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Field infiltration measurements in grassed roadside drainage ditches: Spatial and temporal variability

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SUMMARY

Roadside drainage ditches (grassed swales) are an attractive stormwater control measure (SCM) since they can reduce runoff volume by infiltrating water into the soil, filter sediments and associated pollutants out of the water, and settle solids onto the soil surface. In this study a total of 722 infiltration measurements were collected in five swales located in Twin-Cities, MN and one swale located in Madison, WI to characterize the field-saturated hydraulic conductivity (K_{fs}) derived from the infiltration measurements of these swales. Measurements were taken with a falling head device, the Modified Philip Dunne (MPD) infiltrometer, which allows the collection of simultaneous infiltration measurements at multiple locations with several infiltrometers. Field-saturated hydraulic conductivity was higher than expected for different soil texture classes. We hypothesize that this is due to plant roots creating macropores that break up the soil for infiltration. Statistical analysis was performed on the K_{fs} values to analyze the effect of initial soil moisture content, season, soil texture class and distance in downstream direction on the geometric mean K_{fs} value of a swale. Because of the high spatial variation of K_{fs} in the same swale no effect of initial soil moisture content, season and soil texture class was observed on the geometric mean K_{fs} value. But the distance in downstream direction may have positive or negative effect on the K_{fs} value. An uncertainty analysis on the K_{fs} value indicated that approximately twenty infiltration measurements is the minimum number to obtain a representative geometric mean K_{fs} value of a swale that is less than 350 m long within an acceptable level of uncertainty.

1. Introduction

Impervious surfaces such as roads, parking lots and rooftops, lead to increased runoff volume which will increase the mass of pollutants that reach receiving water bodies (Field, 1975; Booth and Jackson, 1997; Kayhanian et al., 2007, 2012). Stormwater control measures (SCMs) are designed to reduce the runoff volume and to treat runoff to improve water quality before reaching surface water resources (National Research Council, 2008). Many conventional SCMs, such as catch basins, wetlands and retention ponds, are efficient in capturing suspended solids (e.g., Howard et al., 2011, 2012) but are not designed to treat for dissolved pollutants (Erickson et al., 2007, 2012; O'Neill and Davis, 2012a, 2012b). Infiltration practices are believed to reduce runoff generation in a watershed and to remove most pollutants, with the exception of chloride and nitrate, through filtering and adsorption processes of the soil matrix. (National Research Council, 2008; Davis et al., 2012). These practices include permeable pavement, bioinfiltration, infiltration basins and grassed swales (Erickson et al., 2013).

Grassed roadside drainage ditches are shallow, open vegetated channels that are designed to convey stormwater runoff to storm sewers or receiving water bodies. They are often employed along highways, where highway medians and roadside drainage ditches may essentially act as grassed swales because they filter and settle solids and infiltrate water (Barrett et al., 1998a, 1998b; Deletic and Fletcher, 2005). Fig. 1 shows a grassed roadside drainage ditch on Hwy 212 in Chaska, Minnesota that has the capability to reduce runoff volume (Ahmed et al., 2014b). Volume reduction occurs primarily through infiltration into the soil, either as the water flows over the slide slope perpendicular to the roadway into the swale or along the bottom of the swale parallel to the roadway. Pollutant removal can occur by sedimentation of solid particles onto the soil surface, filtration of solid particles by vegetation, or infiltration of dissolved pollutants (with stormwater) into the soil (Abida and Sabourin, 2006).

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Fig. 1. The Roadside drainage ditch on Hwy 212 near Chaska, has been shown to infiltrate stormwater and act as a grassed swale.

As with infiltration trenches and basins, grassed swales can become clogged with particles and debris in the absence of proper maintenance. Several studies have shown that a majority of stormwater pollutants are trapped in the upper soil layers (Wigington et al., 1986; Mikkelsen et al., 1997; Dierkes and Geiger, 1999; Kwiatkowski et al., 2007; Komlos and Traver, 2012). In some cases the sediment deposits can begin to choke out the vegetative cover and create an erodible surface capable of contributing sediment and other pollutants directly downstream (Erickson et al., 2010, 2013).

The fraction of stormwater runoff that can be infiltrated by a grassed swale depends on many variables including rainfall intensity and total runoff volume, swale soil type, the maintenance history of the swale, vegetative cover in the swale, swale slope, and other factors. Using simulated runoff, Yousef et al. (1987) found that swales infiltrated between 9% (input rate of 0.079 m/h) and 100% of the runoff (input rate of 0.036 m/h) with significant variability. Due to the wide range of performance Yousef et al. (1987) stated that to determine the performance of individual swales, each swale should be tested separately. Also because of this wide variability of infiltration rates, even within a single swale, multiple measurements should be made. The Modified Philip-Dunne infiltrometer, a new method of measuring infiltration capacity of the soil surface has recently been developed (Asleson et al., 2009; Olson et al., 2013; Paus et al., 2013; Ahmed et al., 2014b). The infiltrometer allows multiple measurements to be taken over a relatively large area. This falling head type of infiltrometer has an advantage over the commonly employed constant head infiltrometers in that they require less time and water volume to conduct field tests (Ahmed et al., 2011a,b).

Despite the prevalence of grassed roadside drainage ditches within roadway right-of-ways, there has been very limited gathering of data to test the effect of soil textural differences, prevailing vegetation, season, and sedimentation on the spatial and temporal variability of infiltration properties. This research documents the infiltration parameters of six grassed roadside drainage ditches (this term will be used interchangeably with grassed swales) located in the Twin Cities, MN and Madison, WI, providing a large data set for estimation of soil infiltration properties, with consideration for spatial and temporal variability. With this data the effects of soil texture, antecedent soil moisture, season, and location (swale side slope versus swale bottom) are examined. In addition, an uncertainty analysis was also performed on four sets of measurements to determine the required number of infiltration measurement that balances effort and accuracy in deriving a representative mean infiltration capacity of grassed roadside drainage ditches (grassed roadside swales).

2. Methods

2.1. Site Selection

Sixteen highways were selected around the Twin-Cities metropolitan area in Minnesota within a reasonable commute where swales are located either within the median or along the side of the highways. These swales are essentially the drainage ditches constructed by the Minnesota Department of Transportation, and are typically 30–50 years old. For each highway, three soil cores were collected, using a soil corer between the soil surface and 0.6 m of depth to investigate the soil profile. Subdivisions of each soil sample were based on a visual change in soil color. These soil samples were brought into the lab for wet sieving analysis (ASTM D6913) and hydrometer analysis (ASTM D422) to determine% clay, % silt and% sand in each sample. Using these percentages in a textural triangle (USDA, 2014), the soil texture class was identified. The lists of soil texture class for different swales are given in Table 1. The soil textural class of the top 25 cm was taken into consideration because the falling head infiltrometer can capture infiltration properties of this region. If the same highway is addressed in two or more rows in the table it indicates that the swale located in that highway contains all corresponding textural classes of soil (i.e. Hwy 35E, Hwy 35W near TH 10).

Five highways were selected for further study, given in bold in Table 1, to represent the soil combinations found in the region. In addition to the measurements taken at the Minnesota swale sites, infiltration measurements were taken in a swale located at Hwy 51 in Madison, WI, north of Hwy 12/18. The Madison site was chosen because the precipitation, inflow, and outflow monitoring data for the swale were available via the USGS National Water Information System (U.S. Geological Survey, 2014). A comparison with this monitoring data is reported by Ahmed et al. (2014b).

2.2. Infiltrometer operation

At each swale, infiltration measurements were made using Modified Philip Dunne (MPD) infiltrometer, as illustrated in Fig. 2 (Ahmed et al., 2014a), which was used to estimate the field-saturated hydraulic conductivity (K_{fs}) and capillary soil suction

Table 1
Soil texture class[a] up to 25 cm depth from soil surface of different swales located in Minnesota.

Swale locations[b]	Soil texture class
Hwy 10, Hwy 35E, Hwy 35 W near TH 10	Sand (>86% sand)
Hwy 5, **Hwy 47**, Hwy 65, Hwy 96, Hwy 97, **Hwy 77**, Hwy 7, Hwy 35 W Burnsville, Hwy 35E, Hwy 35 W near TH 10	Loamy sand (70–86% sand, 30% > silt, 10–15% clay) and Sandy loam (50–70% sand, 50% > silt, 15–20% clay)
Hwy 51, Hwy 36	Loam (50–72% sand, 28–50% silt, 20–28% clay) and Sandy loam (50–70% sand, 50% > silt, 15–20% clay)
Hwy 212	Silt loam (20–50% sand, 50–80% silt, 28% > clay) and Loam (50–72% sand, 28–50% silt, 20–28% clay)
Hwy 13	Loam (50–72% sand, 28–50% silt, 20–28% clay), Sandy clay loam (72% < sand, 30% > silt, 20–35% clay) and Silt (92% < silt)

[a] Sand (>0.02 mm diameter), silt (0.002–0.02 mm), clay (<0.002 mm).
[b] Number of soil cores at each site is three. Infiltration measurements were collected in swales with Bold letters.