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Using RUSLE2 for the Design and Predicted Effectiveness of Vegetative Filter Strips (VFS) for Sediment

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Using RUSLE2 for the Design and Predicted Effectiveness of Vegetative Filter Strips (VFS) for Sediment

Overview

Vegetative filter strips (VFS) have proven to be an effective practice to trap contaminates (sediment, nutrients, pesticides, pathogens) in field runoff. The effectiveness of the VFS is dependent on the (1) proper design, (2) the proper location and layout, and (3) the proper assessment of the contributing runoff area. Properly designed and located, VFS can remove 70-85% of the sediment entering the VFS (C.-X. Jin, M.J.M. Romkens).

VFS designed to trap sediment will eventually fill with sediment and inhibit the functioning of the VFS to filter/trap sediment. The life span of the VFS, for sediment removal purposes, is dependent upon the rate of soil loss from the contributing area, the ratio of contributing area to the size of the VFS, and trapping efficiency. In 1999 Theo A. Dillaha, Ph.D., P.E. and John C Hayes, Ph.D., P.E. published a report "A Procedure for the Design of Vegetative Filter Strips". In that report the authors developed a procedure to estimate the life of a VFS based on the rate of soil loss from the contributing area, the ratio of contributing area to the size of the VFS, and trapping efficiency.

Although Dillaha and Hayes used the Water Erosion Prediction Process (WEPP), the Revised Universal Soil Loss Equation, Version 2, (RUSLE2) can also be used to design and predict the expected lifespan of a VFS designed for the purpose of sediment removal based on the procedures developed by Dillaha and Hayes.

Using RUSLE2 to design and estimate sediment removal from VFS

The following information is needed:

1. Sediment delivery rate at the upper edge of the VFS for the "contributing area" to the VFS – calculated by RUSLE2 using the "overland flow slope length".
2. Sediment Trapping Efficiency – calculated from RUSLE2 results.
3. Ratio of "Contributing Area to VFS Area.

How to determine sediment delivery rate and sediment trapping efficiency

To use RUSLE2 for the VFS design procedure requires the use of the "Advance", "Summary", or "Science" profile templates within RUSLE2. These templates provide the options to segment slopes when changes in slope, soil type, or management change within the "Overland Flow Slope Length".

This procedure, using RUSLE2, requires the use of the "Overland Flow Slope Length" (fig. 1). <u>The "Overland Flow Slope Length" is defined as the slope length from the point of origin of flow to the point where the slope enters concentrated flow or the upper edge of a VFS.</u> **Note**: This differs from the slope length used for conservation planning which is the length from origin of flow to either concentrated flow or deposition. The slope lengths used for conservation planning purposes are usually shorter. Figure 1 diagrams the difference between slope length for conservation planning purposes and overland flow slope length on a convex/concave slope.

Figures 2 and 3 represent RUSLE2 screen shots that illustrate the use of the "Worksheet" and "Profile" views with the "Advanced" template. The "Summary" and "Science" templates can also be used.

Figures 2 and 3 illustrate the overland flow slope length of 350 feet. This is the length from the point of overland flow until the slope reached the VFS or concentrated flow. The slope is broken into 3 segments for this example. Your situation may require fewer or more segment breaks.

The soil loss for this example is 5.5 tons/acre/year where the slope enters the VFS (figs. 2 and 3). The estimated sediment yield leaving the lower (exit) portion of the VFS is 0.8 tons/acre/year. From the results in Figures 2 and 3 one can calculate the amount of sediment trapped (5.5 tons entering minus (-) 0.8 tons leaving = 4.7 tons/acre/year trapped in the VFS). The trapping efficiency can be calculated by dividing the "Sediment Trapped" by the "Soil Loss Rate entering the VFS". In this example the Sediment Trapped (4.7) divided by Soil Loss (5.5) = 85%.

Figure 1 Overland Flow Slope Length vs. Slope Length for Conservation Planning

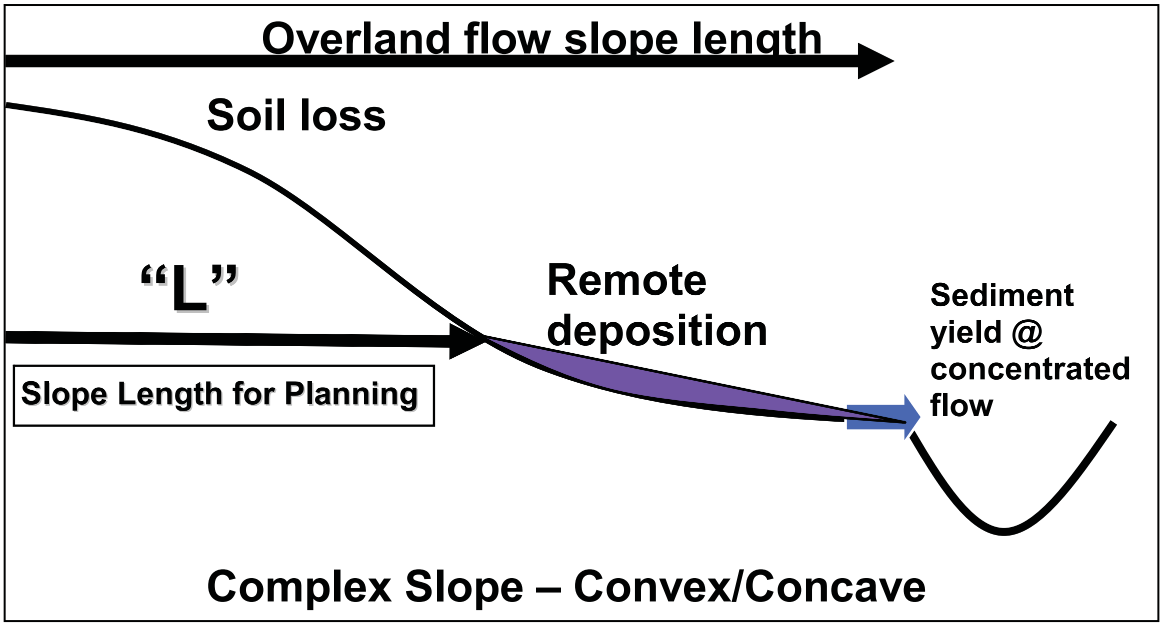
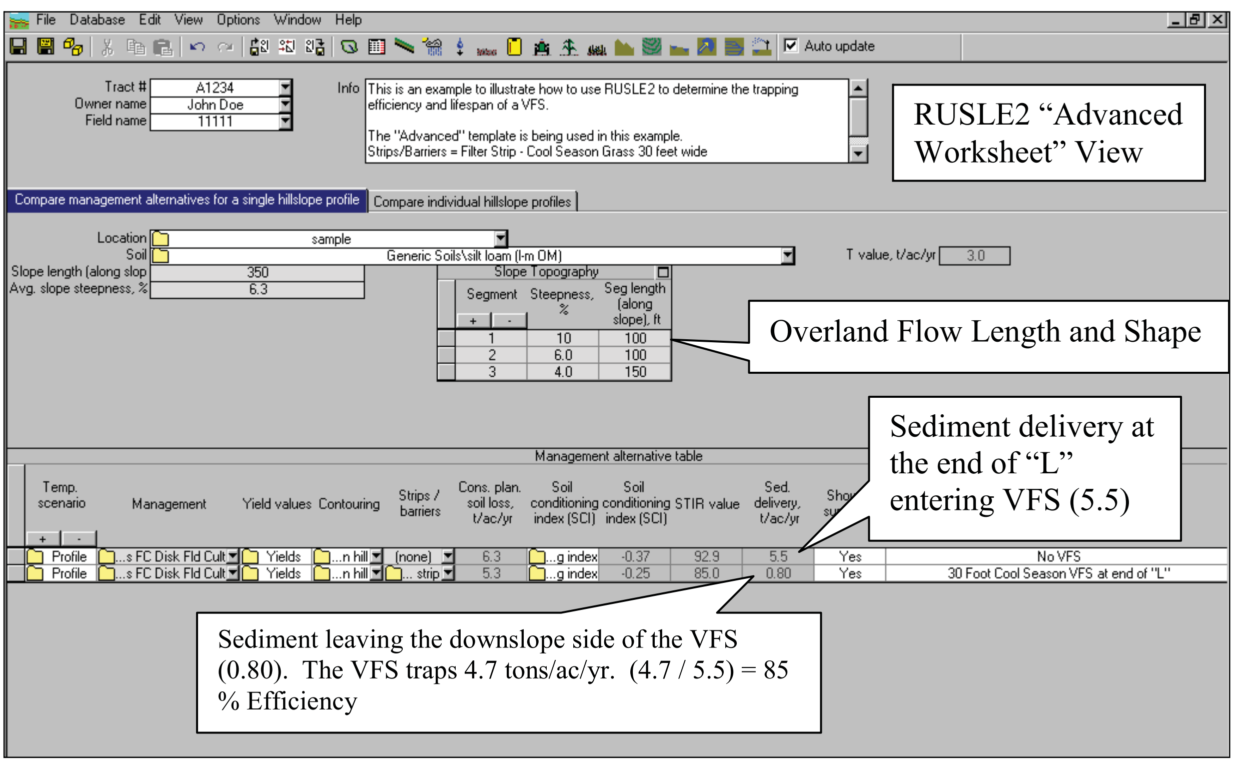


Figure 2 RUSLE2 worksheet view using the "advanced" RUSLE2 template option.



How to calculate the ratio of "Contributing Field Area" to "VFS Area"

Aside from knowing the sediment delivery rate that is entering the VFS and the sediment trapping efficiency one must also know the **ratio** of "Contributing Area" to "VFS Area". Figure 4 illustrates the "Contributing Area" is defined as the area above the VFS that contributes "sheet flow" to the VFS. DO NOT COUNT ACRES THAT REACH THE VFS AS CONCENTRATED FLOW.

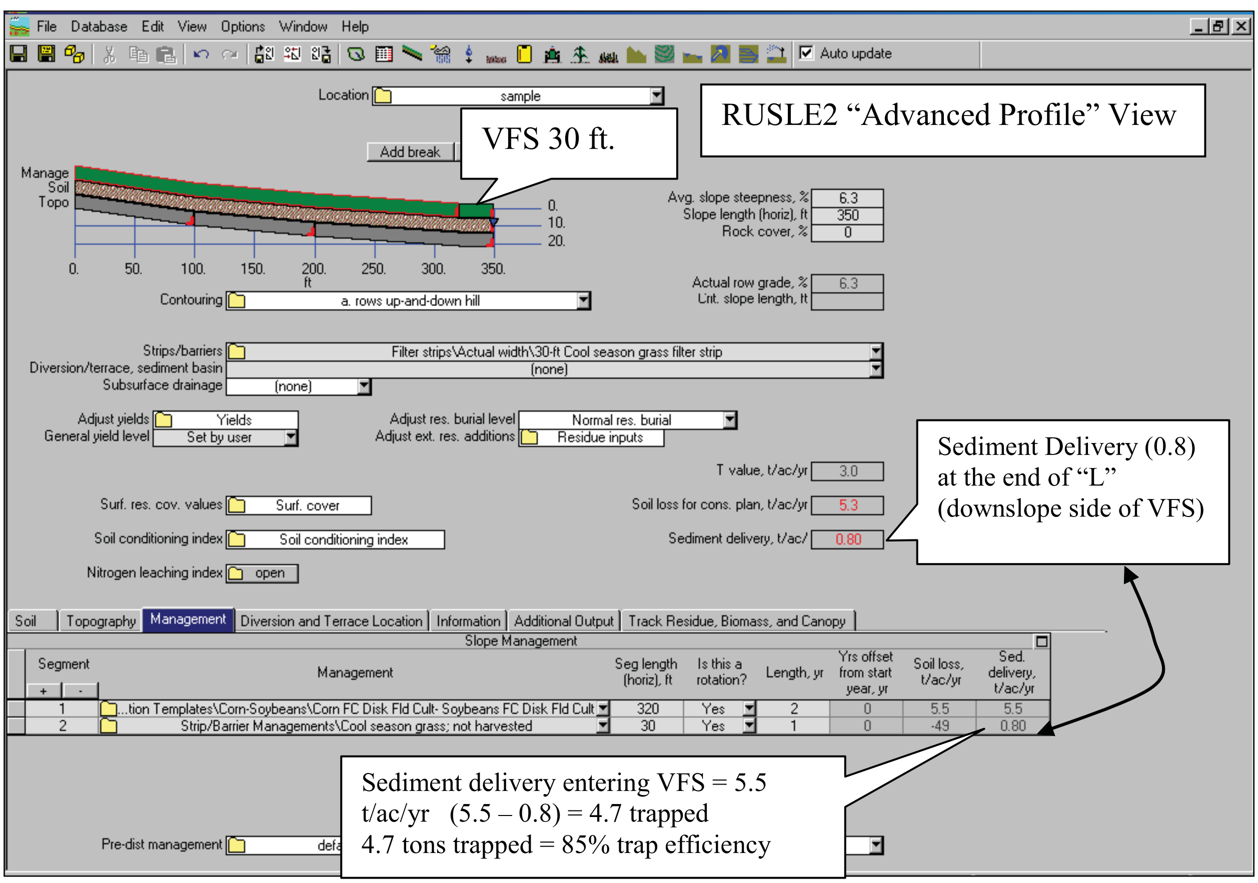
This ratio can be calculated using the following method:

(Ratio of Contributing Area to VFS Area).

1. Measure the "Contributing Area" (in acres) that sheet flows into the VFS.
2. Measure the "Area of the VFS" (in acres).
3. Divide the "Contributing Area" (in acres) by the "Area of the VFS" (in acres). For example, a 20 acre "Contributing Area" divided by a 0.8 acre VFS (20 acres / 0.8 acre. = 25). Therefore the ratio of Contributing Area to VFS is 25:1.

VFS are to be designed to have a minimum life span of ten (10) years. To maintain VFS, the rate of sediment accumulation should not exceed 0.6 inches per year (Dillaha and Hayes). At this rate of accumulation the grass should be able to adjust and survive. However, once the accumulation reaches six (6) inches the VFS will need to be re-graded and re-established.

Figure 3 RUSLE2 profile view using the "advanced" RUSLE2 template option.



Tables 1 - 3 depicts the estimated time (in years) to accumulate six (6) inches of sediment in a filter strip based on (1) sediment delivery rate to the VFS, (2) ratio of contributing area to VFS area, and (3) the trapping efficiency of the VFS. The shaded cells indicate those soil loss rates, trapping efficiencies, and drainage area to VFS ratios that fall within the 10 year projected life span criteria. Knowing the sediment delivery in ton/ac/yr, ratio of contributing area to VFS area, and the sediment trapping efficiency one can determine if the planned VFS has the minimum 10 year life span.

The following formula can also be used to calculate the number of years to accumulate six (6) inches of sediment in the VFS. This procedure assumes sediment weighs 92 lbs/cubic foot. (See EXCEL Spreadsheet Filter_Strip_Life_Span_Design_for_Sediment.xls for an automated formula)

1. Sediment Delivery to VFS (tons/acre/year) X 21.74 cubic feet/ton = Sediment Delivery cubic feet/acre/yr
2. Sediment Delivery cubic feet/acre/yr X Trapping Efficiency X Ratio = Cubic feet trapped in VFS/acre/yr
3. Cubic feet trapped in VFS/acre/yr / 43,560 square feet/acre X 12 in/ft= Accumulated depth (inches/year)
4. 6 inches (Maximum Accumulation) / Accumulated depth (inches/year) = Years to Accumulate 6 inches

Figure 4 Example illustration showing contribution area, VFS area, and ratio of contributing area to VFS area.

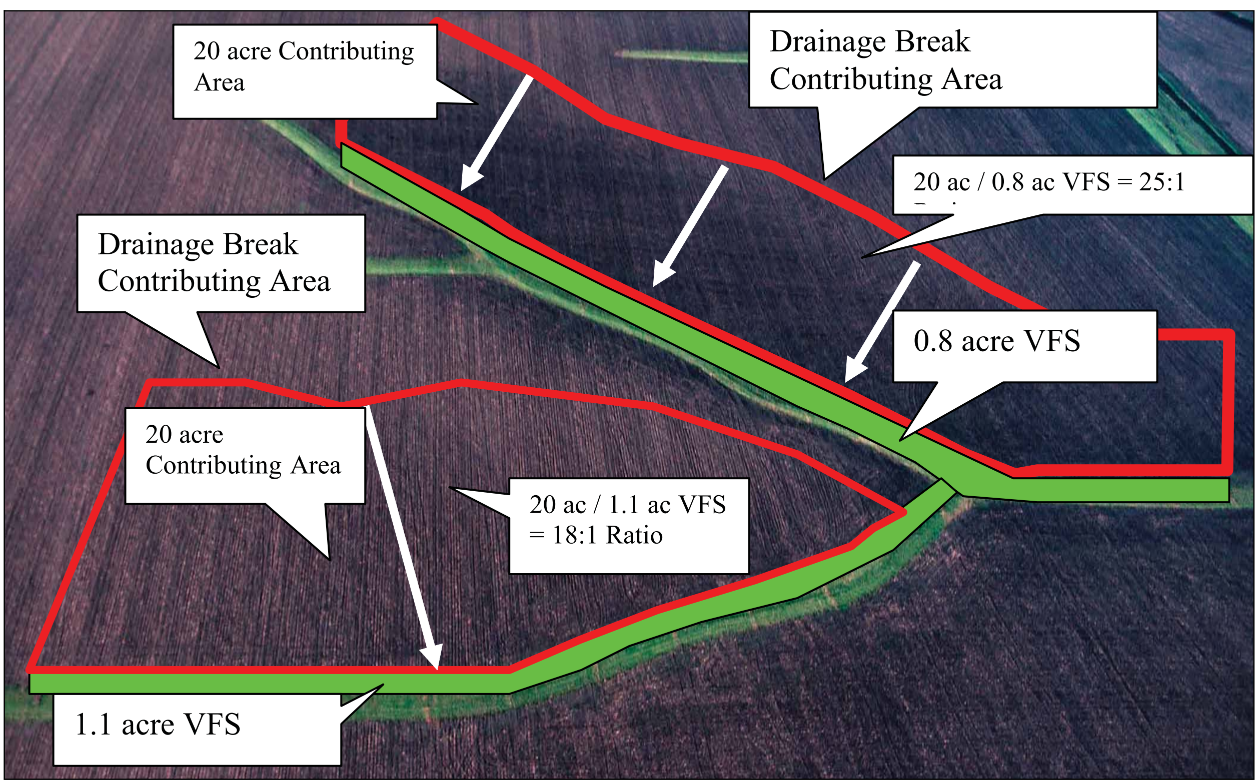


Table 1 Time to accumulate six (6) inches with a 85% trapping efficiency.

Sed. Delivery Tons/Ac/Yr @ upper edge of VFS	Time (years) to accumulate 6 inches of sediment (in years) with a **85%** trapping efficiency based on the contributing area to VFS ratio.						
	Ratio of Contributing Area to VFS						
	5:1	**10:1**	**20:1**	**50:1**	**75:1**	**100:1**	**200:1**
1.1	213.2	106.6	53.3	21.3	14.2	10.7	5.3
2.2	107.1	53.6	26.8	10.7	7.1	5.4	2.7
4.5	52.4	26.2	13.1	5.2	3.5	2.6	1.3
6.7	35.2	17.6	8.8	3.5	2.3	1.8	0.9
10.0	23.6	11.8	5.9	2.4	1.6	1.2	0.6
13.4	17.6	8.8	4.4	1.8	1.2	0.9	0.4
17.8	13.2	6.6	3.3	1.3	0.9	0.7	0.3
20.1	11.7	5.9	2.9	1.2	0.8	0.6	0.3

Table 2 Time to accumulate six (6) inches with a 75% trapping efficiency.

Sed. Delivery Tons/Ac/Yr @ upper edge of VFS	Time (years) to accumulate 6 inches of sediment (in years) with a **75%** trapping efficiency based on the contributing area to VFS ratio.						
	Ratio of Contributing Area to VFS						
	5:1	**10:1**	**20:1**	**50:1**	**75:1**	**100:1**	**200:1**
1.1	208.0	104.0	52.0	20.8	13.9	10.4	5.2
2.2	104.0	52.0	26.0	10.4	6.9	5.2	2.6
4.5	52.0	26.0	13.0	5.2	3.5	2.6	1.3
6.7	34.7	17.3	8.7	3.5	2.3	1.7	0.9
10.0	23.1	11.6	5.8	2.3	1.5	1.2	0.6
13.4	17.3	8.7	4.3	1.7	1.2	0.9	0.4
17.8	13.0	6.5	3.3	1.3	0.9	0.7	0.3
20.1	11.6	5.8	2.9	1.2	0.8	0.6	0.3

Table 3 Time to accumulate six (6) inches with a 50% trapping efficiency.

Sed. Delivery Tons/Ac/Yr @ upper edge of VFS	Time (years) to accumulate 6 inches of sediment (in years) with a **50%** trapping efficiency based on the contributing area to VFS ratio.						
	Ratio of Contributing Area to VFS						
	5:1	**10:1**	**20:1**	**50:1**	**75:1**	**100:1**	**200:1**
1.1	312.0	156.0	78.0	31.2	20.8	15.6	7.8
2.2	156.0	78.0	39.0	15.6	10.4	7.8	3.9
4.5	78.0	39.0	19.5	7.8	5.2	3.9	2.0
6.7	52.0	26.0	13.0	5.2	3.5	2.6	1.3
10.0	34.7	17.3	8.7	3.5	2.3	1.7	0.9
13.4	26.0	13.0	6.5	2.6	1.7	1.3	0.7
17.8	19.5	9.8	4.9	2.0	1.3	1.0	0.5
20.1	17.3	8.7	4.3	1.7	1.2	0.9	0.4

Example:

- Sediment Delivery = 5 tons/acre/year; Sediment Leaving the VFS = 1.25 tons/acre/year
- Trapping Efficiency = 75% (.75) (Sediment Delivered to VFS (5) – Sediment Leaving VFS 1.25) / Sediment Delivered to VFS (5)
- Ratio of Contributing Area (16 ac) to VFS area (0.8 acre) = 20 (16 / 0.8 = 20)

1. 5 t/ac/yr X 21.74 ft3/ton = 108.7 ft3/ac/yr
2. 108.7 ft3/ac/yr X .75 Trapping Eff. X 20 Ratio = 1630.6 ft3/ac/yr in VFS
3. (1630.6 ft3/ac/yr in VFS / 43,560 ft2/ac) X 12 = 0..449 inches/yr Accumulated Sediment
4. 6.0 inches (Maximum Accumulation) / 0.449 in/yr Accumulated Sediment = 13.4 years to accumulate 6.0 inches of sediment in the VFS. (This would be an acceptable system for a minimum life span of 10 years)

It is recommended that the EXCEL Spreadsheet, noted above, be used to calculate years available for the design of VFS for the purpose of sediment removal. The spreadsheet allows actual figures to be entered and reduces the need to perform calculations to determine trapping efficiency and the ratio of contributing area to VFS area.

Other critical design components for a VFS being designed to remove sediment

1. The leading edge of the VFS must be laid out as close to the contour as possible to minimize flow paralleling the VFS. This may require the VFS that varies in width to keep the leading edge on the contour.
2. The slope entering the VFS must be at least 1% to allow runoff to enter the VFS. Slopes less than 1% will cause runoff and sediment to back up into the contributing area and not enter the VFS.
3. VFS are not effective to treat concentrated flow. Concentrated flows need to be converted to overland flow before being routed through the VFS. Care must be taken to calculate the sediment delivery and the contributing area to VFS ratio from the concentrated flow area.
4. A dense vegetation with stems less than one (1) inch apart is required to achieve treatment for sediment, nutrients, pathogens, and pesticides. This will generally require a much higher seeding rate than field borders or hay/pasture plantings.

References

C.-X. Jin, M.J.M. Romkens. October 2000. Experimental Studies of Factors in Determining Sediment Trapping in Vegetative Filter Strips. Transactions of the ASAE Vol. 44(2): 277-288

Theo A. Dillaha, Ph.D., P.E. and John C Hayes, Ph.D., P.E. 1991. "A Procedure for the Design of Vegetative Filter Strips"