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Investigation on the effectiveness of pretreatment in stormwater management technologies

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ABSTRACT

The effectiveness of presettling basins as component of stormwater best management practice (BMP) technologies was investigated. Storm event monitoring and sediment collection were conducted from May 2009 to November 2012 on the presettling basins of the three BMP technologies designed to capture and treat stormwater runoff from highly impervious roads and parking lots. Data on captured runoff and sediment, total suspended solids (TSS) loadings, rainfall and runoff rate, sediment accumulation rate, as well as particle distribution and pollutant concentrations of sediment were gathered and analyzed along with the physical design characteristics of the presettling basins such as surface area and storage volume. Regression models were generated to determine significant relationships between design parameters. Results revealed that the storage volume ratio (ratio of storage volume of presettling basin to BMP) was an important parameter in designing the presettling basin of the BMP. For practicality, optimizing the design of the presettling basin means that the storage volume ratio should be determined based on the desired captured amount of runoff and sediment from runoff to limit the frequency of maintenance caused by the accumulation of sediment. It was recommended that pretreatment of runoff should be employed when the site in which the BMP is to be sited has high TSS loading and runoff rate, and is subjected to high intensity rainfall.

Introduction

Particles washed-off from paved areas contain various sorbed pollutants, and much of the pollutant load associated with stormwater runoff is carried by sediment (Herngren et al., 2006; Kim et al., 2005; Regenmorter et al., 2002; Sansalone and Buchberger, 1997; Urbonas, 1994). Thus, existing technologies for treating stormwater runoff are often targeted at removing pollutants bound to particles. In fact, many best management practices (BMPs) rely on sedimentation as the primary pollutant removal mechanism making pretreatment necessary especially in urban areas having high impervious cover where a large quantity of runoff is generated and the space in which to build a stormwater control is limited. In the case of filtration and water quality infiltration BMP, pretreatment is required to both minimize groundwater contamination and prolong the life of the BMP.

Pretreatment practices such as sediment forebay, vegetated filter strips and swales are commonly designed to dissipate the energy of incoming runoff or receive the initially highly polluted runoff (Grizzard et al., 1986; Iqbal et al., 2003). Other pretreatment practices such as flow-through structures (e.g., water quality inlet, propriety devices) are designed to provide re-suspension and flushing of captured sediments from the device while deep sump catch basin allows for initial settling of coarse sediments, floating debris, and some hydrocarbons or infiltrate runoff as

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sediments settle. Presettling basins may need to be located "off-line" from the primary conveyance/detention system if used to protect infiltration or filtration BMPs from siltation (Urbonas, 1994). Currently, a number of proprietary stormwater treatment devices that use multiple chambers to help trap and retain sediments and floating substances are manufactured with pretreatment units (Sample et al., 2012). Also, most filtering systems incorporate a sedimentation chamber to settle out pollutants before runoff reaches the filter bed. Presettling basins that are often integrated into the design of stormwater management structures provide the primary treatment of "first flush" runoff. In Korea, presettling basin is a popular pretreatment practice since the proposed treatment site is often adversely affected by a pollutant load with a hydrology condition of dominantly low-rainfall frequency occurrence storm events (Maniquiz et al., 2010b).

The efficiency of a presettling basin in a BMP in removing particulates by sedimentation is dependent upon the initial concentration of suspended solids in the runoff. In general, when runoff contains higher initial concentrations of suspended solids, greater removal efficiency could be achieved. In addition, some particles, such as fine clays, will not settle out of suspension without the aid of a coagulant (UDFCD, 1993). Turbulence, eddies, circulation currents, and diffusion at inlets affect the settling ability of particles. Each of these factors can move particles back up into the water column. In general, the larger the stormwater loading rate, the lower the removal of sediment by settling (Novotny and Olem, 1994). Settling will also take place after stormwater is trapped and ponded between storms. Because the time interval between storm events is variable, understanding the effective ratio of storage volume to mean runoff rate and the ratio of sediment volume removed to mean runoff rate is essential to predicting long-term pollutant removal averages. Pollutants such as metals, hydrocarbons, nutrients, and oxygen-demanding substances can become adsorbed or attached to particulate matter, particularly clay soils. Removal of these particulates by sedimentation can therefore result in the removal of a large portion of these associated pollutants (Iqbal et al., 2003). The sediments and associated pollutants captured in the pretreatment devices can be removed for disposal during maintenance operations.

This study aimed to investigate the effectiveness of presettling basin as a component of stormwater BMPs and to determine considerations in the design and application of this type of pretreatment practice.

1. Materials and methods

1.1. Site location and description of the presettling basins

The three stormwater treatment technologies namely the eco-biofilter (EBF), and two types of gravel wetland system (GWS-1 and 2) were developed and constructed as BMPs to capture and treat stormwater runoff from roads and parking lots with catchment area ranging from 450 to 600 m^2 located inside the Kongju National University campus grounds in Cheonan city, South Korea. The BMPs were similarly designed with inlet, presettling basin, plant/filter media bed, and overflow/outlet units. Fig. 1 shows the site location and schematic diagram of the components of each system. In addition, the cross-sectional design profiles of the presettling basins of the BMPs were provided. The presettling basins which differ in terms of aspect ratio, surface area, storage volume, type and configuration of filter media, proportion to whole structure, etc. (Table 1), were integrated in all the BMPs to primarily provide pretreatment of runoff. The storage volume of the presettling basins corresponds to almost 10% to 25% of the total storage volume of the system while the surface area was between 10% and 20% of the total surface area of the system. Table 2 shows the comparative characteristics of the filter media utilized in the presettling basins. The design of the presettling basins and BMPs were based from a number of laboratory tests and research that were conducted prior to this study (Choi et al., 2012; Geronimo et al., 2013; Maniquiz et al., 2010a).

1.2. Storm event monitoring, sediment collection and analytical analysis

Runoff samples, hydrologic and hydraulic data (e.g., total event rainfall, rainfall and runoff duration, flow rates, etc.) were collected from the 56 storm events monitored between May 2009 and November 2012 at the three BMP sites. Manual (grab) sampling was employed at the inlet of each BMP facility. A more intensive sampling during the beginning of storm event was selected to identify the "first flush"; wherein six 4-L grab samples were collected at the first hour with the first sample taken as soon as adequate runoff entered the system. The next five samples were taken after 5, 10, 15, 30, and 60 min subsequently. Then one sample was taken for the succeeding hour until the runoff ended. But, for most of the shorter events, the scheme was modified by adjusting the number of samples until the runoff flow ended. Rainfall data was provided by the Korea Meteorological Administration. Other storm event variables such as runoff volume, hydraulic retention time (HRT), and flow rates were recorded in situ. Continuous flow measurements were manually performed and recorded at 5 min interval using a calibrated bucket and timer (measurement of volume over time). The captured runoff (%) by the presettling basin was estimated as the ratio of the storage volume of the presettling basin (m^3) and influent runoff volume (m^3). The occurrence frequency of captured runoff was expressed by means of probabilistic density function. The plotting position (q, %) was assigned to each captured runoff as:

$$q = \frac{M}{N+1} \tag{1}$$

where, M is the ascending order of magnitude and N is the total number of data points.

The total suspended solids (TSS) concentration was analyzed by filtration in standard 1.2 μm GE Healthcare Life Sciences, Buckinghamshire, UK, drying the residue between 103 and 105 °C (SJ-201DL drying oven, Sejong Scientific Co., Bucheon, Korea) and weighing following Standard Method 2540D (APHA et al., 2005). The runoff volumes were calculated for each storm event using simple numerical integration of flow rate measurements over time increments for the entire flow duration. The TSS loads were calculated by the summation of loadings during each storm event using the volume for that period.