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Transport, Speciation, Toxicity, and Treatability of Highway Stormwater Discharged to Receiving Waters in Louisiana

INTRODUCTION

As centralized wastewater treatment continues to improve while increasingly replacing decentralized systems, urban rainfall-runoff has become the leading contributor of water body impairments in the United States (USEPA, 1996). For many water bodies, runoff from paved land-water interfaces is a primary impairment source consisting of particulate matter (PM) sizes (1 to 10,000 μm), organics, and inorganic species. Of concern are phosphorus (P), nitrogen (N), PM, metals and chemical oxygen demand (COD) (Snyder, 1995; Sansalone et al., 2005) generated from infrastructure-traffic sources, maintenance activities, and daily human activities.

Tire-pavement interaction is a major source of PM, metals, organics, and P for pavements with phospho-gypsum admixtures (McKenzie et al., 1983; Ying et al., 2008). As line loadings from transportation systems, non-point load control is much more challenging than centralized wastewater treatment for at-grade treatment by best management practices (BMPs). However, when such systems cross the land-water interface, common in southeastern coastal states, BMPs may not be viable economically or as context-sensitive solutions compared to current roadway practices. By comparison, the cost to load recovery ratio of practices such as pavement or catch basin cleaning can be an order of magnitude lower than BMPs (Berretta et al., 2011).

OBJECTIVE AND SCOPE

The overall objective of this study was to gain a greater understanding of transport, treatability, speciation, and toxicity of highway stormwater discharged to receiving waters in Louisiana. Specific objectives were to address: (1) the transport and treatability of PM and phosphorus in urban rainfall-runoff, (2) the influence of hydrology on rainfall-runoff metal element speciation, (3) the toxicity of PM in urban rainfall-runoff, (4) the testing of a screened hydrodynamic separator (HS) subject to uncontrolled runoff loads, (5) the evaluation of a HS subject to controlled PM and flows, and (6) to develop, design, and analyze maintenance practices and water management options rainfall runoff for direct discharge into receiving waters.

This report focuses on the transport and fate of PM, metals, and phosphorus by a screened HS, the critical role of frequent maintenance for BMPs, metal speciation, and particulate toxicity in urban rainfall-runoff. The studied rainfall-runoff was restricted to runoff from the I-10 bridge over City Park Lake in Baton Rouge, Louisiana.

METHODOLOGY

The paved watershed consists of both sections (catchments) of the east- and west-bound lanes of I-10 City Park Lake Bridge in Baton Rouge, Louisiana. The total elevated highway bridge span over the lake is 886 ft. The concrete-paved catchment area consists of two sections that are 146 ft. long and 40 ft. wide, from a bridge area of 11,706 ft^2. Rainfall-runoff generated from the catchment is in the form of lateral pavement sheet flow, which drains through the east-most expansion joint of the bridge and is captured in a collection trough where it is combined with the catch basin drainage from each catchment of the bridge before the reaching the testing facility containing the physical models that were evaluated. Screened (HS) units, settling basins, filters, a drop box, flumes, and monitoring instrumentation were plumbed into the runoff capture system.

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Prior to each rainfall-runoff event, the equipment was cleaned and set up. Rainfall-runoff from a catchment or from the entire watershed (both catchments) was routed through a Parshall flume followed by a drop box where influent samples were taken. The free fall from the downstream of Parshall flume was the influent sampling location. This method of sample collection allowed representative sampling that also included the sediment fraction (> 75 µm) of PM. Upon runoff transport to the drop box, influent sample collection was immediately started for each runoff event. Free fall from the 8-in. diameter PVC pipe downstream of the screened HS, basin, or filter was the effluent sampling location. Around 14-17 influent and 13-15 effluent samples were taken for each rainfall-runoff event depending on the duration of the runoff or treatment run.

Rainfall was recorded with a tipping bucket gauge in increments of 0.01 in. A 70-kHz ultrasonic level sensor was mounted 10 in. above the bottom surface of Parshall flume to measure flow depths. Flow levels were transmitted to the datalogger of American Sigma (1994) every second and averaged over one minute to provide a single average flow level for each minute.

At the end of each event, aqueous samples and PM captured by a unit operation tested was recovered separately for further analyses. First, PM in a screened HS or basin were allowed to settle for at least 12 hours but no more than 24 hours from the end of each runoff event. The time frame of settling for PM in the screened HS unit was set up to provide enough time for PM to settle but at the same time to prevent the occurrence of anaerobic conditions, which typically were initiated within 48 hours and could cause re-suspension of suspended PM. The unit supernatant was then siphoned. PM from a unit operation was recovered through the drainage pipes at the bottom of the units tested (HS, basin, and/or filter) and transported to the lab for air-drying at 40ºC in a temperature-controlled isolation room. Once dried, PM was disaggregated and granulometric distributions were determined by mechanical sieve analysis following the modified procedure of ASTM D422 and laser diffraction (ASTM, 1993; Kim and Sansalone, 2008). Additionally, water chemistry analyses for metals, organics, nutrients, and parameters such as COD, pH, redox, temperature, and conductivity were conducted following standard methods.

CONCLUSIONS

Rainfall-runoff (stormwater) conveyed from transportation land uses is a complex heterogeneous mixture of PM, nutrients (N and P), metal elements, inorganic, and organic compounds. To effectively manage stormwater, the transport, toxicity, and treatment of stormwater has been examined. A screened HS as a BMP was tested along with unit operations of settling basins and filters.

Control and treatment is challenging in Louisiana where many transportation-related discharges are directly to receiving waters. The runoff and transported loads were generated from parallel and identical east- and west-bound paved catchments of the bridge deck on the I-10 over City Park Lake in Baton Rouge, Louisiana. Mass separation efficiencies were (from 38 percent to 70 percent for particles and 8 percent to 49 percent for total P) for the screened HS loaded by coarse particle size distributions (d50m of 270 to 2202 µm). Hydrologic response drove transport and metal speciation. Cd and Zn were predominately ionic species, while Pb was predominately associated with dissolved organic matter (DOM), and Cu was predominately associated with carbonate species or DOM. The toxicity of PM in runoff is a concern because many chemicals are bound to PM and transported through the aquatic environment. Early post-larvae life stages are more sensitive to toxicity from runoff containing PM. Testing of screened HS units revealed that PM treatment efficiency were generally less than 50 percent even when HS units were cleaned after every treatment event to ensure no scour. Treatment is a function of surface loading rate, screen size, and scour. After extensive testing of screened HS units results indicated that treatment and maintenance requirements were not sustainable and therefore four additional green infrastructure treatment designs were examined. These results indicated that either Buoyant Adsorptive Media (BAM) filters in the lake or cementitious permeable pavement (CPP) with a BAM network-met treatment requirements were sustainable and provided context-sensitive implementation. Compared to BMPs such as the screened HS, studies of highway maintenance practices such as pavement or appurtenance cleaning are significantly more economical per mass of PM or PM-bound constituent load recovered (Berretta et al., 2011).

RECOMMENDATIONS

Whether roadways are at-grade or elevated, these linearly extended infrastructure systems require linearly extended management for rainfall-runoff and constituent loads. Treatment by BMPs such as screened HS units or even unit operations such as settling basins or engineered filters located at abutments or discrete locations require linear drainage conveyance and unit cleaning, which is not economical and therefore typically not practiced. Utilizing infrastructure as passive treatment, for example with cementitious permeable pavement or porous friction courses (PFCs) represents linearly extended and more sustainable solutions. Additionally a recent study from 14 municipalities that included highway land use demonstrated that pavement cleaning, a linearly extended management tool, produced load recovery costs that were an order of magnitude lower than BMPs such as a screened HS. For elevated roadways such benefits would be even greater.