Al-Khwarizmi Engineering Journal,Vol. 13, No. 2, P.P. 100- 106 (2017)

Al-Khwarizmi Engineering Journal

# Design a Vegetative Filter Strips Length Using VFSMOD_W Model for Reducing Sediments and Pesticides

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(Received 4 October 2016; accepted 29 January 2017)

https://doi.org/10.22153/kej.2017.01.005

## Abstract

The vegetative filter strips (VFS) are a useful tool used for reducing the movement of sediment and pesticide in therivers. The filter strip's soil can help in reducing the runoff volume by infiltration. However, the characteristics of VFS (i.e., length) are not recently identified depending on the estimation of VFS modeling performance. The aim of this research is to study these characteristics and determine acorrelation between filter strip length and percent reduction (trapping efficiency) for sediment, water, and pesticide. Two proposed pesticides (one has organic carbon sorption coefficient, $K_{oc}$, of 147 L/kg which is more moveable than 100, and another one has a $K_{oc}$ of 2070 L/kg which is less moveable than 1000 are presented, where the goal is to prevent 95% of incoming sediment and 85% of the incoming pesticide to reach a receiving stream in still water, Oklahoma from a cultivated field (1250 m²),for 2 hour storm with 5 years return period. Several VFS lengths were simulated including1**,** 3, 5, 6, 9, 11, 12, and 13 m. The results showed that the percent of reduction of sediment, pesticide, and water mainly depends on VFS lengths. Moreover, considering the design storms range, the simulation illustrated that the optimal filter length was13m for silty clay loam. When the value of $K_{oc,}$ was increased from 147 L/kg to 6070 L/kg, the filter length decreased from 13 to 9.5 because of the increase in trapping efficiency. In addition, the results revealed that the trapping efficiency was for sediment but not for water orpesticide which was highly impacted by the narrow filter strips. The amount of the rainfall and runoff of the designated field was larger than the infiltration capacity of filter strips, which resulted in low trapping efficiency for pesticide and water.

***Keywords:*** *Models ,runoff, sediment, vegetative filter strip, , water quality, watershed planning.*

## 1. Introduction

Watershed planners were encouraged by the U.S Environmental protection agency (USEPA) to use a vegetative filter strip as a tool to control runoff quantity and quality [1] since the amount of surface runoff depends on the amount of rain and watershed characteristics such as soil type, land use, size, vegetation cover, soil moisture condition, and topography [2]. An effective way to minimize the amount of water and sediment and other contaminants in surface runoff from reaching a stream was needed [3].

Such an effective way is the vegetative filter strip modeling system (VFSMOD-W) which is a computer model to study hydrology, sediment and pollutant through VFS. Three sub models were connected to the VFSMOD model to study the buffer performance on an event by event basis; a petrov- Galerkin finite element kinematic wave over land flow submodels, a modified Green- Ampt infiltration submodel and University of Kentucky sediment filtration model for grass area [4].

VFS is defined by Grismer [6] as a vegetative land that is planted on purpose to trap sediment and pesticide from runoff water. The goal of VFS is to protect surface water in a number of ways; (1) they trap as much as 75 to 100 percent of water's sediment by infiltrating the surface water; (2) they hold nutrients in runoff through adsorption to soil particles; (3) they increase degradation so that the pollutant become less toxic; (4) they prevent over 60% of certain pathogens form the runoff. When designing VFS, there are some factors that need to be taken into account such as slope, site preparation, soil conditioning, width, placement, maintenance, and monitoring. Slopes less than 5 percent are work in VFS, while slopes greater than 15 percent is not recommended. Grismer [6] concluded that the width of filter strips is an important element affecting the performance of VFSs. As the strips width increases the amount of runoff and sediment also increases.

The design of filter strips has been studied by many researchers and there is an agreement that the length of filter strips needed to obtain a certain level of trapping efficiency is highly variable [5]. Therefore, to effectively measure the length of VFS, it is necessary to study the relationship between the amount of sediment and pollutant that could be stopped and the length of filter strips.

Dosskeyet al [3] evaluated a vegetative filter strip model to develop a design aid that is easy to use. Slope, soil texture, field length and field covers were used as variablesto determine the amount of sediment by using ten different combinations of lengths and widths. They reported that the narrow filter strips can be highly effective in some cases, while in others, even a small impact, could not be achieved at any practical width. In addition to that, it was found that as the slope increased or the texture of soil become finer, the trapping efficiency decreased and the field runoff increased as shown in Figure (1). Moreover, as field length or C factor (crop factor) increased the amount of runoff also increased, thus, the trapping efficiency of sediment become lower than that of shorter field with lower C factor (better condition).

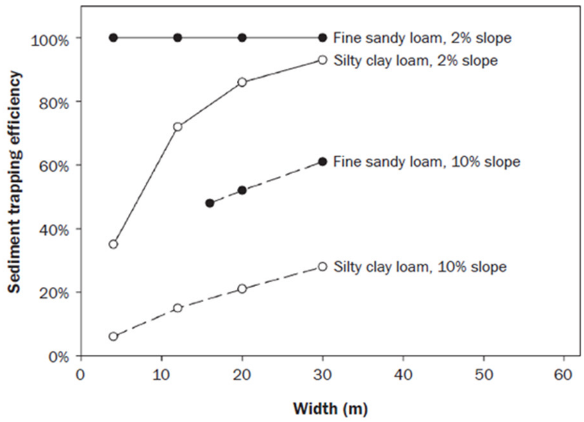


**Fig. 1. Sediment trapping efficiency as a function of VFS width for two different sites having two different soil [3].**

Dillahaet al [9]found that increasing VFS length will help to increase the trapping efficiency up to a certain level thereafter, any additional length does not make any improvement in filter performance. Furthermore, Holvoet et al [2]indicated that the best management practices can decrease the level of different pesticide input to a large extent but, more field study should be made in combination with modeling exercises in order to achieve good results whose measurements are most effective. Barfield et al [1], on the other hand, presented a steady state model to estimate the trapping efficiency of sediment in a filter strip under different variables. The trapping efficiency, $T_r$, of a filter strip can be calculated as follows [1]:

$$T_r = \frac{q_{si}-q_{so}}{q_{si}} \quad \ldots(1)$$

Where $q_{si}$ and $q_{so}$ are incoming and outgoing sediment load per unit channel width.

The aim of this research is to study the characteristics of VFS (i.e., length) and determine a correlation between filter strip length and percent reduction (trapping efficiency) for sediment, water, and pesticide.

## 2. Materials and Method

The vegetative filter strip modeling system (VFSMOD-W) version 5.x[4] was used to estimate the reduction of sediment, pesticide, and water by many different lengths of grass filter strip. A field site in Oklahoma was selected to monitor the performance of VFS. The design will receive water and sediment from a 50 m wide by 25 m long source area. By using Table (1)with the soil- texture triangle of 17.1 % sand, 54.1 %

silt, and 28.9 % clay, the soil type was found to be silty clay loam type D[10]. For type D, cultivated area, and row cropscurve number is equal to 91 [9].

Soil hydraulic parameters which are shown in Table (1) were taken from the United States Department of Agriculture (USDA) SSURGO database [9]. Default parameters of the VFS model were used and Bermuda grass type was assumed. The flow pattern of the source area is shown in Figure (2).

**Table 1,**
**Input parameters for the VFSMOD-W[8,9].**

| Parameter | Model Input Value |
|---|---|
| Soil type | Silt clay loam with 17.1% sand, 54.1% silt,and 28.9% clay and 2.58% organic carbon. |
| Soil hydraulic conductivity | 9.3 cm/hr |
| Soil bulk density | 1.44 $g/cm^3$ |
| Average section at the wetting front (SAV) | 0.43m |
| Intial water content $\theta_0$ | 0.17 |
| Slope | 5.25 % |
| Crop factor (C) | 0.05 |
| Practice factor (P) | 0.5 |
| Mediam parcticle size of incomin sediment ( $d_{50}$) | 0.001 |
| Adsorption coefficient ($K_{oc}$) | 147 L/kg -6070 L/kg |

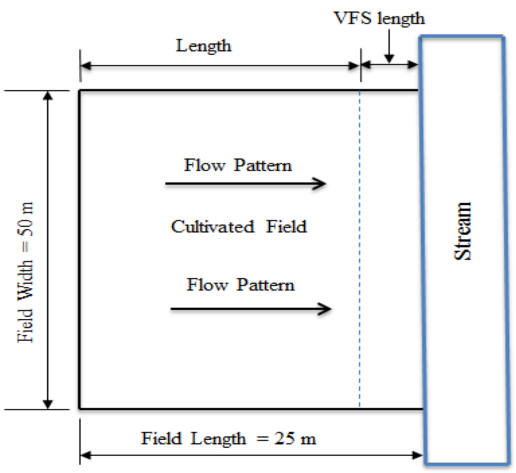


**Fig. 2. Case study characteristics (source area).**

The Porosity,(∅), which is the fraction of void space in the soil, is defined by the ratio:

$$\emptyset = \frac{V_V}{V_T} = 1 - \frac{bulk\ density}{particle\ density\ (2.65\frac{g}{cm^3})} \quad \ldots(2)$$

Where $V_V$ is the volume of void space, and $V_T$ is the total or bulk volume of the materials [11].

VFSMOD required storm-based hourly rainfall data. In this study, the Natural Resource Conservation Soil method (NRCS) for calculating the rainfall excess was used for5-year-2hr storm, Type ll curve [10]. The dimensionless precipitation, $\frac{P_t}{P_{24}}$, is the cumulative rainfall ($P_t$)as function of time divided by the total 24-hour rainfall amount ($P_{24}$). The 24hr, 5-year storm is equal to 5 inches[10]. The peak rainfall intensity occurs at the time when the slope of the cumulative rainfall distribution is the steepest, which for the NRCS 24-h hyetograph type II is from 11hrto 13 hr. The rainfall event was calculated to be 68 mm as shown in Table (2).

**Table 2,**
**Rainfall depth calculations using NRCS method.**

| Time, hr | $\frac{P_t}{P_{24}}$ | Depth, in |
|---|---|---|
| 11 | 0.235 | 0.0 |
| 11.5 | 0.283 | 0.25 |
| 12 | 0.663 | 1.9 |
| 12.5 | 0.735 | 0.36 |
| 13 | 0.772 | 0.18 |
| | | $\sum$ **2.69 in = 68mm** |

## 3. Design Guide Procedures

One of the most important steps to develop a design guide for evaluating VFS performance is that the user must provide inflow hydrographs from the source area. Using the inputs of hyetograph in Figure (3) and the hydrograph in Figure (4), VFSMOD simulates the transport and deposition of sediment within the VFS. In the VFS model, the field length is defined as the distance from the edge of the field to the edge of the VFS as shown in Figure (2). VFS width which is the same as the field width is calculated by dividing the area of the field (1250 m²)by the field length. Several VFS lengths (1, 3, 5, 6, 9, 11, and 13 m) were used in the simulation to estimate the reduction of sediment, runoff inflow, and pesticide as explained in Table (3). Then, the results were developed into graphical representation which are easier to understand than those of the tables as shown in Figure(5).In addition, to study the effect of the width of the filter strip on the trapping efficiency of the pesticide, the width was reduced to 90%, 75%, 25%, 10% and 5% of the field width and applied to the model. The percent reduction in the pesticide which were obtained from the VFSMOD simulation are listed in Table (4) and were developed into graphical representation as illustrated in Figure (6).

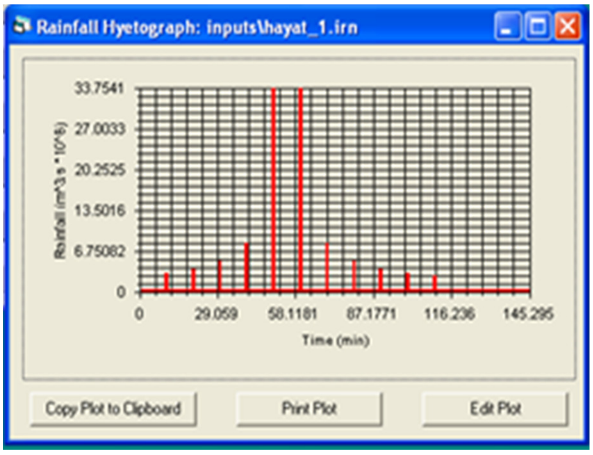


**Fig. 3. Hyetograph of the case study.**

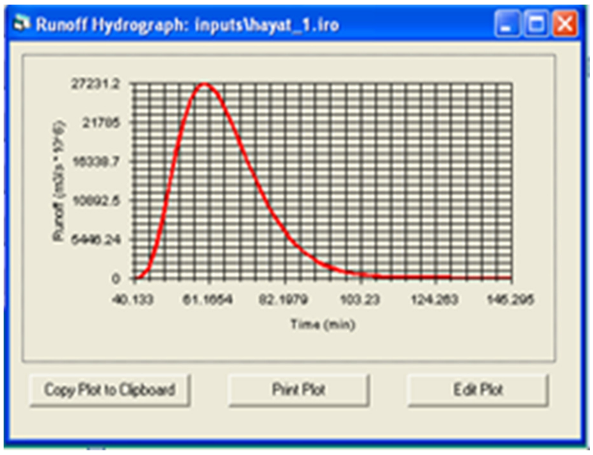


**Fig. 4. Hydrograph of the case study using VFSMOD.**

**Table 3,**
**VFSMOD-W output file.**

| VFS Length, m | Source length, m | Vegetation Type | H,cm | Sediment Reduction, % | Runoff Inflow Reduction, % | Pesticide Reduction, % |
|---|---|---|---|---|---|---|
| 1 | 24 | Bermudagrass | 1.35 | 74.187 | 10.19 | 35.018 |
| 3 | 22 | Bermudagrass | 1.35 | 89.699 | 23.142 | 52.766 |
| 5 | 20 | Bermudagrass | 1.35 | 94.174 | 32.056 | 62.36 |
| 6 | 19 | Bermudagrass | 1.35 | 94.582 | 34.84 | 66.672 |
| 8 | 17 | Bermudagrass | 1.35 | 96.514 | 40.289 | 71.67 |
| 9 | 16 | Bermudagrass | 1.35 | 96.89 | 42.164 | 77 |
| 11 | 14 | Bermudagrass | 1.35 | 97.8 | 56.294 | 78.6 |
| 12 | 13 | Bermudagrass | 1.35 | 98 | 58.361 | 79.8 |
| 13 | 12 | Bermudagrass | 1.35 | 99.47 | 60.149 | 89.889 |

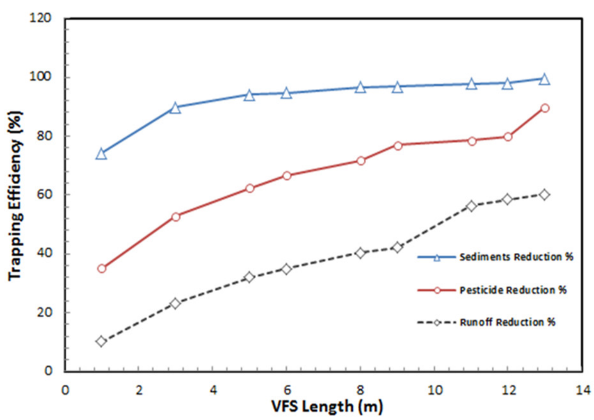


**Fig. 5. Percent reduction in sediments, pesticides, and runoff relative to vegetative filter strip (VFS) length (1, 3, 5, 6, 9, 11, 12, and 13 m) with organic carbon sorption coefficient, $K_{OC}$ of 147 L/kg.**

**Table 4,**
**Values of VFS width and trapping efficiency of pesticide.**

| Width, m | Trapping Efficiency % |
|---|---|
| 50.0 | 89.889 |
| 45.0 | 89.115 |
| 37.5 | 86.539 |
| 25.0 | 79.566 |
| 15.0 | 63.341 |
| 5.0 | 41.756 |

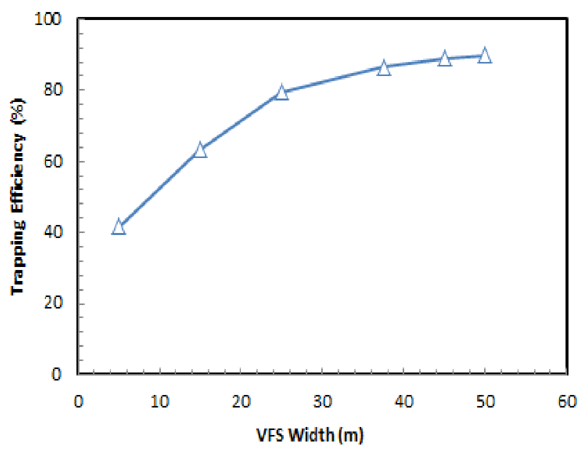


**Fig. 6. Relationship between VFS widths and trapping efficiency of pesticide.**

## 4. Results and Discussion

The simulation results clearly showed that increasing the filter strips length will help to increase the trapping efficiencies for sediment and pesticide as shown in Figure (5).The filter strip as narrow as 5 m was estimated to trap nearly 95% of the incoming sediment and only 62% of incoming pesticide, while 13 m strips trapped 99.47% of incoming sediment and 89.9% of incoming pesticide(see Figure(5)). Thus, the relatively narrow filter strips can have great impact on the trapping efficiency for sediment but not for water or pesticide.

The trapping efficiencies of a given length of filter strips also depend on the spacing of vegetation being planted and the kind of material being trapped. High trapping efficiencies were estimated for sediment and much lower trapping efficiencies were estimated for water under the same conditions as displayed in Figure (5). The low trapping efficiencies for water illustrates that rainfall plus field runoff often greatly exceeds the infiltration capacity of filter strips. The filter length decreased from 13 to 9.5 when the value of ( $K_{oc}$) was increased from 147 L/kg to 6070 L/kg because the trapping efficiencies of the sediment and pesticide increased as presented in Table (5). The VFS width also affected the trapping efficiency, as the width increases, the trapping efficiency also increases as shown in Figure (6).

**Table 5,**
**Values of $K_{oc}$ and VFS**

| Length, m | $K_{oc}$ | Sediment Reduction, % | Pesticide Reduction, % |
|---|---|---|---|
| 13 | 6070 | 99.47 | 94.692 |
| 11 | 6070 | 90.310 | 90.616 |
| 9 | 6070 | 97.244 | 84.238 |
| 9.5 | 6070 | 97.385 | 85.088 |

## 5. Conclusion

Vegetation filter strips (VFS) are areas planted on purpose along streams, ponds, and lakes to remove sediment, organic materials, and chemicals carried in runoff or wastewater. The VFSMOD model is recommended to use by the U.S Environmental Protection Agency (USEPA) as a design aid to remove the amount of sediment, organic materials, and chemical carried in surface water. The results showed that the vegetative filter strips length is the most important parameter that directly affects the trapping efficiency. Increasing the filter strips length will help to increase the trapping efficiency up to a certain level thereafter, any additional length does not make any improvement in filter performance.

To prevent 85% of incoming pesticide to reach a receiving stream, it requires longer filter strips than sediment. The optimal filter length obtained was 13m. High trapping efficiencies were estimated for sediment and much lower trapping efficiencies were estimated for water under the same conditions. The low trapping efficiencies for water illustrates that rainfall plus field runoff often greatly exceeds the infiltration capacity of filter strips. When the value of adsorption coefficient ($K_{oc}$) was increased from 147 L/kg to 6070 L/kg, the filter length decreased from 13 m to 9.5 m because the trapping efficiencies for sediment and pesticide increased.

The advantages of VFSMOD model over other models used to simulate VFS are the flexibility to change the parameters (slope, vegetation type, spacing of vegetation, etc.) along the filter and handling of complex storm pattern and intensity.

Based on this study, it is recommended to implement vegetation filter strips in many regions in Iraq along the numerous streams where the prevalent areas are agricultural fields which are full of pesticides and fertilizers used by farmers. In addition, since the soil characteristics are important factors in the VFS performance, field studies including evaluation of the implemented VFS are recommended as well.

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# تصميم طول شريحة الغطاء النباتي باستعمال VFSMOD_W موديل للحد من الرواسب والمبيدات الحشرية

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**الخلاصة**

شرائح الغطاء النباتي (VFS) هي أداة مفيدة تستخدم للحد من الرواسب والمبيدات الحشرية الداخلة إلى مجرى مائي كنهر او بحيرة . تصمم الـ VFS قرب المجاري المائية وبموازاة خطوط جريان الماء فتساعد على خفض حجم الجريان السطحي بوساطة عملية الترشيح. من جهة اخرى، الخصائص الفيزيائية الطبيعية كطول الشريحة مثلا ليست حاليا محددة على أساس النمذجة التنبؤية لأداء VFS.لهذا كان من الضروري دراسة هذه الخصائص وإيجاد علاقة بين طول الشريحة والنسب المئوية للرواسب والمبيدات المنخفضة. تم فحص عدة أطوال ١، ٣، ٥، ٦، ٩، ١١، ١٢ وكذلك ١٣ متر لمساحة طولها ٢٥ متر و عرضها ٥٠ متر لتربة طينية غرينية في مدينة Stillwater في الولايات المتحدة الأمريكية تستقبل ٢ hrsعاصفة مطرية لفترة رجوع كل خمس سنوات . تم أيضا فحص نوعين من الكربون العضوي ذي قابلية حركة عالية والآخر ذي قابلية حركة قليلة بهدف الحصول على نسبة انخفاض مقدارها ٨٥% من المبيدات و ٩٥% من الرواسب الواردة الى المجرى المائي. لوحظ وجود علاقة جيدة بين طول الVFS ومقدار المبيدات المنخفضة لطول ١٣ متراً كما تبين ان لطول شريحة الـ VFS أثرا كبيراً على نسبة الرواسب والمبيدات المنخفضة .