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Modeling Water and Sediment Trapping by Vegetated Filters Using VFSMOD: Comparing Methods for Estimating Infiltration Parameters

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Introduction

Vegetated filters (buffers) are used to intercept overland runoff and reduce sediment and other contaminant loads to streams (Dosskey, 2001). Filters function by reducing runoff velocity and volume, thus enhancing sedimentation and infiltration. Infiltration is the main mechanism for soluble contaminant removal, but it also plays a role in suspended particle removal. By decreasing the discharge and velocity of overland flow, infiltration causes a decrease in sediment transport capacity, and thus sedimentation is enhanced.

Although the impact of infiltration on soluble and suspended contaminant removal has not been directly documented, many researchers suggest infiltration plays a significant role (Table 1). In developing a design algorithm for vegetative filters, Edwards et al. (1996) suggested that infiltration is the only significant mechanism for removal of soluble nutrients.

Table 1. Examples of overland flow studies with vegetated filters where infiltration was thought to be the significant removal mechanism

Research Team	***Contaminant Thought to be Removed Mainly by Infiltration in Vegetated Filters***
Asmussen et al. (1977)	2-4D
Dickey and Vanderholm (1981)	Nutrients and Suspended Solids
Chaubey et al. (1995)	PO_4-P, Organic N
Edwards et al. (1997)	Heavy Metals
Patty et al (1997)	Pesticides, Nitrates, Soluble Phosphorous

Infiltration is dependent upon many things including: rainfall intensity, soil texture and structure, vegetation, and soil hydraulic properties, like hydraulic conductivity and water retention. Macroporosity may significantly influence soil hydraulic properties and play a key role in vegetated filter infiltration, and thus filter functioning. Riparian areas and vegetative filters, having perennial vegetation and being void of annual tillage, may possess a high level of macroporosity. Macropores may result from natural root channels, wormholes, small burrows, and non-tillage management practices (Beven and Germann, 1982). Flow of water through macropores can result in a more rapid wetting of soil and at deeper depths, possibly resulting in ground and/or surface water (interflow) contamination (Thomas and Phillips, 1979). Saturated water flow through macropores (>0.1 cm diameter) was found to account for up to 70-80 percent of total saturated water flow in a forested area (Watson and Luxmoore, 1986).

Soil hydraulic properties, especially saturated hydraulic conductivity, in vegetated filters may be vastly different from what one might expect based on soil texture alone. Rachman et al. (2004) found that saturated water content and saturated hydraulic conductivity were significantly higher in ten year-old switchgrass hedge plots than in adjacent corn rows. It was also found that the grass hedge plots had a significantly higher (two times higher) number of macropores than the crop rows (pores > 0.1 cm in diameter, found with the capillary rise equation and the soil water retention data).

Computer models such as the vegetated filter strip model (VFSMOD) can be used to predict water and contaminant transport through vegetated filters. VFSMOD, developed by Munoz-Carpena and Parsons (1999), simulates water and sediment transport in vegetated filters based on overland flow hydraulics and infiltration into the soil matrix. Infiltration is characterized by a

***Abstract*.** The vegetated filter strip model (VFSMOD) was used to investigate the effect of Green-Ampt infiltration parameters (found with different estimation techniques) on sediment and water trapping in vegetated filters of varying soil types. Field-measured and empirically-estimated infiltration parameters were compared. Field saturated hydraulic conductivity (K_{fs}) values were calculated with an inverse Green-Ampt equation using infiltration data measured in three vegetated filter plots located near Mead Nebraska. Also, three pedotransfer functions (PTFs) were used to empirically generate average K_{fs} values for each plot, based on percent sand, percent clay, and bulk density. Pedotransfer functions underestimated K_{fs} (10 to 99 percent) compared to field-measured values. Using VFSMOD to replicate actual field scenarios, more runoff (up to 62 percent) from the filter was predicted with the PTF K_{fs} input values than with the field-measured input K_{fs} values. These results were compared to data from overland flow studies performed on these plots in July 2004. Using the field-measured K_{fs} values resulted in the closest match for model water trapping predictions (in 2 of the 3 plots). Water trapping was more sensitive to K_{fs} than was sediment trapping, even at a higher sediment loading rate. Neither water trapping nor sediment trapping was sensitive to changes in wetting front suction or initial water content. One reason PTFs may underestimate K_{fs} and thus infiltration, is that they do not account for preferential flow (e.g. macropore flow). Vegetated filters may have a substantial number of preferential flow pathways. Tension infiltrometers were used on these three plots to measure infiltration rates and determine if macropores contributed significantly to flow in these soils. We found that 45-47 percent of the saturated flow was through pores larger than 0.1 cm in diameter indicating that macropores may significantly impact (increase) the infiltration rates and thus the field saturated hydraulic conductivities at our site. The inverse Green-Ampt method, being based on field measured data, may implicitly account for preferential flow and may better approximate field saturated hydraulic conductivity than PTFs.

Keywords: *vegetated filter strips, conservation buffers, VFSMOD, sediment trapping, infiltration, Green-Ampt, pedotransfer functions, macropores*

modified Green-Ampt method. The infiltration of water into macropores is not directly accounted for but can be implied in the field saturated hydraulic conductivity parameter (the single domain approach).

At a field scale, soil hydraulic properties like field saturated hydraulic conductivity usually vary greatly with space and time; therefore, it is often difficult to obtain accurate input parameters by simple and inexpensive means. Pedotransfer functions (PTFs), which may use only soil textural information and bulk density, are a simple and inexpensive way to estimate many hydraulic parameters (Leij et al., 2002). However, these functions do not account for the impact of macroporosity on soil hydraulic properties and they are, for the most part, built with data from agricultural soils (Elsenbeer, 2001). Stahr et al. (2004) found that saturated hydraulic conductivity in macroporous soils was under-estimated by 70-80 percent using pedotransfer functions. However, they found that the inverse Green-Ampt procedure could be used with field infiltration data to estimate hydraulic conductivity to within 30 percent of laboratory measurements.

Green-Ampt parameters suggested for use in VFSMOD, such as field saturated hydraulic conductivity and wetting front suction, are commonly PTF estimates (Munoz-Carpena et al., 2003). Using PTF estimated hydraulic parameters may result in an inaccurate prediction of water and sediment trapping in vegetated filters.

Research Hypothesis and Objectives

Our central hypothesis is that using infiltration parameters derived from field data rather than those derived from PTFs will result in a better VFSMOD prediction of water and sediment trapping in vegetated filters. This hypothesis was tested using the following objectives: 1) Compare field measured Green-Ampt infiltration parameters (mainly field saturated hydraulic conductivity) to PTF estimated parameters, and 2) Investigate how different methods for estimating infiltration equation parameters affect modeled estimates of water and sediment trapping in vegetated filters.

Methods

Obtaining Infiltration Parameters from Field Measurements

Infiltration data was collected at the University of Nebraska's Agricultural Development Center (ARDC) near Mead, Nebraska in August 2004. The field site consisted of 3 vegetated plots, which were established in 1995. Each plot was 15 m long and 3 m wide. The upstream half of each plot had switchgrass (*Panicum virgatum*) planted and the downstream half had shrubs [bush honeysuckle (*Lonicera maackii)* and golden currant (*Ribes aureum*)] and trees[eastern cottonwood (*Populus deltoides*) and silver maple (*Acer saccharinum*)] (Figure 1).

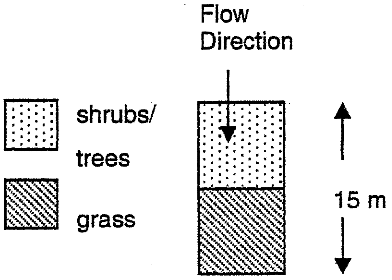

Figure 1. Plot Schematic

Soils in all plots are classified as Sharpsburg silty clay loam (fine, montmorillonitic, mesic Typic Argiudoll) with surface textures ranging from sandy loam to silty clay loam (Schmitt et al., 1999). Surface textures of the three plots used in this study were: sandy loam (Plot 1-3), silt loam (Plot 2-8), and silty clay loam (Plot 4-5) (See table 4 in VFMSOD Simulations section).

Infiltration was measured at 8 locations in each plot (4 in grass and 4 in shrub/tree). Ring infiltrometers, with a diameter of 15 cm, were inserted 10 cm into the soil. The time for a known depth of water (I, approximately 2 cm) to infiltrate (until half of surface was exposed) was recorded. Soil samples were taken adjacent to the infiltration rings for bulk density and initial water content measurements. The final water content was assumed to be 90 percent of the porosity (estimated from the bulk density, assuming particle density =2.65 g/cm^3). Soil samples were analyzed for percent sand, silt, and clay, and organic matter. Percent sand, silt, and clay, and bulk density data were used for estimating the wetting front suction calculation (equation 2).

The following inverse Green-Ampt equation was used for calculating the field-saturated hydraulic conductivity (K_{fs}). We measured the time for a given depth of water to infiltrate and used equation (1) to solve for the K_{fs} (Clothier and Smettem, 2002).

$$K_{fs} = \frac{1}{t} \times \left[I - \Delta\theta \times h_f \times \ln\left(1 + \frac{I}{\Delta\theta \times h_f} \right) \right] \qquad (1)$$

where:

$\Delta\theta = \theta_{fs} - \theta_i$ = soil moisture deficit

θ_i = initial water volumetric water content

θ_{fs} = field-saturated volumetric water content (taken to be 0.9 x porosity)

h_f = wetting front suction (L)

I = cumulative depth of infiltration

h_f was estimated from Rawls and Brakensiek (1985) (equation 2 in next section)

Tension infiltrometers were also used at each of the 8 locations (adjacent to the ring infiltrometers) for measuring the infiltration rates at various tensions (-3, -6, and -15 cm) at the soil surface. The saturated conductivity along with the tension infiltrometer data were then used to solve for the unsaturated hydraulic conductivity at different pressure ranges (Reynolds and Elrick, 1991). From the unsaturated conductivity data, it is possible to estimate the number of pores of given size ranges in the soil as well as the contribution of these pores to flow of water at saturation (Watson and Luxmoore, 1986).

Obtaining Infiltration Parameters from Pedotransfer Functions

Field saturated hydraulic conductivity and wetting front suction can be estimated with PTFs using soil textural data, bulk densities, organic matter contents, and sometimes one or two points from the soil water retention curve. In this study, h_f was calculated with the following PTF from Rawls and Brakensiek (1985) and was not field measured:

$$
\begin{aligned}
h_f = \exp[&6.5309 - 7.32561 \times POR + 0.001583 \times PC^2 + 3.809479 \times POR^2 + \\
&0.000344 \times PS \times PC - 0.049837 \times PS \times POR + 0.001608 \times PS^2 \times POR^2 + \\
&0.001602 \times PC^2 \times POR^2 - 0.0000136 \times PS^2 \times PC - 0.003479 \times PC^2 \times POR - \\
&0.000799 \times PS^2 \times POR]
\end{aligned}
\tag{2}
$$

where:

POR = 0.9 x total porosity,

PC = % clay

PS = % sand

Three PTFs: Rosetta, Rawls et al., (1998), and Rawls and Brakensiek (1985) were used for estimating field saturated hydraulic conductivity. Rosetta (Schaap, 1999) is a PTF that is able to estimate van Genuchten (van Genuchten, 1980) water retention parameters, saturated hydraulic conductivity, and unsaturated hydraulic conductivity parameters. Rosetta is actually a collection of five hierarchical PTFs. Input data may be textural class only or any combination of textural data (percent sand, silt, and clay), bulk density, and one or two measured water retention curve points.

The Rawls et al. (1998) PTF is based on the Kozeny-Carman equation relating the effective porosity to the saturated hydraulic conductivity and requires porosity (from bulk density), percent sand, percent clay, and water content at –33 kPa:

$$K_s = C\phi_e^{3-\lambda} \tag{3}$$

where,

K_s is the saturated hydraulic conductivity (mm/h)

C =1930 (an empirically derived constant)

ϕ_e is effective porosity (porosity minus water content at -33 kPa (θ_{-33}))

λ = Brooks and Corey pore size distribution (calculated with Rawls and Brakensiek, 1985)

$$
\begin{aligned}
\lambda = \exp[&-0.7842831 + 0.0177544 \times PS - 1.062498 \times POR - 0.00005304 \times PS^2 - \\
&0.00273493 \times PC^2 + 1.11134946 \times POR^2 - 0.03088295 \times PS \times POR + \\
&0.00026587 \times PS^2 \times POR^2 - 0.00610522 \times PC^2 \times POR^2 - 0.00000235 \times PS^2 \times PC + \\
&0.00798746 \times PC^2 \times POR - 0.00674491 \times POR^2 \times PC]
\end{aligned}
\tag{4}
$$

Water content at –33 kPa was estimated from Rawls et al (1993):

$$\theta_{-33} = 0.2576 - 0.002 \times PS + 0.0036 \times PC + 0.0299 \times POM \tag{5}$$

where:

POM = % organic matter

The third PTF, which looks similar to equations (2) and (4), can be found in Rawls and Brakensiek (1985) and requires porosity, percent sand, and percent clay.

Field Experiment

Runoff experiments were conducted in July 2004. A detailed description of the field methods is provided in Schmitt et al. (1999). The simulated storm was 2.54 cm of rainfall in 0.5 hour (1-yr return period). The runoff volume applied to the plots, 1.89 m^3, was calculated with the curve number method (U.S. Soil Conservation Service, 1972).

Simulated runoff (from a 4 m^3 polyethylene tank) and rainfall (overhead sprinkler system) were applied at steady rates (Table 2). The runoff began 10 minutes after the rainfall was initiated and continued for ten minutes after rainfall ended. The runoff had a sediment (Table 2) concentration of 10 g/L. Outflow from the plots was collected in 2.7 m^3 steel tanks. The mixture in the inflow tank was continuously mechanically mixed and that in the outflow tank was mixed before grab sampling for contaminant analysis.

A summary of the field experiment results are shown in Table (3). In plot 1-3, the sandy loam plot, all the applied water infiltrated, so outflow of water and sediment was zero.

Table 2. Overland flow study protocol

Sediment Class	Silty Clay Loam
Average Sediment Diameter	0.0025 cm
Input Sediment Concentration	10 g/L
Input Sediment Loading Rate (from source area)	4.3×10^{-5} kg/m^2/s
Steady Rainfall Intensity	0.0000141 m/s (5.08 cm/h)
Steady Runoff Rate	0.00126 m^3/s (76 L/min)

Table 3. Summary of measured inflow and outflow from overland flow study

Plot	***Applied Volume (m^3)***	***Rainfall Volume (m3)***	***Outflow Volume (m3)***	***Inflow Sediment Mass (kg)***	***Outflow Sediment Mass (kg)***
1-3, Sandy Loam	1.89	1.14	0	18.9	0
2-8, Silt Loam	1.89	1.14	0.2	18.9	0.16
4-5, Silty Clay Loam	1.89	1.14	1.18	18.9	0.42

VSMOD Simulations

VFSMOD is a mechanistic, field-scale, event-based model that concurrently simulates hydrologic (overland flow and infiltration) and sediment transport/deposition mechanisms through vegetated filters by linking three sub-models (components) (Munoz-Carpena et al., 1999). Unlike other grassed waterway/sediment transport models (like SEDIMOT and GRASSF), VFSMOD also handles time-dependent infiltration, changes in flow caused by sediment deposition (during the storm event), and changes in slope and vegetation along the filter length (Munoz-Carpena and Parsons, 2003).

The infiltration submodel is based on the Green-Ampt equations (equations 6 and 7). The following assumptions are made: the soil is uniform with depth, there is a uniform distribution of initial soil moisture, and the water moves into the soil as a piston-type wetting front (diffusion neglected).

$$f = K_s + \frac{K_s \times \Delta\theta \times h_f}{F} \tag{6}$$

$$K_s(t - t_p + t_o) = F - \Delta\theta \times h_f \times \ln\left(1 + \frac{F}{\Delta\theta \times h_f}\right) \tag{7}$$

where:

f = infiltration rate after surface ponding

F = cumulative depth of infiltration after surface ponding

t = time since beginning of infiltration event

t_p = time to ponding

t_o = time shift to correct for not having ponding conditions at the start of the event

VFSMOD was used to simulate overland flow through a buffer with varying infiltration parameters and initial water contents to compare outputs from each experimental plot. The model input parameters were set up to replicate the field experiment described earlier. A steady hyetograph, steady inflow hydrograph, and steady inflow sediment concentration were entered into VFSMOD. Rainfall began approximately 10 minutes prior to initiating runoff into the plots and runoff into the plots ended at approximately 10 minutes after the thirty-minute rainfall ended.

The soil characteristics used in the simulations are given in Tables (4), (5), and (6). Each filter was 15 m long and 3 m wide with an average slope, in the direction of flow, of 6.5%. To simulate a 1/2 grass and 1/2 shrub/tree filter as seen in Figure (1), a Manning's "n" of 0.1 was assigned to the grass and 0.4 to the shrub/tree area, as recommended by Munoz-Carpena et al. (1999). For the sediment trapping component of the model, a grass spacing of 3 cm (Helmers, 2003) and a grass height of 76 cm were used.

When varying K_{fs}, four simulations were performed for each plot with an initial volumetric water content ($\boldsymbol{\theta_i}$) measured in the field and four simulations were performed for each plot with an initial water content approximated to be about at field capacity ($\boldsymbol{\theta_{fc}}$) (Table 5). After these analyses were performed, h_f was varied. Holding K_{fs} and initial water content constant, model outputs were compared for three values of h_f.

Table 4. Vegetated Filter Soil Characteristics*

Plot	**Soil Textural Class**	**Bulk Density (g/cm^3)**	**% Sand**	**% Silt**	**% Clay**	**% Organic Matter**
1-3	Sandy Loam	1.36	67	20	12	1.8
2-8	Silt Loam	1.11	23	52	26	4
4-5	Silty Clay Loam	1.19	18	55	27	4

*All characteristics are averaged over 8 samples per plot

Table 5. Wetting front and soil water parameters

Location	**h_f (cm)***	**θ_i**	**θ_{fc}**	**θ_{fs}****
Plot 1-3	7.25 (6.02-8.73)	0.11	0.21	0.44
Plot 2-8	27.52 (14.89-30.43)	0.19	0.33	0.52
Plot 4-5	65.56 (29.04-46.01)	0.24	0.37	0.5

* Geometric mean ± 1 standard deviation (the mean was used in the simulations), all h_f values were calculated with equation (2)

** θ_{fs} is the field saturated volumetric water content (taken as 0.9 x porosity)

Table 6. Geometric Mean K_s values (± 1 standard deviation)

Location	**No. of points at each location**	**Inverse Green-Ampt**	**Rosetta**	**Rawls et al. (1998)**	**Rawls and Brakensiek (1985)**
Plot 1-3	8	12 (5.6-24)	2.9 (2.3-3.9)	2.9 (2.0-4.1)	10 (6.9-16)
Plot 2-8	8	11 (6.8-18)	2.4 (1.8-3.1)	15 (13-16)	0.95 (0.73-1.2)
Plot 4-5	8	48 (34-68)	1.5 (0.95-2.4)	16 (15-17)	0.46 (0.24-0.86)

Results and Discussion

For all plots, pedotransfer functions underestimated saturated hydraulic conductivity (10-99 percent) compared with field-measured K_{fs} (Table 5). These results agree with Stahr et al. (2004).

The proportion of sediment trapped and the proportion of water trapped (infiltrated) were calculated as follows:

$$\text{Sediment Trapping Efficiency} = \frac{M_{in} - M_{out}}{M_{in}} = E_{ST} \tag{8}$$

$$\text{Water Trapping Efficiency} = \frac{V_{in} - V_{out}}{V_{in}} = E_{WT} \tag{9}$$

Using VFSMOD to replicate actual field scenarios, more filter runoff (up to 62 percent) was predicted with the PTF K_{fs} input values than with the field-measured input K_{fs} values (Tables 7-9). Using K_{fs} values of 1-2 orders of magnitude less than the Inverse Green Ampt K_{fs} values resulted in an under-prediction of water infiltrated (trapped) by 43-68 percent. For example, when using the Rosetta K_{fs} of 2.9 cm/h (from plot 1-3), VFSMOD predicted a water trapping efficiency of 0.41. Forty-one percent of the volume entering the filter was trapped within the filter, fifty-nine percent left the filter at the downstream outlet. When using the field-measured K_{fs} of 11.52 cm/h for this same plot, $E_{WT} = 1.0$, meaning all of the incoming water was trapped in the filter.

In this experiment, sediment trapping was not influenced by saturated hydraulic conductivity. This may be because we had a relatively low runoff flow rate (as compared to commonly found natural runoff events documented by Helmers, 2003). In this case, water trapping was much more sensitive to the saturated hydraulic conductivity than was sediment trapping. However, if the volume of water entering the plot (in the same amount of time) is multiplied by ten (0.0126 m^3/s), E_{ST} for plot 1-3 (using the Rosetta K_s of 2.89 cm/h) decreases from 0.99 to 0.73. Increasing sediment loading rate, but keeping concentration constant will make sediment trapping more sensitive to infiltration and K_{fs}.

Neither water nor sediment trapping were noticeably sensitive to wetting front suction or initial water content. When initial water content was changed to field capacity (Table 5), only slight changes were noticeable in sediment and water trapped. In the silt loam and silty clay loam filters, slightly more runoff was generated, and in the sandy filter, about the same amount was generated. According to Wilson and Oduro (2004), water trapped is much more sensitive to field saturated hydraulic conductivity than to initial water content. A VFSMOD sensitivity analysis resulted in the same conclusion (Munoz-Carpena et al., 1999).

In plots 1-3 and 2-8 (the sandy loam and the silt loam), using the field-measured K_{fs} values resulted in the closest match to the field-measured E_{WT} values. In plot 4-5, none of the E_{WT} values matched field measured. For this plot, a K_{fs} of approximately 2 cm/h would be needed for these efficiency ratios to match. The field-measured K_{fs} (47 cm/h) is an order of magnitude larger than this. The reason for this is most likely due to shrinking and swelling soil. This soil contains montmorillonite clay. Montmorillonite has an expanding crystal lattice and can experience "extreme swelling upon wetting"(Brady, 1974). Upon drying, desiccation cracks were observed in this soil during the summer of 2004.

Table 7. Results for plot 1-3

	Modeled Results				Measured Results
	K_{fs} Estimation Method				
	Field-Measured	***Rosetta***	***Rawls et al. (1998)***	***Rawls and Brakensiek (1985)***	***July 2004***
	K_{fs}=12 (cm/h)	K_{fs}=2.9 (cm/h)	K_{fs}=2.9 (cm/h)	K_{fs}=10 (cm/h)	
Sediment In (kg)	18.428	18.428	18.428	18.428	18.87
Sediment Retained (kg)	18.428	18.318	18.319	18.42	18.87
Sediment Out (kg)	0	0.11	0.109	0.008	0
E_{ST}	**1**	**0.99**	**0.99**	**1.0**	**1.0**
Runoff In (m^3)	1.843	1.843	1.843	1.843	1.893
Rainfall (m^3)	1.142	1.142	1.142	1.142	1.136
Infiltration (m^3)	2.982	1.228	1.249	2.978	3.029
Runoff Out (m^3)	0	1.757	1.736	0.007	0
E_{WT}	**1.0**	**0.41**	**0.42**	**1.0**	**1.0**

Table 8. Results for plot 2-8

	Modeled Results				Measured Results
	K_{fs} Estimation Method				
	Field-Measured	***Rosetta***	***Rawls et al. (1998)***	***Rawls and Brakensiek (1985)***	***July 2004***
	K_{fs}=11 (cm/h)	K_{fs}=2.4 (cm/h)	K_{fs}=15 (cm/h)	K_{fs}=0.95 (cm/h)	
Sediment In (kg)	18.428	18.428	18.428	18.428	18.87
Sediment Retained (kg)	18.428	18.337	18.428	18.305	17.36
Sediment Out (kg)	0	0.091	0	0.123	1.51
E_{ST}	**1.0**	**1.0**	**1.0**	**0.99**	**0.92**
Runoff In (m^3)	1.843	1.843	1.843	1.843	1.893
Rainfall (m^3)	1.142	1.142	1.142	1.142	1.136
Infiltration (m^3)	2.982	1.7	2.982	1.142	2.78
Runoff Out (m^3)	0.003	1.285	0.003	1.843	0.242
E_{WT}	**1.0**	**0.57**	**1.0**	**0.38**	**0.92**

There are no observable patterns and no observations can be made as to why certain PTFs perform better for certain soil types, in this case. It would be helpful to have better knowledge as to what types of soils (agricultural, grassland, forest) went in to making these empirical equations. Elsenbeer et al. (2001) reminds us that most of the data is from agricultural soils. Rosetta performed more poorly than the other two PTFs when compared to the field E_{ST} and E_{WT} measurements. Rawls et al. (1998) performed well for the silt loam and the silty clay loam soils whereas Rawls and Brakensiek (1985) only performed well for the sandy loam. The pedotransfer functions used in this study depended only on percent clay, percent sand, and bulk density (porosity) except for Rosetta, which also used the percent silt content.

Table 9. Results for plot 4-5

	Modeled Results				Measured Results
	K_{fs} Estimation Method				
	Field-Measured	***Rosetta***	***Rawls et al. (1998)***	***Rawls and Brakensiek (1985)***	***July 2004***
	K_{fs}=48 (cm/h)	K_{fs}=1.5 (cm/h)	K_{fs}=16 (cm/h)	K_{fs}=0.46 (cm/h)	
Sediment In (kg)	18.428	18.428	18.428	18.428	18.87
Sediment Retained (kg)	18.428	18.321	18.428	18.294	18.11
Sediment Out (kg)	0	0.108	0	0.134	0.76
E_{ST}	**1.0**	**0.99**	**1.0**	**0.99**	**0.96**
Runoff In (m^3)	1.843	1.843	1.843	1.843	1.893
Rainfall (m^3)	1.142	1.142	1.142	1.142	1.136
Infiltration (m^3)	2.982	1.246	2.982	0.943	1.572
Runoff Out (m^3)	0.003	1.739	0.003	2.042	1.451
E_{WT}	**1.0**	**0.42**	**1.0**	**0.32**	**0.52**

PTFs can significantly under-estimated K_{fs} and thus water and sediment trapping in a vegetated filter. Under-estimating how much water will be trapped in a filter may result in inaccurate predictions of contaminant transport to adjacent water bodies as well as vertical contaminant transport. Also, if filters are designed to trap a majority of runoff, using PTFs to generate infiltration equation parameters may lead to over design of filters, which may be economically unfavorable.

For these reasons, it is important to have accurate estimates of field saturated hydraulic conductivity when designing vegetated filters. The inverse Green-Ampt method, being based on field measured data, may implicitly account for preferential flow and may better approximate saturated hydraulic conductivity than PTFs. As a result, the authors of VFSMOD suggest that model users measure the infiltration parameters from the field site (if at all possible) rather than use the PTF estimates suggested for use (Munoz-Carpena and Parson, 2003).

One reason PTFs may underestimate K_s and thus infiltration, is that they do not account for preferential flow (e.g. macropores). The inverse Green-Ampt method may better do this because it is based on actual measured infiltration data, and thus it implicitly includes the preferential flow effects, in a single domain.

To determine if water flow through macropores may be significant in these plots, tension infiltrometer data were used to determine the unsaturated hydraulic conductivity function. From this, the number of macropores per unit area (based on size) as well as their percent contribution to saturated flow was estimated using the methods of Watson and Luxmoore, (1986) (Table 10).

Macropore data was averaged for the grass and shrub/tree regions rather than the whole entire grass/shrub/tree plots. This was done for comparison of grass and shrub/tree macropore densities and contribution to flow. The grass filters had slightly higher saturated hydraulic conductivities than the forest filters (on the same order of magnitude, however).

On average, the grass filters had 160 macropores (>0.05 cm in diameter) while the forest filters had 137 macropores. The grass filter macropores contributed slightly less to saturated flow (45 percent) then the forest (47 percent). In other words, 45-47 percent of water flow at saturation is through pores greater than 0.1 cm in diameter (Table 10). This indicates that preferential flow in the form of macropores may indeed be controlling infiltration and significantly influencing contaminant transport in these plots.

Table 10. Tension Infiltrometer Data

Grass Filter Area

Tension range (cm)	***No. of samples***	***Pore radius (cm)***	***Number of pores per m^2***	***Percent of saturated conductivity****
0-3	8	>0.05	160	45 (19.2-105)
3-6	8	0.025-0.05	1138	22
6-15, 6-10	8,4	0.015-0.025,0.01-0.025	2.3×10^4	22

Shrub/Tree Filter Area

Tension range (cm)	***No. of samples***	***Pore radius (cm)***	***Number of pores per m^2***	***Percent of saturated conductivity****
0-3	8	>0.05	134	47 (20-110)
3-6	8	0.025-0.05	1216	20
6-15,6-10	8,4	0.015-0.025,0.01-0.025	1.9×10^4	17

* Geometric mean ± 1 standard deviation

Conclusions

PTFs underestimated K_{fs} (10 to 99 percent) compared to field-measured values. Using VFSMOD to replicate field scenarios, more runoff (up to 62 percent) from the filter was predicted with the PTF K_{fs} input values than with the field-measured K_{fs} input values. When using field-measured K_{fs} values, VFSMOD provided good estimates of water and sediment trapping compared to field measured water and sediment trapping, with the exception of the silty clay loam plot (possibly due to shrinking and swelling). Water trapping was more sensitive to K_{fs} than was sediment trapping, even at a higher sediment loading rate. Neither water trapping nor sediment trapping was sensitive to wetting front suction or initial water content.

One reason PTFs may underestimate K_{fs} and thus infiltration, is that they do not account for preferential flow (e.g. macropore flow). Vegetated filters may have a substantial number of preferential flow pathways. With tension infiltrometer data, we estimated that 45-47 percent of the saturated flow was through pores larger than 0.1 cm in diameter indicating that macropores may significantly impact (increase) the infiltration rates and thus the field-saturated hydraulic conductivities at our site.

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