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Stormwater quality of spring–summer-fall effluent from three partial-infiltration permeable pavement systems and conventional asphalt pavement

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ABSTRACT

This study examined the spring, summer and fall water quality performance of three partial-infiltration permeable pavement (PP) systems and a conventional asphalt pavement in Ontario. The study, conducted between 2010 and 2012, compared the water quality of effluent from two Interlocking Permeable Concrete Pavements (AquaPave® and Eco-Optiloc®) and a Hydromedia® Pervious Concrete pavement with runoff from an Asphalt control pavement. The usage of permeable pavements can mitigate the impact of urbanization on receiving surface water systems through quantity control and stormwater treatment. The PP systems provided excellent stormwater treatment for petroleum hydrocarbons, total suspended solids, metals (copper, iron, manganese and zinc) and nutrients (total-nitrogen and total-phosphorus) by reducing event mean concentrations (EMC) as well as total pollutant loadings. The PPs significantly reduced the concentration and loading of ammonia ($NH_4^+ + NH_3$), nitrite (NO_2^-) and organic-nitrogen (Org-N) but increased the concentration and loading of nitrate (NO_3^-). The PP systems had mixed performances for the treatment of phosphate (PO_4^{3-}). The PP systems increased the concentration of sodium (Na) and chloride (Cl) but EMCs remained well below recommended levels for drinking water quality. Relative to the observed runoff, winter road salt was released more slowly from the PP systems resulting in elevated spring and early-summer Cl and Na concentrations in effluent. PP materials were found to introduce dissolved solids into the infiltrating stormwater. The release of these pollutants was verified by additional laboratory scale testing of the individual pavement and aggregate materials at the University of Guelph. Pollutant concentrations were greatest during the first few months after construction and declined rapidly over the course of the study.

1. Introduction

Permeable pavements (PP) allow for the treatment and management of stormwater near to its source. PP systems reduce the total pollutant mass delivered to receiving systems by capturing pollutants within the pavement system and removing them from stormwater (Bean et al., 2007). In partial-infiltration systems, a significant proportion of stormwater will infiltrate into native soils while some excess stormwater is discharged to a receiving surface water system by way of underdrains. Outflow from an underdrained PP system is not considered runoff and is referred to as exfiltrated stormwater or effluent (Bean et al., 2007; Roseen et al., 2012). Particulates within stormwater are captured by mechanical filtration through the PP surface and base layers. As water migrates through the PP additional treatment is possible through adsorption, transformation, biological degradation and volatization.

Numerous researchers (Rushton, 2001; Brattebo and Booth, 2003; Bean et al., 2007; Toronto and Region Conservation Authority, 2008; Roseen et al., 2009; Fassman and Blackbourn, 2010) have observed that PP effluent has lower suspended solids and heavy metal (e.g. Pb, Zn, Cu, Cd and Fe) concentrations than runoff from traditional asphalt pavements. Legret and Colandini (1999) reported that, relative to a reference catchment, runoff from a porous asphalt pavement reduced the loading of suspended sediments, Pd, Cd and Zn by 59%, 84%, 77% and 73% respectively to downstream systems. Rushton (2001) evaluated the annual loads

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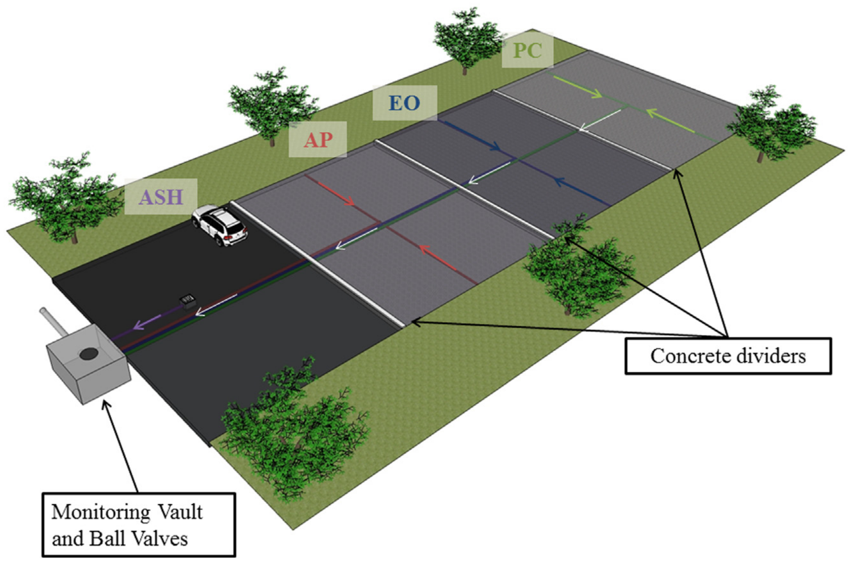

Fig. 1. Study site schematic.

from runoff from two PP-to-swale systems. Relative to a traditional asphalt pavement, the PP and swale reduced TSS, and heavy metal (Fe, Pb, Mn and Zn) loads. The PP system was particularly effective at capturing solids and metals as removal rates for these pollutants ranged between 75% and 94%. Fassman and Blackbourn (2010) observed 70% reduction in total suspended solids and Cu loads and a 96% reduction in total Zn loads from sampled storms.

Long term studies, such as Brattebo and Booth (2003), have noted that PP systems can continue to improve stormwater quality even after several years of use. Effluent quality, however, does change with time which can result in both positive and negative changes in performance. The capacity for pollutant removal over time and the possibility of remobilization have important implications for sustained benefits of PP systems as well as the potential contamination of groundwater systems.

PP exfiltrate has been consistently shown to have a pH ranging between 8 and 9.5 (Pratt et al., 1995; Sansalone and Teng, 2004; Kwiatkowski et al., 2007; TRCA, 2008) whereas rainfall and asphalt runoff tend to be more acidic. For the protection of aquatic life, common water quality guidelines recommend that pH should be maintained between 6.5 and 8.5 (MOE, 1994) so PP effluent sometimes fails to meet this guideline. Monitoring studies conducted by Roseen et al. (2009) and TRCA (2008) have observed that PP effluent contains low or non-detectable concentrations of petroleum-based hydrocarbons.

Nutrient concentrations in PP effluent have been addressed in several studies (Bean et al., 2007; Roseen et al., 2009; Collins et al., 2010; Tota-Maharaj and Scholz, 2010). Collins et al. (2010) reported that PP exfiltrate had consistently lower TKN and NH_4^+ concentrations and higher NO_3^- concentrations than asphalt runoff indicating occurrence of nitrification ($NH_4^+ \rightarrow NO_3^-$). As a filtering system, PP can capture particulate-bound P leading to reductions in TP concentrations. Although several studies (Bean et al., 2007; TRCA, 2008; Roseen et al., 2009; Tota-Maharaj and Scholz, 2010) have noted that PP effluent has reduced TP levels, the long-term retention of nutrients has not yet been demonstrated.

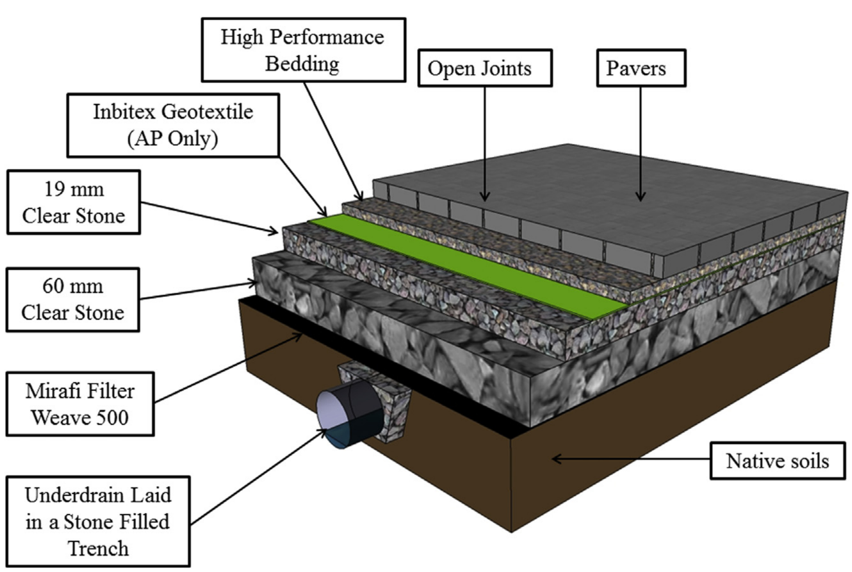

Fig. 2. Profile of permeable interlocking concrete pavers.