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Curbing Sediment: Pretreatment of Stormwater through Added Surface Roughness in the Curb and Gutter

Freinage des sédiments : prétraitement des eaux pluviales par l'ajout d'une rugosité de surface dans la bordure et le caniveau

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RÉSUMÉ

Les mesures de contrôle des eaux pluviales (MCS) sont conçues pour réduire les impacts négatifs du ruissellement urbain sur les eaux réceptrices. Les SCM basés sur l'infiltration risquent de se boucher à cause des sédiments accumulés dans les eaux pluviales ; des dispositifs de prétraitement, tels que des biefs d'alimentation, des bandes filtrantes ou des puisards de puisard, sont utilisés en amont des ajouts cimentaires pour piéger les sédiments et réduire les besoins d'entretien. Les dispositifs de prétraitement simplifient également la maintenance car ils la concentrent dans un endroit confiné et facilement accessible. Des modifications à la bordure et au caniveau standard ont été testées comme dispositif de prétraitement alternatif pour les infrastructures vertes en bordure de rue. De la rugosité a été ajoutée à la bordure et/ou au caniveau de feuilles de mousse de polystyrène expansé à l'échelle du laboratoire à l'aide d'une toupie à commande numérique par ordinateur. Vingt et un modèles candidats avec une profondeur, une forme et un espacement variables ont été découpés dans la bordure et/ou la gouttière pour piéger les sédiments du ruissellement simulé ; des échantillons de ruissellement ont été prélevés lors d'événements de ruissellement simulés à partir d'emplacements en amont et en aval de la rugosité ajoutée ; ceux-ci ont été analysés pour le TSS et la distribution granulométrique. Les modèles de rugosité les plus performants comprenaient une rugosité supplémentaire dans la bordure et le caniveau, réduisant les concentrations de TSS jusqu'à 95 % (médiane 85 %) et la médiane d₅₀ et d₉₀ de 46,9 à 39,4 µm et de 322 à 100,1 µm, respectivement. Des tests de ruissellement simulés répétés sans élimination des sédiments des modèles de rugosité ont montré une capture continue de TSS après jusqu'à 7 événements de ruissellement simulés. L'entretien régulier programmé par balayage des rues pourrait être utilisé pour enlever les sédiments accumulés, ce qui suggère que la réduction des sédiments peut être une technologie de prétraitement viable pour les SCM des infrastructures vertes.

ABSTRACT

Stormwater control measures (SCMs) are designed to reduce the negative impacts of urban runoff on receiving waters. Infiltration-based SCMs are at risk of clogging through accumulated stormwater-borne sediments; pretreatment devices, such as forebays, filter strips, or catch basin sumps, are employed upstream of SCMs to trap sediment and reduce maintenance needs. Pretreatment devices also make maintenance simpler as they focus it in a confined, easily accessible location. Alterations to the standard curb and gutter were tested as an alternative pretreatment device for streetside green infrastructure. Roughness was added to the curb and/or gutter of laboratory-scale expanded polystyrene foam sheets using a computer numerical control router. Twenty-one candidate patterns with varying depth, shape, and spacing were cut into the curb and/or gutter to trap sediment from simulated runoff; runoff samples were collected during simulated runoff events from locations upstream and downstream of the added roughness; these were analyzed for TSS and particle size distribution. The best performing roughness patterns included added roughness in both the curb and gutter, reducing TSS concentrations by as much as 95% (median 85%) and median d₅₀ and d₉₀ from 46.9 to 39.4 µm and 322 to 100.1 µm, respectively. Repeated simulated runoff testing without removal of sediment from the roughness patterns showed continued TSS capture after as many as 7 simulated runoff events. Regularly scheduled maintenance by street sweeping could be used to remove accumulated sediment, suggesting that curbing sediment may be a viable pretreatment technology for green infrastructure SCMs.

KEYWORDS

Green infrastructure, Sustainable urban drainage systems, Operation and maintenance, Clogging, Low impact development, stormwater control measures

1 INTRODUCTION

Urban stormwater carried a large variety of pollutants to receiving waters, creating adverse conditions for aquatic organisms. With respect to runoff quantity, the percentage of impervious surfaces in a watershed is directly related to the magnitude of the urban stream syndrome (Walsh et al. 2005). Stormwater control measures (SCMs) are employed worldwide to partially offset these negative impacts of development; of recent interest are green infrastructure SCMs which focus on runoff reduction through infiltration and evapotranspiration. However, infiltration-based filters are prone to clogging with time; therefore, pretreatment is often provided to reduce the hydraulic effects of sediment accumulation on filter performance.

Pretreatment is a focused location with screens or where velocity is slowed to allow for sediment and trash accumulation to occur, reducing the maintenance burden for an SCM (McNett and Hunt 2011; Maniquiz-Redillas et al. 2014). Erickson and Hernick (2019) evaluated four pretreatment devices - a grassed filter strip, two proprietary devices, and a rock lined inlet - with all four reducing at least 88% total sediment. Financially, maintenance of SCMs is expensive (Houle et al. 2013); thus, focusing maintenance needs in a defined pretreatment system may be cost efficient. Since green infrastructure SCMs are often located in the right-of-way it can be difficult to provide properly sized pretreatment in these space-constrained locations. Curbs and gutters are employed along most urban roads and thus provide a potential space for pretreatment of stormwater to occur.

In this study, we investigated whether added roughness in the curb and gutter could act as an effective pretreatment for stormwater. A laboratory-scale evaluation of this innovative pretreatment device was undertaken to determine: (1) its ability to reduce sediment concentrations during simulated runoff events, (2) the optimal roughness pattern in the curb and/or gutter for sediment trapping, and (3) the expected maintenance interval necessary to ensure long-term sediment removal.

2 MATERIALS AND METHODS

Simulated roads were constructed out of 1.2 m x 2.4 m x 0.2 m sheets of expanded polystyrene (EPS) foam (Figure 1). Roughness patterns were modeled in Rhino 3D software; computer numerical control (CNC) milling was used to construct the roughness patterns in the physical models. Road sections had a 15.2 cm tall curb and 1 m scaled-down road width with a 1.5% cross slope to mirror that of a crowned road. After routing, models were cleaned of loose EPS foam and painted with Latex primer. A total of 21 foam roads were constructed as such with roughness patterns either in the curb, gutter, or both. Triplicate simulated runoff tests of curb only and gutter only roughness patterns were completed first, and then data collected in these tests were used to inform the best patterns to combine for curb and gutter models. Eight patterns were tested with both curb and gutter roughness.

A submersible pump conveyed synthetic stormwater from a mixing tank onto the physical models. Synthetic stormwater was created by adding 70-100g of sediment to 68-80 kg of water. The sediment mixture was selected to mimic the typical particle size distribution (PSD) and textural class (sandy loam) measured in runoff from 11 roads in Ohio (Winston and Witter 2019). A digital lab stirrer mixer (maximum 2000 rpm) was utilized to create a uniform sediment-laden mixture in the mixing tank. At the downstream edge of each physical model, runoff which had passed through the roughness patterns entered a vinyl gutter. Grab samples of influent and effluent were collected at two-minute intervals from the vinyl gutters bracketing the physical model. Influent and effluent grab samples were composited to determine event mean influent and effluent concentrations. Composite samples for three successive trials of each roughness pattern (Figure 1); sediment was not removed between each trial. For the three best performing combined curb and gutter roughness patterns, continued simulated runoff events were used to estimate when maintenance might be needed.

Total suspended solids (TSS) and particle size distribution (PSD) were measured on composite samples obtained from all trials. TSS was measured using ASTM method D5907-18. A Beckman Coulter LS 13-320 laser diffraction instrument was used to measure PSD. TSS and PSD data were analyzed using R statistical software version 3.6.2. Summary statistics were developed for TSS, and the 10th, 50th, and 90th percentile particle sizes in the influent and effluent during each simulated runoff event. TSS reductions were determined for each simulated event. For statistical testing, the Kruskal-Wallis test was applied to compare TSS removal among the various roughness pattern groups (i.e., curb only, gutter only, or curb and gutter). A one-way ANOVA was used to test for differences between d_{10} , d_{50} , and d_{90} particle sizes among pattern configurations, with follow on Tukey HSD tests for paired comparisons. Statistical significance was set at an $\alpha=0.05$.



Figure 1: Still images of various roughness patterns being testing for sediment retention.

3 RESULTS AND DISCUSSION

Roughness patterns that employed combined curb and gutter roughness and had the greatest median TSS removal (87%) compared to curb (65%) or gutter only (81%) patterns (Figure 2). TSS removal for the curb only roughness patterns was significantly lower than for the curb and gutter patterns. Increased frequency and number of indentations in the curb-only roughness patterns appeared to be related to higher sediment removal as flow passed over the roughness patterns. Four gutter-only roughness patterns produced median TSS removal above 80%. All of these patterns utilized roughness which was perpendicular to flow, suggesting more impact to flow by this orientation. Additionally, another top performer mimicked a meandering stream with high sinuosity. Patterns that included the alternating deep and shallow roughness also tended to perform well. Regardless of roughness pattern, all gutter only trials provided median TSS removal of 60% or more. Of the combined curb and gutter patterns tested, nine out of ten had median TSS reductions above 80% (Figure 2). Patterns that had gutter roughness connected to that in the curb performed best. Sediment accumulated in the indentations in the gutter first, then was guided into the curb indentations which acted like reservoirs for sediment accumulation. Curb and gutter roughness patterns performed the best overall, suggesting they are optimal for sediment capture.

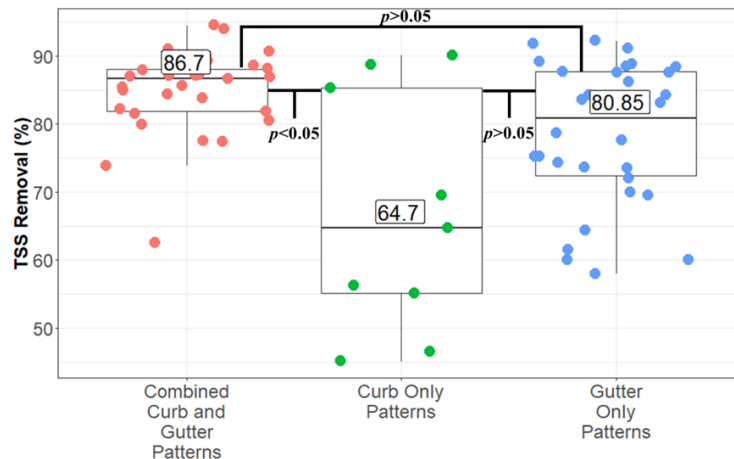


Figure 2: Boxplots of percent reductions in TSS for the three groups of roughness patterns. Values in black boxes represent median TSS removal for each respective pattern.

Influent PSDs were dominated by larger silt and sand sized fractions which typify runoff from Ohio's roads (Winston and Witter, 2019). PSD was little changed between the influent and effluent for the curb only patterns. For gutter only trials, influent and effluent PSD varied more widely than curb only patterns, with PSDs differing for 20 μm and larger particles. This suggested better removal of medium silts and sands for gutter only patterns. However, differences in d_{10} , d_{50} , and d_{90} between curb only and gutter only patterns were not statistically significant. Combined curb and gutter patterns resulted in the largest differences in PSD, with median influent and effluent PSD deviating above the 10 μm particle size. These patterns also had the smallest (significantly) median d_{90} (100.1 μm) compared to both the curb (198.1 μm) or gutter only (127.7 μm) roughness patterns. These results further confirm that combined curb and gutter patterns provide the most roughness, promote the most sedimentation, and lead to the removal of finer sand and larger silt fractions. MPCA (2020) recommend pretreatment practices capture particles greater than 100 μm . Given d_{90} at the outlet of the combined curb and gutter roughness patterns (100.1 μm), this recommendation was met.

All patterns tested for longevity substantially reduced sediment concentrations across all simulated runoff events. In one case, 7 simulated runoff tests were conducted with few signs of performance decline (i.e., the seventh trial achieved 87% TSS reduction). However, there was a general increase in effluent TSS concentrations following each trial, signaling a potential decline in performance as sediment accumulated. After 7 trials, pattern F1 had noticeable accumulation of sediment in the upgradient half of the physical model but the latter half had available storage for continued sediment removal. Similarly, the B1 and G1 patterns also had available storage for sediment after four simulated runoff events.

4 CONCLUSIONS

Pretreatment technologies are used to reduce sediment and trash prior to treatment of stormwater in SCMs. Since pretreatment can be difficult to fit into space-constrained sites, a novel pretreatment device was evaluated wherein roughness patterns milled into the curb and gutter were evaluated for their sediment trapping efficiency. Twenty-one physical models were created to test roughness patterns in the curb, gutter, or both. Roughness patterns in the gutter only performed better for sediment retention than curb only patterns. Roughness patterns in both the curb and gutter were optimal for sediment retention since this provided the largest amount of storage. These patterns reduced TSS concentrations by up to 95% (median 85%) and reduced median d_{50} and d_{90} in runoff from 46.9 to 39.4 μm and 322 to 100.1 μm , respectively. Longevity tests suggested that the best performing curb and gutter roughness patterns could successfully retain sediment for as many as 7 simulated runoff events. Field tests of this novel pretreatment method are needed to determine its efficacy under real rainfall and pollutant conditions as well as to better benchmark maintenance intervals.

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