement and collected from the lower expansion joint. The pavement catchment area is 12.2-m wide by 44.6-m long with a tangential slope of 2.02%. Arrows indicate the direction of flow. All flow was captured from the downspout connected to the lower expansion joint, as shown in Figures 1a and 1b.

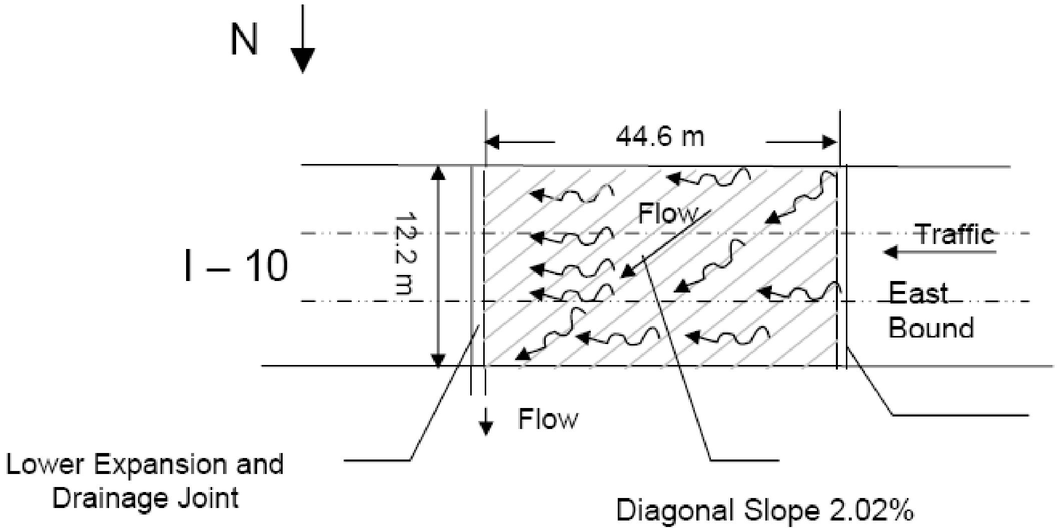


Figure 1b
Plan view of experimental site (not to scale)

Laboratory experiments were subsequently conducted using three columns with different combinations of filtering material layers, as shown in Figure 2. Influent (raw stormwater) and effluent (treated stormwater) samples were analyzed for conventional water quality parameters (TSS, TN, NO_2, NO_3, TKN, total petroleum hydrocarbons (TPH), and fecal coliform) in the Water Quality Laboratory in the Department of Civil and Environmental Engineering at LSU. Heavy metals were analyzed in the Laboratory of Professor Robert P. Gambrell in the Department of Oceanography and Coastal Sciences at LSU. Hydrocarbon samples were analyzed in the Gulf Coast Analytical Laboratories (GCAL), Inc. in Baton Rouge.

The influent is continuously pumped into columns using a micropump; the effluent is controlled through a valve. In order to achieve a minimum residence time of 24 hours, the effluent flow rates vary in the range of 400–600 ml/hour. Actual residence time of the stormwater in the columns ranges from 25–31 hours. The column that consistently achieves the highest contaminant removal rates is considered to possess the optimum combination of filter media.

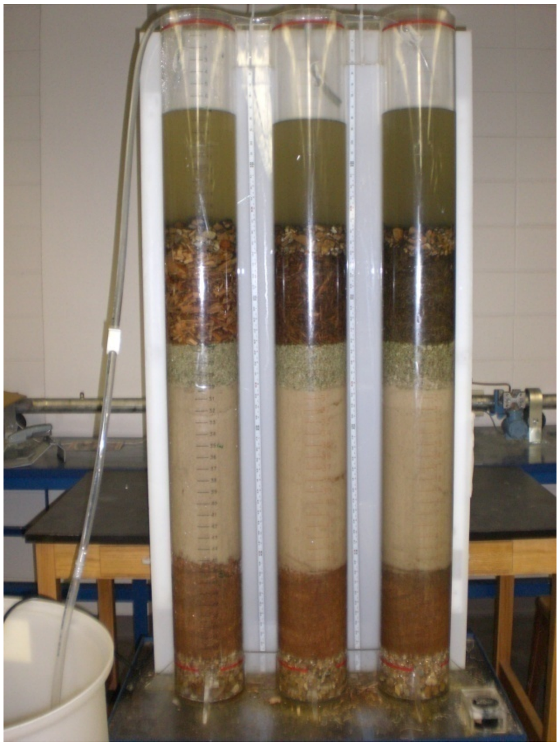


Figure 2
Column experiment setup of the first flush reactor

Task 2: Laboratory Testing of Pilot Scale First Flush Reactor with Intermittent Influent

The research objective under this task was to evaluate the performance of the first flush reactor optimized in Task 1 under conditions of intermittent loadings. The initial recoveries of the reactor after three dormant periods of 45 days, 50 days, and 56 days were studied by measuring effluent concentrations and subsequently determining contaminant removal efficiencies.

Task 3: Manual Preparation for Design and Construction and Maintenance of First Flush Reactor

The research objective under this task was to develop guidelines for field construction, operation, and maintenance of the first flush reactor to achieve the stormwater pollutant removal efficiency required in the MS4 program. The following guidelines are generally required in the implementation of stormwater BMPs:

1. General description of MS4 regulations related to linear transportation systems, stormwater BMPs, and the first flush reactor
2. Stormwater treatment principles/mechanisms (How It Works)
3. Performance/reduction rate for each type of pollutants
4. Detailed design procedure for the first flush reactor
5. Construction requirements
6. Operation requirements
7. Maintenance requirements
8. Cost Estimation

DISCUSSION OF RESULTS

Six sets of column experiments were conducted and the results are summarized and discussed as follows:

Task 1: Bench Scale Column Experiments with Continuous Influent

Test #1 Results

The first set of column experiments were conducted from September 14-15, 2008. The effluent flow rates of the columns were equal to 500 ml/hour, corresponding to a residence time of 25.23 hours.

The filter media used in three columns included:

- Column A: (1) woodchips (top layer), (2) zerolite, (3) sand, (4) sawdust, and (5) gravel (bottom layer)
- Column B: (1) Spanish moss (top layer), (2) zerolite, (3) sand, (4) sawdust, and (5) gravel (bottom layer)
- Column C: (1) Mulch (top layer), (2) zerolite, (3) sand, (4) sawdust, and (5) gravel (bottom layer)

The experiment results showed:

(1) TSS removal rates in the three columns were 31% (A), 14% (B), and 22% (C). The relative low TSS removal rates in the first set of experiments may be caused by the low TSS concentration (72 mg/L) in the influent and the relative high TSS concentration produced by the filter media.

(2) Significant TN removal was observed only in Column B (38%). There was no significant TN removal through Columns A and C.

(3) It appeared that the columns were very efficient in removing NO_2-N and NO_3-N. While the NO_2-N and NO_3-N concentrations in the influent were 0.52 mg/L and 1.64 mg/L, NO_2-N and NO_3-N was not detected in the effluent.

(4) While 15 heavy metals (including Al, As, Ca, Cd, Cr, Cu, Fe, Mg, Mn, Na, Ni, P, Pb, Si, and Zn) were analyzed, as shown in the Appendix, researchers were primarily concerned with the four toxic heavy metals, including cadmium (Cd), copper (Cu),

lead (Pb), and zinc (Zn). Cd concentration in the first stormwater sample was undetectable. Cu removal rates in the three columns were 48% (A), 79% (B), and 75% (C). Column A had the lowest Cu removal rate. Pb concentration in the stormwater sample (influent) was 0.017 ppm and was not detectable (< 0.01 ppm) in the effluents of the three columns. Zn removal rates in the three columns were -207% (A), -72% (B), and -186% (C), indicating a release of Zn from all three columns.

(5) Fecal coliform levels were not tested for the first sample.

Test #2 Results

The second set of column experiments were conducted from November 5-6, 2008 using the same columns used in the first set of experiments. The effluent flow rates of the columns were equal to 420 ml/hour, corresponding to a residence time of 30.04 hours. The experiment results showed:

(1) TSS removal rates in the three columns were 79% (A), 92% (B), and 81% (C).

(2) Significant TN removal was observed only in Column A (52%). It appeared that Columns B and C released TN instead of removing TN. It is not clear why the same Column B removed TN (38%) in the first run, while it released TN in the second run. The column C consistently released TN in the first two runs.

(3) The columns were continuously efficient in removing NO_2-N in the second run. However, the NO_3-N concentration of Column B increased from 3.05 mg/L in the influent to 14.69 mg/L in the effluent. The NO_3-N was not detected in the effluent of Column C and 46% was removed in Column A.

(4) TKN release occurred in Column C. This result is consistent with the TN release in the same column.

(5) Bacterial concentrations in the effluent of Columns A and C were surprisingly high, showing bacterial growth in Columns A and C.

(6) Cd concentration in the second stormwater sample was 0.001 ppm and was not detectable (< 0.001 ppm) in the effluents of the three columns. Cu removal rates in the three columns were 70% (A), 87% (B), and 59% (C). Column C had the lowest but acceptable Cu removal rate. Pb concentration in the stormwater sample (influent) was 0.04 ppm and was not detectable (< 0.01 ppm) in the effluents of the three

columns. Zn removal rates in the three columns were -269% (A), -134% (B), and -203% (C), showing the release phenomenon of Zn from all the three columns.

The relative high contaminant removal rates in the second run are partially attributed to the longer residence time. The results indicated that the filter media used in the first two runs were unable to meet the required contaminant removal rate (at least 50%). In order to avoid nitrogen release and bacterial production from the columns, the top layers of Columns A and B were replaced with a mixture of the Smart Sponge and Hydra CX2 for Column A and Hydra CX2 for Column B. The Smart Sponge was found to be effective in removing bacteria *[6]*. Therefore, the filter media used in the remaining experiments included:

- Column A: (1) Smart Sponge and Hydra CX2 (top layer), (2) zerolite, (3) sand, (4) sawdust, and (5) gravel (bottom layer)
- Column B: (1) Hydra CX2 (top layer), (2) zerolite, (3) sand, (4) sawdust, and (5) gravel (bottom layer)
- Column C: (1) Mulch (top layer), (2) zerolite, (3) sand, (4) sawdust, and (5) gravel (bottom layer)

The Smart Sponge is an innovative polymer technology (Figure 3) that is chemically selective to hydrocarbons and can destroy bacteria *[6]*. The Smart Sponge fully encapsulates recovered oil, resulting in a substantially more effective response that prevents absorbed oil from leaching. Hydra CX2 is a type of fiber mulch.

Figure 3
The Smart Sponge used in the first flush reactor

Test #3 Results

The third run conducted from December 9–10, 2008 showed encouraging results:

(1) TSS removal rates in the three columns were 98% (A), 90% (B), and 98% (C).

(2) TN removal rates in the three columns were 69% (A), -106% (TN release from Column B), and 82% (C), respectively.

(3) NO_2-N and NO_3-N was not detected in the effluents except Column C that released NO_2-N.

(4) TKN removal rates of Columns A, B, and C were 58%, -178% (TKN production occurred in Column B), and 82%. This result is consistent with the TN removals from the corresponding columns.

(5) Fecal coliform removal rates in the three columns were 94% (A), -433% (Column B produced bacteria rather than removing bacteria), and 99% (C), respectively.

(6) Cd concentration in the third stormwater sample was 0.004 ppm and was not detectable (< 0.001 ppm) in the effluents of the three columns. Cu removal rates in the three columns were 96% (A), 86% (B), and 93% (C). Cu removal rates in all the three columns were high due to possibly the high Cu concentration (0.191 ppm) in the influent. Pb concentration in the stormwater sample (influent) was 0.228 ppm and was not detectable (< 0.01 ppm) in the effluents of the three columns. Zn removal rates in the three columns were -20% (A), -144% (B), and -65% (C), showing again the release phenomenon of Zn from all three columns, while the release from Column A reduced significantly in this run.

The third set (run) of column experiments indicated that both Columns B and C experienced problems due to net production of contaminants or nutrients. Column A containing the mixture of Smart Sponge and Hydra CX2 as the top filter layer performed well and met the removal rate requirements except for the metal Zn.

Task 2: Laboratory Testing of Pilot Scale First Flush Reactor with Intermittent Influent

The intermittent periods for tests #4, #5, and #6 were 45 days, 50 days, and 56 days. The columns were kept dry during the intermittent periods to mimic the potential natural scenario to occur in the first flush reactor and to investigate the effect of the dormant periods on contaminant removal efficiency of the columns. Tests #4–6 were intended to examine the durability of the first flush reactor and the long term variability of contaminant removal efficiency of the reactor. Therefore, experiment conditions including the filter media and flow rates were not changed for the last three runs.

Test #4 Results

The fourth set of column experiments conducted from January 24 – 25, 2009 showed similar results as those from the third run:

(1) TSS removal rates in the three columns were 91% (A), 82% (B), and 84% (C). The TSS removal rates were high.

(2) TN removal rates in the three columns were 63% (A), -2% (TN release from Column B), and 52% (C), respectively.

(3) NO_2-N concentrations were not detected in the effluents of the three columns. The NO_3-N concentration in the effluent of Column A was not detected. The NO_3-N removal rates of Columns B and C were identical (84%).

(4) TKN removal rates of Columns A, B, and C were 28%, -87% (TKN production occurred in Column B), and 20%.

(5) Total phosphorus removal rate was higher that 99%.

(6) Fecal coliform analysis was not conducted for this run.

(7) Hydrocarbon concentration in the stormwater samples was not detected in the laboratory analysis conducted by the GCAL. Due to the high cost involved in hydrocarbon analysis and the result of undetectable concentration, this was the only laboratory analysis for hydrocarbon.

(8) Cd concentration in the fourth stormwater sample was 0.001 ppm and was not detectable (< 0.001 ppm) in the effluents of the three columns. Cu removal rates in

the three columns were 94% (A), 89% (B), and 90% (C). Cu removal rates in all the three columns were high. Pb concentration in the stormwater sample (influent) was 0.039 ppm and was not detectable (< 0.01 ppm) in the effluents of the three columns. Zn removal rates in the three columns were 1% (A), 6% (B), and 3% (C), indicating a slight removal of Zn from all the three columns. This was the only run where Zn release was not observed.

The fourth run of column experiments indicated that Column A consistently exhibited the highest contaminant removal rate among the three columns except Zn. As compared to the third run conducted for Task 1 where all contaminant removal rates of Column A were higher than 50%, the TKN removal rates of all three columns in the fourth run were less than 30%.

Test #5 Results

The fifth set of column experiments conducted from March 16-17, 2009 showed similar results as those from the fourth run:

(1) TSS removal rates in the three columns were 85% (A), -91% (B), and -13% (C). It was not clear why the TSS concentrations in the effluents of Columns B and C increased as compared to the influents.

(2) TN removal rates in the three columns were 25% (A), -210% (TN release from Column B), and 20% (C), respectively.

(3) NO_2-N and NO_3-N were not detected in the effluents of the three columns.

(4) TKN removal rates of Columns A, B, and C are 15%, -250% (TKN production occurred in Column B), and 10%, respectively. The TKN removal rates were very low in this run.

(5) Fecal coliform removal rates in the three columns were 72%(A), 82%, and 66% (C), respectively.

(6) Cd concentration in the fifth stormwater sample was undetectable (< 0.001 ppm). Cu removal rates in the three columns were 95% (A), 63% (B), and 78% (C). Pb concentration in both the stormwater sample (influent) and the effluents of the three columns were not detectable (< 0.01 ppm). Zn removal rates in the three columns were -17% (A), -186% (B), and -46% (C). Column A had the lowest release rate of Zn among the three columns.

The fifth set (run) of column experiments indicated that both Columns B and C experienced release problems due to net production of contaminants or nutrients in the columns. Column A containing the mixture of Smart Sponge and Hydra CX2 as the top filter layer performed well and met the removal rate requirements except the metal Zn. One possible source of TN and TKN might be the Hydra CX2.

Test #6 Results

The sixth set of column experiments were conducted from May 12-13, 2009. The laboratory analysis result of fecal coliform indicated that removal rates in the three columns were 69% (A), 0% (B), and 69% (C).

The transportation system is a primary source of metals in stormwater runoff to urban streams and groundwater. In general, removal rates of heavy metal through the columns are higher than 60% except Mg, Na, Si, and Zn, which showed increased concentrations in effluents. Conventional toxic heavy metals including cadmium (Cd), copper (Cu), and lead (Pb) in stormwater runoff were almost completely removed in the three columns. Lead, which is often used as an indicator for other toxic pollutants in stormwater, can be harmful or deadly for human and aquatic life. Cadmium can bioaccumulate in an ecosystem; soil microorganisms are especially sensitive to it, and it is harmful to human health. Low levels of copper inhibit the olfactory systems of salmonid fish, decreasing their ability to hide in response to warning signals. Zinc, although not harmful to humans at concentrations normally found in stormwater, can be deadly for aquatic life. It is not clear why zinc (Zn) release occurred in all three columns because the sorption ability of zinc is commonly greater than cadmium, i.e., Zn ≥ Cd.

It can be seen from the above column experiments conducted for Tasks 1 and 2 that Column A had the highest overall contaminant removal efficiency. Therefore, the following filter media layers and their combination are recommended as the filter media for the first flush reactor: (1) Smart Sponge and Hydra CX2 (top layer); (2) zerolite, (3) sand, (4) sawdust, and (5) gravel (bottom layer).

More column tests are necessary to determine the reasons causing releases of TN, TKN, and Zn from the columns.

Task 3: Manual for Design and Construction and Maintenance of First Flush Reactor

General Description of MS4 Regulations Related to Linear Transportation Systems, Stormwater BMPs, and the First Flush Reactor

Polluted stormwater runoff is commonly transported through MS4s, from which it is often discharged untreated into local waterbodies. The term MS4 does not only refer to storm sewer systems. It can also include highways and roads with drainage systems, gutters, and ditches. According to 40 CFR 122.26(b)(8), municipal separate storm sewer means a conveyance or system of conveyances (including roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, or storm drains) *[5]*. To prevent harmful pollutants from being washed or dumped into an MS4, operators must obtain a National Pollutant Discharge Elimination System (NPDES) permit, and develop and implement a stormwater management program (SWMP) *[7]*.

The following manual is intended to provide a guideline for the initial design and operation of the first flush reactor to achieve the stormwater pollutant removal efficiency required in the MS4 Program for elevated linear transportation projects. The “first flush” refers to the delivery of a disproportionately large load of pollutants during the early portion of a storm runoff event *[1]*. The existence of this first flush of pollutants provides an opportunity for efficient treatment of stormwater runoff from elevated linear transportation pavements. The innovative idea behind the device is to combine a first flush collection system with multilayer reactive filter media to form a first flush reactor and, thereby, capture and treat the most polluted portion of stormwater runoff from a catchment site. Each layer targets at a specific type of pollutants. The multilayer-formed first flush reactor is therefore expected to be able to achieve the pollutant removal efficiency required in the MS4 regulations.

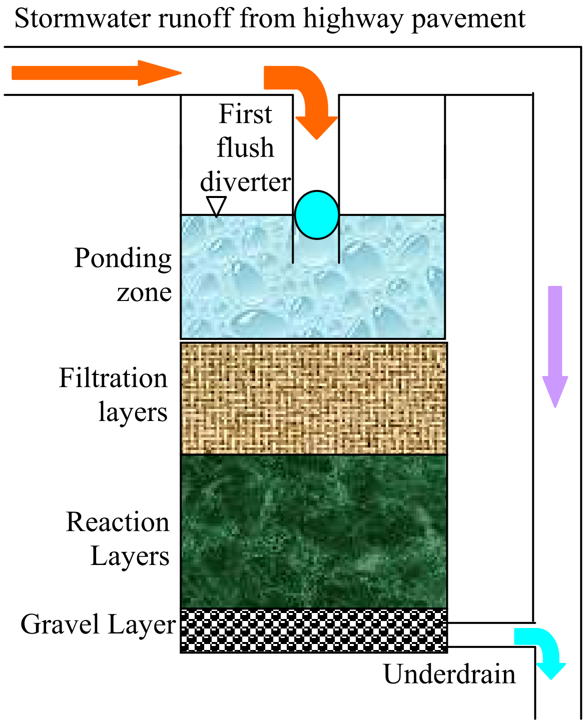


Figure 4
Conceptual design of the first flush reactor

Stormwater Treatment Principles

An initial design of the first flush reactor is shown in Figure 4. The passive first flush reactor is composed of:

(1) A first flush diverter for capturing the first flush portion of stormwater runoff and diverting subsequent runoff to downspout or stormwater drains by means of a floating ball. As the water level rises in the reactor the ball floats and once the reactor is full, the ball rests on a seat inside the diverter chamber preventing any further water entering the ponding zone of the reactor. The subsequent flow of water is then automatically directed to the stormwater drain.

(2) Multilayer reactive filter media which consist of at least the following layers: (a) a ponding zone for allowing sediments to settle; (b) filtration layers for removing particulate-bound contaminants; (c) sorption and biogeochemical reaction layers for removing dissolved heavy metals, nutrients and other contaminants; and (d) a bottom layer to prevent the reactive media from clogging the effluent piping.

(3) Reactor container with underdrain for holding reactive filter media and the first flush portion of stormwater runoff. The first flush runoff is stored in the reactor for a designed residence time to allow reactions to proceed and, thereby, achieve required contaminant removal efficiency.

Pollution Reduction Capabilities

Volume Reduction. The first flush reactor (FFR) is designed to capture and retain 1 inch of precipitation from the drainage area, which is roughly 80% of the annual runoff volume for the region. The storage volume of a FFR is defined as the sum total of the surface and subsurface void volumes below the top of the ponding zone. Inter-media void volumes may vary considerably based on design variations.

The volume of a FFR has 2 components:

1. Surface Storage Volume (CF) = Bed Area (ft2) x Average Design Water Depth

2. Filter Storage Volume (CF) = Bed Area (ft2) x Depth of Filter (ft) x Holding Capacity

FFR Volume = Surface Storage Volume + Filter Storage Volume

Pollutant Removal Capability. The FFR is designed to be able to remove at least 50% of various contaminants in typical highway and urban post-development runoff when sized, constructed, and maintained in accordance with the recommended specifications. Undersized or poorly designed FFRs can reduce contaminant removal performance. The following design pollutant removal rates are conservative average pollutant reduction percentages for design purposes derived from the laboratory testing data. In a situation where a removal rate is not deemed sufficient, additional FFRs may be put in place at the given site in series or in a “treatment train” approach.

Table 1
Pollutant removal efficiency

Parameter	Removal Efficiency (%)
Total Suspended Solids	> 85
Total Phosphorus	> 90
NO_2 and NO_3	> 99%
Total Nitrogen	25 - 70
Pathogens	70 - 90
Heavy Metals	> 90 except Zn
Hydrocarbons	NA
Runoff Volume	1 inch

FFRs remove pollutants using physical, chemical, and biological mechanisms. Specifically, they use absorption, microbial action, sedimentation, and filtration.

Design Procedure for the First Flush Reactor

The following steps outline a recommended design procedure for the first flush reactor.

Step 1. Make a Preliminary Judgment

Make a preliminary judgment as to whether site conditions are appropriate for the use of a FFR, and identify the function of the practice in the overall treatment system.

A. Consider basic issues for initial suitability screening, including:

- Site drainage area
- Site topography and slopes
- Downspout or stormwater drain
- Site location/minimum setbacks

B. Determine how the FFR will fit into the overall stormwater treatment system

- Decide whether the FFR is the only BMP to be employed, or if there are other BMPs addressing some of the treatment requirements.
- Decide where on the site the FFR is most likely to be located.

Step 2. Confirm Design Criteria and Applicability

- Determine whether the FFR must comply with local permits.
- Check with local officials (LADOTD, LDEQ, Planning Commission of the City of Baton Rouge), and other agencies to determine if there are any additional restrictions and/or surface water or watershed requirements that may apply.

Step 3. Perform Field Verification of Site Suitability

It is highly recommended that the field verification be conducted by a qualified environmental/water resources engineer.

Step 4. Determine Runoff Depth

Runoff Depth in Inches = $(P-0.2*S)^2/(P+0.8*S)$

where,

P = Precipitation (typically use 1 inch for the first flush),

S = 1,000/CN – 10, and

CN = Curve Number (see table below).

Table 2

Partial listing of NRCS curve numbers in urban areas*

Land Use/Cover	Hydrologic Soil Group			
	A	B	C	D
100% Impervious (parking lots, rooftops, paved roads)	98	98	98	98
Open space (lawns and golf courses) with grass cover <50%	68	79	86	89
Open space with grass cover 50% to 75%	49	69	79	84
Open space with grass cover > 75%	39	61	74	80
Woods in fair hydrologic condition	36	60	73	79

*Source: USDA. 1986. *Urban Hydrology for Small Watersheds.* Washington, D.C.: U.S. Department of Agriculture. Technical Release No. 55.

Step 5. Compute the Water Quality Volume

The Water Quality Volume (WQv) to be treated:

WQv (ft^3) = Drainage Area (ft^2) × Runoff Depth (inches) /12

Step 6. Compute WQv Flow Rate

The peak rate of discharge for water quality design storm (Qwq) is needed for sizing diversion structures.

1. Use WQv; compute CN.
2. Compute time of concentration using TR-55 method.
3. Determine appropriate unit peak discharge from time of concentration.
4. Compute Qwq from unit peak discharge, drainage area, and WQv.

5. An alternate method is to determine the Qwp using the Rational method; use the design rainfall depth and a 2-hour duration to provide a design rainfall intensity for use in the rational method equation (i.e., Q cfsec = C × I × A); use the Rv calculated above for the “C” runoff coefficient.

$$Q_{wp} = C \times I \times A \qquad (1)$$

where,
Q_{wp} = Peak discharge (cfs);
C = Runoff coefficient = 0.05 + (0.009)(I), where I = impervious area in %;
I = Rainfall intensity (in/hour); and
A = Drainage area (acres).

Step 7. Size Flow Diversion Structure

A flow regulator (or flow splitter diversion structure) must be used to divert the WQv to the first flush reactor based on the water quality flow rate computed in Step 6.

Step 8. Determine Size of FFR Ponding/Filter Area with Under-drain

A FFR usually occupies between 5% and 7% of the drainage area. The FFR can be designed to hold the first inch of rainfall from the entire drainage area. The required filter bed area is computed using the following equation (based on Darcy’s Law):

$$A_f = \frac{(W_{QV}) \times (d_f)}{(k) \times (h_f + d_f) \times t_f} \qquad (2)$$

where,
A_f = surface area of ponding area (ft2);
W_{Qv} = water quality volume in cubic feet (or total volume to be captured);
d_f = filter bed depth (2 feet minimum);
k = coefficient of permeability of filter media (ft/day) (must be at least 0.5 ft/day);
h_f = average height of water above filter bed (ft) (Average depth of water is typically 9 inches, but depends upon the height of the overflow structure) (typically 3 inches, which is half of the 6-inch ponding depth); and
t_f = design filter bed drain time (days) (2.0 days or 48 hours is recommended maximum).

Step 9. Design Pretreatment

Pretreat with a screen filter on-line configuration.

Step 10. Size Underdrain System

Pipes must be selected so that they drain water from the rock layer substantially faster than water enters from the filter layers above. Peak inflow is achieved when water is at its highest level in the FFR (typically set at 9 inches). Only smooth-walled plastic pipes are recommended for underdrains. They maintain higher flow rates than non-smooth walled corrugated pipes and are less prone to be a habitat for mosquitoes. The number of pipes needed for the underdrain system is determined using the following 5-step process:

1. Determine maximum filtration rate through the filter media by applying Darcy's equation as follows:

$$q_{\max} = A_f \left(k \frac{h_f + d_f}{d_f} \right) \tag{3}$$

where,

A_f = surface area of ponding area (ft^2);
k = coefficient of permeability of filter media (ft/s);
d_f = filter bed depth (2 feet minimum);
h_f = average height of water above filter bed (ft); and
$q_{\max}$ = maximum filtration rate (ft^3/s).

2. Apply a factor of safety: range from 2 to 10 to the flow rate. That is, the pipe design will carry at least 2 to 10 times the amount of water that would flow through the media. This is underdrain design flow, Q.

3. Use the Manning equation:

$$D = 16 \times \left(\frac{Q \times n}{s^{0.5}} \right)^{3/8} \tag{4}$$

where,

D = Diameter of single pipe (in.),
n = roughness factor,
s = internal slope, and
Q = discharge (cfs).

4. The only unknown is D. This is the diameter of a single pipe that could carry all the water if it's the only underdrain. Pipe diameters are typically either 4 inches or 6

inches. The table below converts D (in inches) to an equal number of 4- or 6-inch underdrains at 0.5% slope.

5. It is strongly recommended to have at least two underdrains, even if only one is needed. This prevents system failure if one pipe inadvertently clogs.

Table 3
Selection of underdrains

If D is less than	# of 4" pipes	If D is less than	# of 6" pipes
5.13	2	7.84	2
5.95	3	9.11	3
6.66	4	10.13	4
7.22	5		
7.75	6		
8.20	7		

Step 11. Design Appropriate Overflow Structure

The overflow structure should be sized to accommodate storm volumes in excess of the first flush (typically the first inch of rainfall). In highway settings, the downspout or stormwater drain is often used as an overflow pipe.

Step 12. Prepare Filter Media

See the Appendix for more details about filter media.

Step 13. Prepare Operations and Maintenance (O&M) Plan

See the Operations and Maintenance Requirements section for guidance on preparing an O&M plan.

Step 14. Prepare Cost Estimate

See the Construction and Maintenance Costs section for guidance on preparing a cost estimate that includes both construction and maintenance costs.

Construction Specifications

It is highly recommended that the field construction be conducted by a qualified contractor in consultation with LSU Civil and Environmental Engineering Department.

Operation and Maintenance Requirements

Regular inspection and maintenance is critical to the effective operation of FFRs as designed. It is the responsibility of the property owner to maintain all stormwater BMPs in accordance with the minimum design standards and other guidance provided in this manual. This section provides guidance on maintenance activities that are typically required for FFRs, along with a suggested frequency for each activity. Individual FFRs may have more or less frequent maintenance needs, depending upon a variety of factors including the occurrence of large storm events, overly wet or dry (i.e., drought) regional hydrologic conditions, and traffic conditions. Each property owner shall perform the activities identified below at the frequency needed to maintain the FFR in proper operating condition at all times.

The most frequently cited maintenance concern for FFR is surface and under-drain clogging caused by organic matter, fine silts, hydrocarbons, and algal matter. Common operational problems include:

- Standing water
- Clogged filter surface
- Inlet, outlet, or under-drain clog

Recommendations described in this section are aimed at preventing these common problems.

Design Phase Maintenance Considerations

Implicit in the design guidance in the previous sections is the fact that many design elements of FFRs can minimize the maintenance burden and maintain pollutant removal efficiency. Key examples include: limiting drainage area, providing easy site access, providing pre-treatment, and utilizing proposed filter media and combination.

Construction Phase Maintenance

Proper construction methods and sequencing play a significant role in reducing problems with operation and maintenance. In particular, with construction of FFR the most important action for preventing operation and maintenance difficulties is to ensure that the contributing drainage area has been fully stabilized prior to bringing the FFR online. Inspections during construction are needed to ensure that the FFR is built in accordance with the approved design, standards, and specifications. Detailed inspection checklists should be used that include sign-offs by qualified individuals at critical stages of construction to ensure that the contractor's interpretation of the plan is acceptable to the professional designer.

Post-Construction Operation and Maintenance

A maintenance plan clarifying maintenance responsibility is required. Effective long-term operation of FFR necessitates a dedicated and routine maintenance schedule with clear guidelines and schedules. Proper maintenance will increase the expected life span of the facility.

FFRs require inlet, mulch, Smart Sponge, and under-drain maintenance to ensure optimal infiltration, storage, and pollutant removal capabilities. When the filtering capacity diminishes substantially (e.g., when water ponds on the surface for more than 12 hours), remedial actions must be taken. One possible problem is that underdrain pipe systems can become clogged. Annual flushing through pipe cleanouts is recommended to facilitate unclogging of the pipes without disturbing FFRs. If the water still ponds for more than 12 hours, the top few inches of material should be removed and replaced with fresh material. The removed sediments should be disposed in an acceptable manner (e.g., landfill). If that does not solve the problem, more extensive rebuilding is required.

More experiments are needed to determine the lifespan of the filter media.

Construction and Maintenance Costs

Table 4
Cost components for first flush reactor

Implementation Stage	Primary Cost Components	Basic Cost Estimate	Other Considerations
Structural components	Under-drains	Under-drain Cost ($/linear foot) × Length of Device	Pipes
	Inlet structure	($/structure) or ($/curb cut)	
	Outlet structure	($/structure)	
	Filter media: Smart Sponge, Hydra CX2, zerolite, sand, sawdust, and gravel	Liner Cost ($/square yard) × Area of Device	

(continued next page)

Annual operation, maintenance, and inspection	Debris removal	Removal Cost ($/acre) × Area (acre) x Frequency	
	Sediment removal	Removal Cost ($/acre) × Area (acre) x Frequency	
	Inspection	Inspection cost ($) × Inspection Frequency	

*****Construction and maintenance budgets should be based on site specific information.

CONCLUSIONS

A novel first flush-based stormwater treatment device, first flush reactor (FFR), has been developed in this study for elevated linear transportation projects/roadways for complying with the MS4 regulations. The FFR has the following features:

- The passive first flush reactor is composed of (1) a first flush diverter for capturing the first flush and diverting subsequent runoff to downspout or stormwater drain by means of a floating ball, (2) multilayer reactive filter media, and (3) a reactor container with underdrain for holding reactive filter media and the first flush portion of stormwater runoff.
- In terms of contaminant removal efficiency, the optimum filter medium combination determined based on the column tests consists of (a) the mixture of Smart Sponge and Hydra CX2 (top layer), (b) zerolite, (c) sand, (d) sawdust, and (e) gravel (bottom layer).
- The current design of FFR is able to remove most contaminants, including TSS, nutrients, bacteria, and toxic metals. Specifically, a first flush reactor with the optimized filter medium layers is able to remove over 85% of TSS (Total Suspended Solids), 90% of total phosphorus, 99% of NO_2-N and NO_3-N, and 70-90% of fecal coliform bacteria.
- In general, removal rates of heavy metals through the recommended filter media are higher than 80%. The removal rates of three toxic heavy metals including cadmium (Cd), copper (Cu), and lead (Pb) are higher than 90%.
- Hydrocarbon levels in the stormwater samples were too low to be detected. It is expected that the hydrocarbon removal rate of the FFR should be higher than 50%, meeting MS4 regulations.

RECOMMENDATIONS

A further study is needed to significantly increase the removal rates of TKN and the toxic metal zinc (Zn) in the first flush reactor by conducting additional column tests and possibly replacing Hydra CX2 with other types of fiber mulch.

It is recommended that a pilot-scale first flush reactor be constructed and installed at the I-10 roadway section at City Park Lake in urban Baton Rouge for field monitoring and demonstration.

ACRONYMS, ABBREVIATIONS, AND SYMBOLS

ADT	Annual Daily Traffic
Al	Aluminum
As	Arsenic
BMPs	Best Management Practices
Ca	Calcium
Cd	Cadmium
Cr	Chromium
Cu	Copper
EPA	Environmental Protection Agency
Fe	Ferrum
FFR	First Flush Reactor
GCAL	Gulf Coast Analytical Laboratories
LADOTD	Louisiana Department of Transportation and Development
LTRC	Louisiana Transportation Research Center
Mg	Magnesium
Mn	Manganese
MS4	Municipal Separate Stormwater Sewer System
Na	Sodium
Ni	Nickel
P	Phosphorus
Pb	Lead
PER	Partial Exfiltration Reactor
Si	Silicon
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
TRB	Transportation Research Board
TSS	Total Suspended Solids
Zn	Zinc

REFERENCES

1. Deng, Z., de Lima, J.L.M.P., and Singh, V. P. “Fractional Kinetic Model for First Flush of Stormwater Pollutants.” *Journal of Environmental Engineering*, ASCE, 131(2), 2005, pp. 232-241.

2. Sansalone, J., and Teng, Z. “In situ Partial Exfiltration of Rainfall Runoff. I: Quality and Quantity Attenuation.” *Journal of Environmental Engineering,* 130 (9), 2004, pp. 990-1007.

3. Sansalone, J. J., and Teng, Z. “Transient Rainfall-Runoff Loadings to a Partial Exfiltration System-Implications for Urban Water Quantity and Quality.” *Journal of Environmental Engineering*, 131(8), 2005, pp. 1155-1167.

4. TRB (Transportation Research Board). Evaluation of Best Management Practices for Highway Runoff Control, NCHRP Report 565, 2006.

5. LADOTD. http://www.dotd.state.la.us/highways/construction/lab/ms4/home.asp. Accessed October 11, 2009.

6. AbTech. http://www.abtechindustries.com/index.asp?mid2=169. Accessed October 11, 2009.

7. USEPA. http://cfpub.epa.gov/npdes/stormwater/munic.cfm. Accessed October 11, 2009.

APPENDIX

Laboratory Analysis Results of Stormwater Samples

Table 5

Non-metal contaminants

Test No. /Sampling date	Column test	TSS (mg/l)	TN (mg/l)	NO_2 as N (mg/l)	NO_3 as N (mg/l)	TKN (mg/l)	Fecal Coliform (/100 ml)	Total TPH (ug/L)
Test 1 09/14/08 09/15/08	1-0**	72	2.16	0.52	1.64	<0.2	—	—
	1-A	50	2.0	n.a.	<0.02	2.0	—	—
	1-B	62	1.35	n.a.	<0.02	1.35	—	—
	1-C	56	2.45	n.a.	<0.02	2.45	—	—
Test 2 11/05/08 11/06/08	2-0	192	12.87	1.78	3.05	8.04	280	—
	2-A	40	6.24	n.a.	1.64	4.60	>1600	—
	2-B	15	14.69	n.a.	14.69	<0.5	220	—
	2-C	36	15.2	n.a.	n.a.	15.2	>1600	—
Test 3 12/09/08 12/10/08	3-0	1029	11.59	0.27	2.71	8.61	3,000	—
	3-A	20	3.6	n.a.	<0.02	3.60	170	—
	3-B	97	23.9	n.a.	<0.02	23.90	>16,000	—
	3-C	18	2.10	0.59	<0.02	1.51	30	—
Test 4 1/24/09 1/25/09	4-0	239	10.40	0.41	4.74	5.25	—	16800
	4-A	22	3.80	n.a.	<0.02	3.80	—	<150
	4-B	42	10.60	n.a.	0.78	9.82	—	—
	4-C	37	5.00	n.a.	0.78	4.22	—	—
Test 5 03/16/09 03/17/09	5-0	54	2.00	0.07	0.16	1.77	5,000	—
	5-A	8	1.50	n.a.	<0.02	1.50	1,400	—
	5-B	103	6.20	n.a.	<0.02	6.20	900	—
	5-C	61	1.60	n.a.	<0.02	1.60	1,700	—
Test 6 05/12/09 05/13/09	6-0						16,000	—
	6-A						5,000	—
	6-B						16,000	—
	6-C						5,000	—

** First number denotes the number of experiment and the second number/alphabets denote either it is raw sample (0) or columns (A or B or C).

Table 6
Metal contaminants

Para-meters	Test 1				Test 2				Test 3			
	1-0	1-A	1-B	1-C	2-0	2-A	2-B	2-C	3-0	3-A	3-B	3-C
Al (ppm)	1.089	1.158	1.299	2.304	2.573	0.591	0.141	0.9	4.144	0.125	0.214	1.085
As (ppm)	<0.02	<0.02	0.021	<0.02	<0.02	<0.02	0.022	<0.02	<0.02	<0.02	<0.02	<0.02
Ca (ppm)	21.37	9.701	13.75	9.991	80.73	44.91	44.62	54.32	116.9	27.63	28.64	20.96
Cd (ppm)	<0.001	<0.001	<0.001	<0.001	0.001	<0.001	<0.001	<0.001	0.004	<0.001	<0.001	<0.001
Cr (ppm)	0.006	0.001	0.002	0.002	0.008	0.003	<0.001	0.009	0.015	<0.001	<0.001	0.001
Cu (ppm)	0.048	0.025	0.01	0.012	0.114	0.034	0.015	0.047	0.191	0.008	0.027	0.014
Fe (ppm)	1.981	0.863	1.121	1.777	3.269	0.449	0.111	0.876	7.747	0.223	1.016	0.578
Mg (ppm)	1.929	1.11	1.578	1.251	6.386	2.882	2.815	5.001	6.653	6.59	7.407	4.867
Mn (ppm)	0.109	0.263	0.328	0.325	0.388	0.481	0.119	1.089	1.154	0.375	0.876	0.26
Na (ppm)	5.664	31.52	36.7	35.31	18.47	76.62	89.5	100.4	28.52	143.4	153.1	131.2
Ni (ppm)	0.008	0.003	0.003	0.002	0.028	0.008	0.004	0.011	0.038	0.033	0.009	0.004
P (ppm)	0.096	0.171	0.144	0.294	0.73	0.278	0.175	0.365	0.855	0.331	0.925	0.248
Pb (ppm)	0.017	<0.01	<0.01	<0.01	0.04	<0.01	<0.01	<0.01	0.228	<0.01	<0.01	<0.01
Si (ppm)	4.781	11.26	13.43	14.73	9.425	13.06	12.2	13.51	11.16	15.52	16.92	13.59
Zn (ppm)	0.212	0.651	0.364	0.607	0.634	2.337	1.485	1.921	1.258	1.51	3.064	2.076

(continued next page)

Parameters	Test 4				Test 5			
	4-0	4-A	4-B	4-C	5-0	5-A	5-B	5-C
Al (ppm)	2.878	0.203	0.314	0.299	0.554	0.116	0.285	1.123
As (ppm)	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04	<0.04
Ca (ppm)	79.4	27.67	20.93	29.64	19.89	13.5	11.14	6.999
Cd (ppm)	0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Cr (ppm)	0.008	0.001	0.001	0.001	0.005	0.001	0.001	0.002
Cu (ppm)	0.104	0.006	0.011	0.01	0.059	0.003	0.022	0.013
Fe (ppm)	3.424	0.671	0.453	0.342	1.646	0.554	0.722	0.904
Mg (ppm)	4.791	4.181	2.466	3.293	0.868	1.506	1.418	0.649
Mn (ppm)	0.168	0.21	0.328	0.13	0.054	0.103	0.169	0.047
Na (ppm)	51.5	139.2	121.5	118.6	2.6	51.2	33.2	33.5
Ni (ppm)	0.023	0.007	0.007	0.003	0.007	0.003	0.006	0.004
P (ppm)	0.401	0.299	0.617	0.4	0.08	0.116	0.179	0.097
Pb (ppm)	0.039	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Si (ppm)	10.14	14.87	14.22	11.94	1.739	10.62	9.081	8.48
Zn (ppm)	0.464	0.46	0.403	0.451	0.19	0.222	0.544	0.277

Table 7

Sampling date and conditions

Test Number	Sampling date and rainfall	Prev. rainfall date and amount
Test 1	09/14/2009; 0.44 inch	09/11/2009; 0.41 inch
Test 2	11/5/2009; 0.02 inch	10/23/2009; 0.21 inch
Test 3	12/09/2009; 0.57 inch	12/04/2009; 0.94 inch
Test 4	01/24/2009; 0.05 inch	01/18/2009; 0.04 inch
Test 5	03/16/2009; 0.76 inch	03/15/2009; 1.43 inch
Test 6	05/11/2009; 0.3 inch	05/03/2009; 0.7 inch

Table 8
Column setup

Storm water sample volume collected: 10 Gallons
Effluent flow rate: 400 ml/hr to 500 ml/hr

(a) Tests 1 and 2

Layer/ scenario	A	B	C
1	Wood Chip	Spanish Moss	Mulch
2	Zeolite	Zeolite	Zeolite
3	Sand	Sand	Sand
4	Sawdust	Sawdust	Sawdust
5	Gravel	Gravel	Gravel

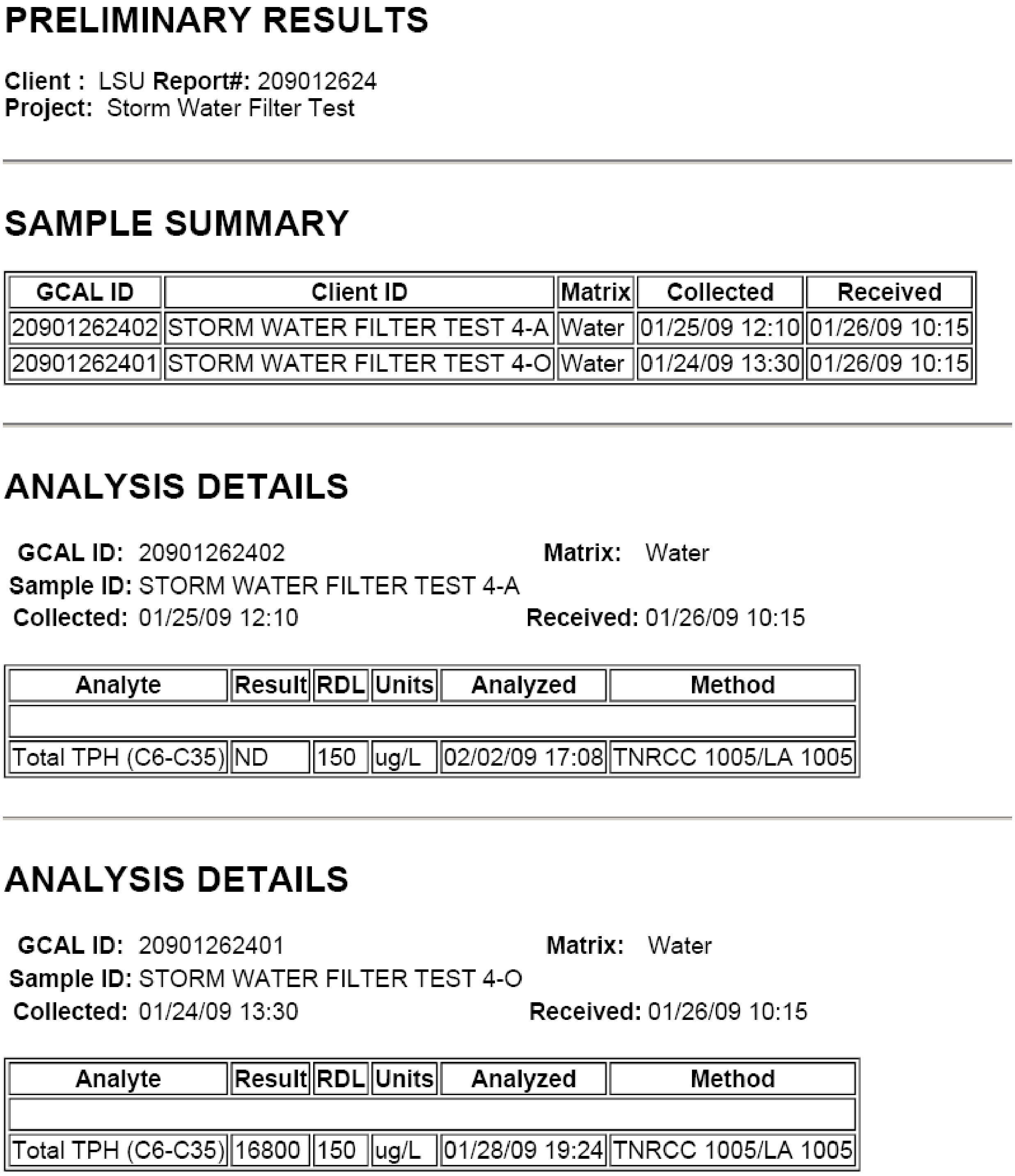
(b) Tests 3, 4, 5, and 6

Layer/ scenario	A	B	C
1	Sponge/Hydra CX2	Hydra CX2	Mulch
2	Zeolite	Zeolite	Zeolite
3	Sand	Sand	Sand
4	Sawdust	Sawdust	Sawdust
5	Gravel	Gravel	Gravel

Table 9
Sampling volume

TSS	100 ml	
NO3	25 ml	
TKN	50 ml	add H2SO4
Fecal coliform	100 ml	
Heavy Metal	20 ml	add nitric acid
Hydro Carbon	40 ml*3	

Hydrocarbon Analysis Report from Gulf Coast Analytical Laboratories (GCAL), Inc., Baton Rouge



PRELIMINARY RESULTS

Client : LSU **Report#:** 209012624
Project: Storm Water Filter Test

SAMPLE SUMMARY

GCAL ID	Client ID	Matrix	Collected	Received
20901262402	STORM WATER FILTER TEST 4-A	Water	01/25/09 12:10	01/26/09 10:15
20901262401	STORM WATER FILTER TEST 4-O	Water	01/24/09 13:30	01/26/09 10:15

ANALYSIS DETAILS

GCAL ID: 20901262402 **Matrix:** Water
Sample ID: STORM WATER FILTER TEST 4-A
Collected: 01/25/09 12:10 **Received:** 01/26/09 10:15

Analyte	Result	RDL	Units	Analyzed	Method
Total TPH (C6-C35)	ND	150	ug/L	02/02/09 17:08	TNRCC 1005/LA 1005

ANALYSIS DETAILS

GCAL ID: 20901262401 **Matrix:** Water
Sample ID: STORM WATER FILTER TEST 4-O
Collected: 01/24/09 13:30 **Received:** 01/26/09 10:15

Analyte	Result	RDL	Units	Analyzed	Method
Total TPH (C6-C35)	16800	150	ug/L	01/28/09 19:24	TNRCC 1005/LA 1005

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