Testing, Analyses, and Performance Values for Slope Interruption and Perimeter Control BMPs

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ABSTRACT

Owners and designers in the erosion industry have been searching for performance information on best management practices (BMPs) that are used for slope interruption or placed around the perimeter of construction sites. The function of these products is to break up long slopes and/or retain eroded soil within the project site, which results in reduced sediment concentrations in the exiting runoff.

Over a year's worth of test data for slope interruption and perimeter control products are contained in this paper. Products tested include: 22.9 cm (9.0 in) diameter straw wattle, 30.5 cm (12.0 in) diameter straw wattle, 15.2 cm (6.0 in) diameter excelsior fiber log, 30.5 cm (12.0 in) diameter excelsior fiber log, 1.2 m (4.0 ft) wide excelsior buffer strip, 2.4 m (8.0 ft) wide excelsior buffer strip, and 2.4 m (8.0 ft) wide straw buffer strip.

Bare soil tests, where no product was installed at the toe of the plot, were used as the control for the testing. The ability of the BMPs to reduce rainfall-induced erosion and improve the water quality of the resulting runoff is presented.

Analyses to calculate numeric performance values for the BMPs followed the framework of the Revised Universal Soil Loss Equation (RUSLE). The processes of testing and data analysis are detailed.

The performance values provide missing data for project owners and designers who utilize perimeter control and slope interruption devices.

INTRODUCTION

Slope interruption and perimeter control BMPs are commonly used on active disturbed sites before final grading and seeding take place. These products are typically temporary sediment control solutions before erosion control measures, such as hydraulically-applied mulch, sod, or erosion control blankets, are installed. Little is known about the ability of these BMPs to reduce soil loss and filter sediment-laden runoff generated by rainfall-induced erosion when they are utilized for slope interruption or perimeter control.

OBJECTIVE

To evaluate the performance capabilities of BMPs commonly used for slope interruption and/or perimeter control.

METHODS

Test BMPs installed at the toe of a slope by utilizing simulated rainfall and compare soil loss and sediment concentration data to bare soil control data set.

Study Site

All testing conducted for this study was completed at ErosionLab, which is a large-scale erosion and sediment control research laboratory located near Rice Lake, WI. More specifically, the Sediment Control Facility (SCF) was utilized. The facility contains five test plots that are 10.7 m (35.0 ft) long by 2.4 m (8.0 ft) wide at an 8H:1V (12.5%) slope and are filled with a veneer of loam-textured soil (according to USDA classifications). Each plot is surrounded by 10 rainfall riser holders in which portable rainfall simulator risers are placed. The simulator can produce rainfall events up to 20.3 cm/hr (8.0 in/hr). Water is pumped from an onsite pond, which provides a constant flow of water to the simulator.

Bare Soil Controls

A series of bare soil control tests were conducted before any BMPs were tested. All factors remained consistent with BMP tests with the only exception being there was no BMP installed at the toe of the slope. Data from BMP tests will be compared to bare soil control tests to give a baseline performance level of the BMPs versus utilizing no practice at all.

BMPs Evaluated

Testing was completed on seven BMPs by the end of the 2005 summer. The seven products that will be discussed herein are: 22.9 cm (9.0 in) diameter straw wattle, 30.5 cm (12.0 in) diameter straw wattle, 15.2 cm (6.0 in) diameter excelsior fiber log, 30.5 cm (12.0 in) diameter excelsior fiber log, 1.2 m (4.0 ft) wide excelsior buffer strip, 2.4 m (8.0 ft) wide excelsior buffer strip, and 2.4 m (8.0 ft) wide straw buffer strip.

Erosion Plot Preparation

Each plot tested for this study was prepared the same way. Plots were tilled up and down slope with a walk-behind roto-tiller. The plots were hand-raked to a uniform surface after tilling. If a BMP was to be tested, it was then installed at the toe of the slope according to recommended guidelines. Bare soil control tests were conducted without a BMP installed at the toe of the slope. The plots were not manipulated between storm increments. All plots were reconditioned following the final storm increment applied to the test plot.

BMP Installation

All tubular BMPs (excelsior fiber logs and straw wattles) were cut to a length of 3.0 m (10.0 ft) before installation. A length of 3.0 m allowed for the entire width of the test plot to be covered along with 0.3 m (1.0 ft) of each end of the BMP to be curled up slope. In addition, the down slope side of all tubular BMPs was installed 45.7 cm (18.0 in) from the end of the test slope. Both diameters of straw wattles were installed in a 5.1 cm (2.0 in) trench with wooden stakes driven through the center of the products every 1.2 m (4.0 ft) across the length of the wattle. Figure 1 shows an installed 22.9 cm straw wattle and the complete test plot set up. Both diameters of excelsior fiber logs were installed directly on the soil surface with wooden stakes driven through the netting only on the down slope side of the BMP every 0.6 m (2.0 ft) across the length of the log.

Figure 1. Erosion plot set up used during this study.

All buffer strip BMPs (excelsior fiber and straw fiber) were cut to a length of 2.4 m (8.0 ft) before installation. A length of 2.4 m allowed the BMP to cover the entire width of the test plot. Eleven gauge steel wire staples that were 15.2 cm x 2.5 cm x 15.2 cm (6 in x 1 in x 6 in) were utilized to anchor the buffer strips. A staple density of 1.9 staples/m^2 (2.3 staples/yd^2) was used for the 1.2 m wide excelsior buffer strip and a staple density of 1.3 staples/m^2 (1.6 staples/yd^2) was used for the 2.4 m wide excelsior and straw buffer strips.

Simulated Rainfall Testing

Each BMP was exposed to the same target rainfall series, which was replicated three times for each BMP. A target 5.1 cm/hr (2.0 in/hr) event was first applied to a plot. All soil and water that exited the test plot was collected and measured following the 20 minute long event. Next, a target 10.2 cm/hr (4.0 in/hr) event lasting 30 minutes was applied to the plot as soon as all data from the first segment were collected. Finally, a target 15.2 cm/hr (6.0 in/hr) event lasting 30 minutes was applied to the plot as soon as all data from the target 10.2 cm/hr segment were collected. The rather severe storm contain increasing increments was chosen so the failure point of the BMPs could be determined.

Grab samples were taken during all test segments at the toe of the slope when runoff commenced and every three minutes thereafter until runoff ceased. All soil and water that exited the test plot was measured and a sample of the soil slurry was taken to later determine the equivalent dry weight of the soil runoff.

Laboratory Analyses

Grab samples that were obtained during testing were analyzed for sediment concentration, which measures the ratio of the mass of dry sediment in a water-sediment mixture to the mass of the mixture.

Runoff samples were used to determine the moisture content of the soil lost from the plots. The Microwave Method, ASTM #4643, was followed (ASTM, 2000). After the moisture content of the sample was known, the ratio of dry to wet soil was used to calculate the equivalent amount of dry soil that was collected during the test.

Data Analyses

Data were analyzed to determine the BMPs' ability to reduce rainfall erosion and improve water quality as compared to bare soil controls. The Revised Universal Soil Loss Equation (RUSLE) (Equation 1) structure was followed to develop numeric performance values for the products following the framework outlined by Clopper et al. (2001), which allows different rainfall intensities and durations to be evaluated.

Equation 1. RUSLE

$$A=R*K*LS*C*P$$

where

A = soil loss

R = rainfall-runoff erosivity factor

K = soil erodibility factor

LS = slope length and steepness factor

C = cover management factor

P = support factor

All soil was collected during testing, thus the product of the equation (A) was known. RUSLE R factors were calculated for each simulated rainfall event as described by Clopper et al. (2001). The K factor was back-calculated from bare soil testing (Clopper et. al, 2001). The LS factor for the plot dimensions were calculated following equations detailed in Agriculture Handbook 703 (1997). By definition, a C factor equals 1 for bare soil conditions (Renard et al., 1997). The remaining factor from the equation was the P factor, which is the support practice factor. Cumulative runoff was plotted vs. cumulative rainfall for each BMP tested and Least Square linear regression was applied to the data sets. Using the framework of Equation 1, P can be calculated by plugging in the slope of the regression line and the other known variables. Figure 2 illustrates the regression plot used for the 2.4 m excelsior buffer strip.

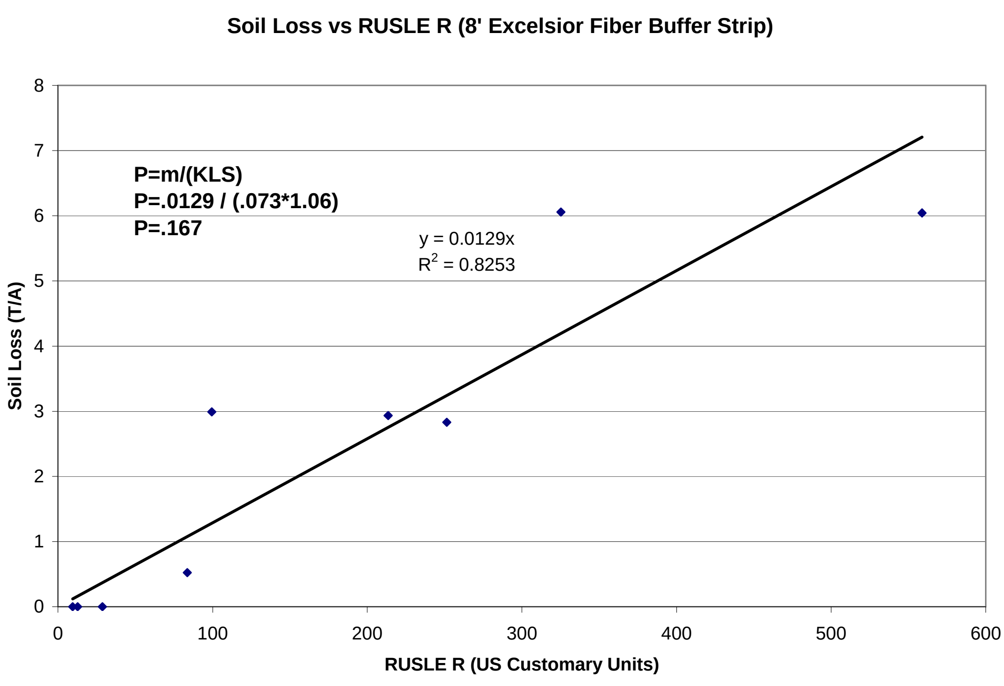

Figure 2. Soil loss vs. RUSLE R regression for 2.4 m excelsior fiber buffer strip.

According to Agriculture Handbook 703, the P factor in RUSLE is “the ratio of soil loss with a specific support practice to the corresponding loss with up slope and down slope tillage. These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff." Thus, a product having a P factor of 0.5 would reduce soil losses by 50% as compared to bare soil conditions with all other RUSLE factors being equal.

It should be noted that RUSLE P factors are time varying over the course of a year and P factors developed within this study produce event-based values. This important fact needs to be considered when reviewing the results. P values listed for the BMPs tested are soil loss ratios that were calculated over varying rainfall intensities and durations using the RUSLE framework.

The ability of the products to improve water quality was also quantified through sediment concentration analyses. Grab sample bottles were placed into a forced-draft drying oven until all water was removed from the sample. Sediment concentrations were then calculated based on the total sediment within the sample bottle. Sample bottle sediment concentration results were utilized to determine peak sediment concentrations for each BMP. Total dry soil and total water collected for each test were utilized to calculate average sediment concentrations for each BMP.

RESULTS

Table 1 contains the results of the P factors (soil loss ratios) that were calculated from the regression graphs for each BMP. In addition, the percent soil retained is presented in Table 1. Percent soil retained is simply one minus the soil loss ratio multiplied by 100.

Table 1. P factor values for BMPs tested in study.

BMP	P factor	% Soil Retained
*6" Excelsior Fiber Log	0.448	55.2
*12" Excelsior Fiber Log	0.288	71.2
*9" Straw Wattle	0.657	34.3
*12" Straw Wattle	0.805	19.5
**4' Excelsior Fiber Buffer Strip	0.361	63.9
**8' Excelsior Fiber Buffer Strip	0.167	83.3
**8' Straw Buffer Strip	0.461	53.9

*Values based on data through cumulative 10.2 cm/hr (4 in/hr) target events
**Values based on data through cumulative 15.2 cm/hr (6 in/hr) target events

Figure 3 displays the percent reduction of sediment concentration during target 10.2 cm/hr events as compared to bare soil controls and Figure 4 displays the same data for target 15.2 cm/hr events. Zero represents bare soil control values. Bars above zero represent a reduction in sediment concentration and bars below zero represent sediment concentrations that exceeded the bare soil controls.

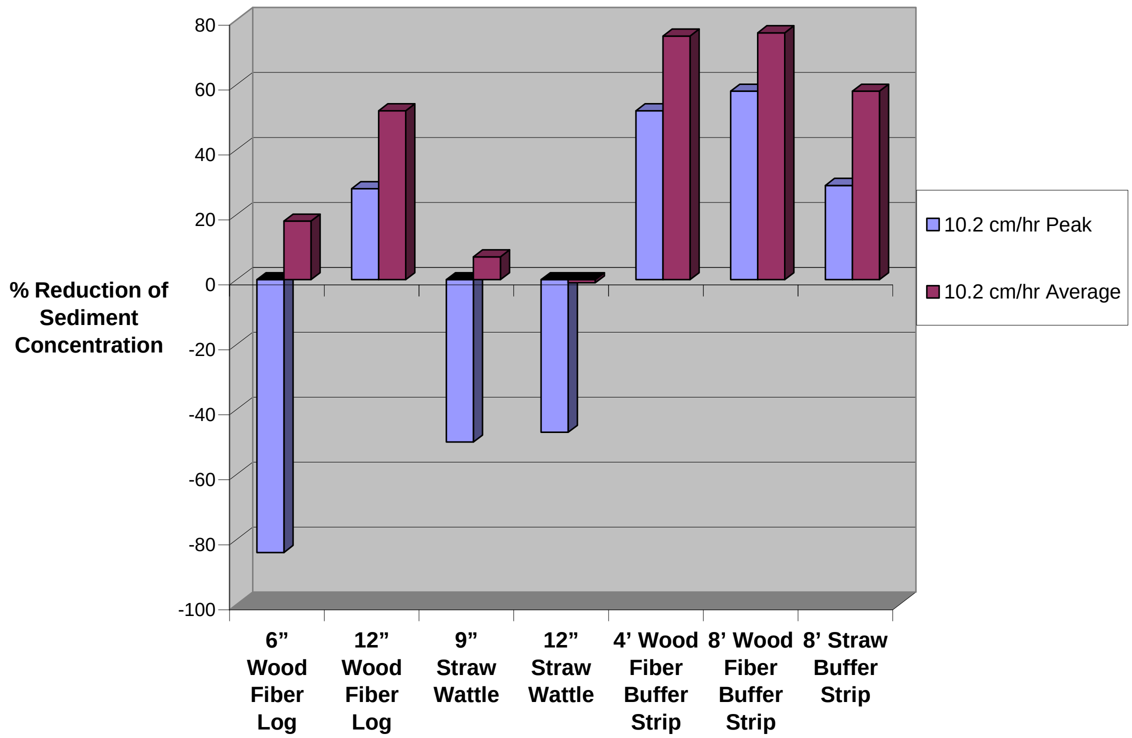

Figure 3. Percent reduction of sediment concentration during target 10.2 cm/hr events as compared to bare soil controls.

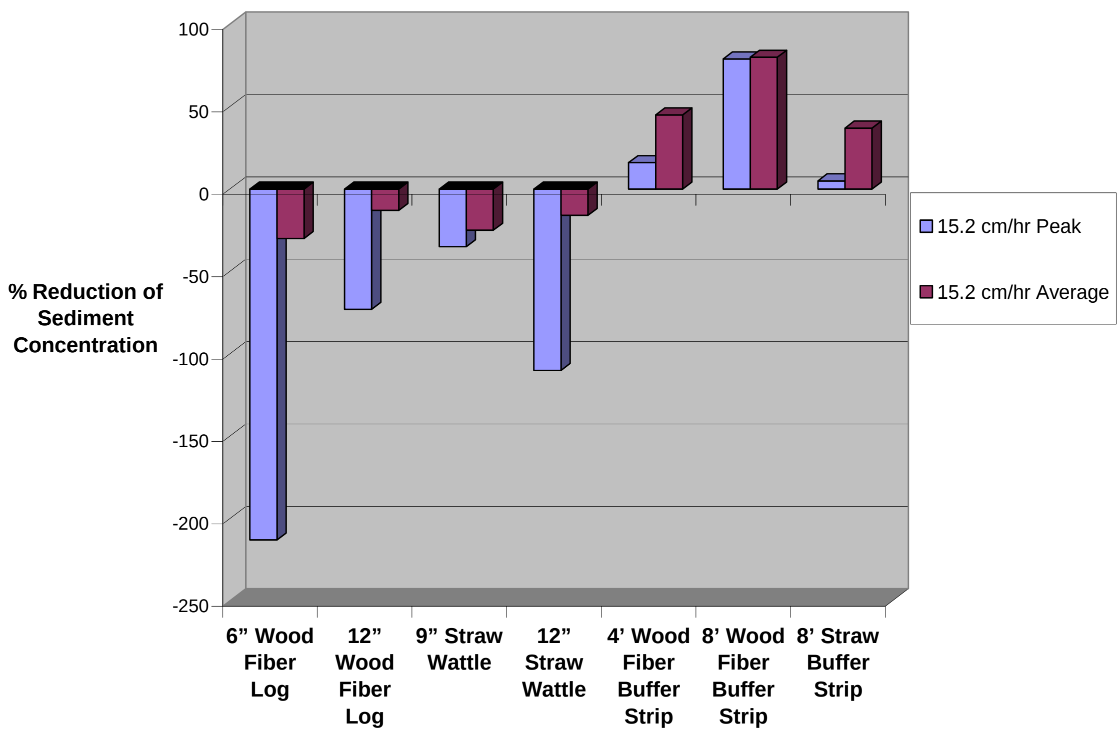

Figure 4. Percent reduction of sediment concentration during target 15.2 cm/hr events as compared to bare soil controls.

DISCUSSION

All BMPs evaluated reduced the amount of soil loss as compared to bare soil controls. The tubular BMPs were only evaluated through the target 10.2 cm/hr event because the products could not handle the third segment of the test. All tubular products caused soil deposition in front of them through the target 10.2 cm/hr event, but the deposition was commonly eroded and carried off the plot during the 15.2 cm/hr event (see Figures 5 & 6). In a field setting, routine maintenance measures would not allow the storage capacity of the logs to be exceeded as was seen during this study. Soil loss amounts for tubular BMPs exceeded those of bare soil controls during the 15.2 cm/hr segment in some cases. Rill networks developed on the test plots during all bare soil and BMP tests. During bare soil tests, the rill network that formed during the 10.2 cm/hr segment increased during the final test segment, but the rills offered a direct path for water to exit the slope. On the other hand, during tubular BMP tests, the rill networks that started to develop during the 10.2 cm/hr segment commonly became plugged with deposition toward the toe of the slope. The deposition that accumulated during the 10.2 cm/hr segment did not allow for a direct exit path for runoff during the 15.2 cm/hr. Runoff was channelized through the rills to the deposition during the final test segment and the erosive forces of the water exceeded the stability of deposition in front of the BMP. The reduction of soil loss by the four tubular BMPs examined decreased drastically during the 15.2 cm/hr segment, which meets or exceeds the 100-year, 20-minute event for many cities in the United States (Chow, 1964).

Figure 5. Deposition from 10.2 cm/hr starting to erode during 15.2 cm/hr segment (15.2 cm excelsior fiber log test).

Figure 6. Nearly half the 10.2 cm/hr deposition washed off the plot by the conclusion of the 15.2 cm/hr segment.

Density of the tubular products appeared to have a direct effect on performance; however, the values were opposite between excelsior fiber and straw fiber products. The optimal density of excelsior fiber tubular BMPs was found to be more than 50% less than straw fiber tubular BMPs. This is explained quite obviously by simply evaluating the nature of the fibers. Excelsior fibers contained in the tubular BMPs in this study were curled and barbed excelsior fibers that expand and anchor to the soil when wetted. These excelsior fibers natural cling to each other so they do not need to be tightly packed into the netting sock. Straw fibers contained in the tubular BMPs in this study were straight fibers that did not expand when wetted. The straw fibers had to be packed into the netting sock tighter than the excelsior fibers because the straw fibers do not cling together. In addition, straw fibers would fall out of the netting if the increased density was not used during manufacturing.

The 22.9 cm diameter straw wattle reduced soil loss better than the 30.5 cm diameter straw wattle. More BMP-soil contact exists with the 30.5 cm straw wattle than the 22.9 cm straw wattle. The only difference between the two products other than diameter was density. The 22.9 cm straw wattles used in this study are manufactured at a target density of 72.62 kg/m^3 (4.53 lb/ft^3) and the 30.5 cm straw wattles are manufactured at 61.24 kg/m^3 (3.82 lb/ft^3). Denser 22.9 cm straw wattles maintained better BMP-soil contact than the larger, but less dense 30.5 cm straw wattles. Figure 7 shows a rill under a 30.5 cm straw wattle during the 10.2 cm/hr test segment.

Figure 7. Rill under 30.5 cm straw wattle during 10.2 cm/hr segment.

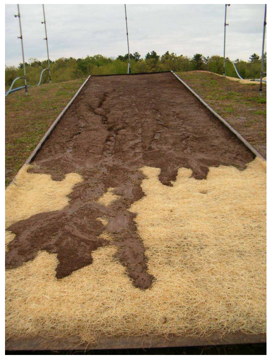

Figure 8. Soil on 2.4 m excelsior buffer strip following test series.

Figure 9. Runoff flowing over 2.4 m straw buffer strip and directly off toe of slope during 15.2 cm/hr segment.

All three buffer strips evaluated reduced soil loss better than the tubular BMPs even through the cumulative 15.2 cm/hr event. Obvious differences between the tubular BMPs and the buffer strips are the width of BMP-soil contact and height. All three buffer strips projected off the soil surface less than 1.3 cm (0.5 in). The 2.4 m wide excelsior buffer strip (see Fig. 8) performed the best by reducing soil loss by 83.3%. Interestingly, the 1.2 m wide excelsior buffer strip reduced soil loss better than the 2.4 m straw buffer strip even with half the area. Curled excelsior fibers have a greater Manning's n than straw fibers, thus straw fibers allowed less resistance to runoff as compared to the excelsior fibers (Georgia Soil..., 2005). Figure 9 shows runoff flowing straight over a 2.4 m straw buffer strip during a 15.2 cm/hr segment.

Figures 3 and 4 illustrate the sediment concentrations associated with the runoff during the BMP tests as compared to the bare soil control data set. All seven BMPs reduced the average sediment concentration during the 10.2 cm/hr segment of the test with the 2.4 m wide excelsior buffer strip providing the greatest reduction and the 30.5 cm straw wattle providing the least reduction. All three buffer strips also reduced the peak sediment concentration during the 10.2 cm/hr segment, while only one of the tubular BMPs did. Peak sediment concentrations were lowered with the 30.5 cm diameter excelsior fiber log, but increased peak sediment concentrations were measured during the 10.2 cm/hr segment with the 22.9 cm diameter straw wattle, 30.5 cm diameter straw wattle, and 15.2 cm diameter excelsior fiber log. As previously mentioned, deposition occurred in front of the tubular products and a flush of the deposition may have been captured by the grab samples causing the peak sediment concentration to exceed that of the bare soil controls even though the overall average of the sediment concentration was less than the controls.

Performance differences increased between tubular BMPs and buffer strip BMPs based on sediment concentration data during the 15.2 cm/hr test segment. All four tubular BMPs yielded increased peak and average sediment concentrations as compared to bare soil controls. Once again, the tubular products caused soil to build up in front of them early in the test series and this deposition was eroded and washed off the plot during the 15.2 cm/hr event. All three buffer strips reduced peak and average sediment concentrations as compared to bare soil controls. Deposition began at the up slope edge of the buffer strips and then progressed onto the buffer strips later into the rainfall series. The larger surface area of the buffer strips allowed deposition to accumulate on the BMPs through the 15.2 cm/hr test segment, which resulted in reduced sediment concentrations in the runoff.

CONCLUSIONS and RECOMMENDATIONS (Based on the results of this study)

- Buffer strips are more effective than tubular BMPs when installed as slope interruption/perimeter control devices. Excelsior fiber buffer strips that were 2.4 m wide were the most effective product tested by reducing soil loss by 83.3% and sediment concentrations by 80% through cumulative storms up to approximately 15.2 cm/hr, which meets or exceeds the 100-year, 20-minute event for many cities in the United States (Chow, 1964).

- Tubular BMPs installed as slope interruption/perimeter control devices are effective tools for reducing soil loss and sediment concentration through cumulative storms up to approximately 10.2 cm/hr. Excelsior fiber logs reduced soil loss better than both diameters of straw wattles.

- Additional testing is required on other products that could be used for slope interruption/perimeter control such as: siltfence, compost logs, and rock bags.

- Additional testing is required on the seven BMPs that were evaluated during this study. Excelsior fiber logs need to be tested when installed in a shallow trench, straw wattles need to be tested when installed without a trench and with stakes 0.6 m apart, turf staples should be substituted for stakes on smaller diameter tubular BMPs, and all tubular BMPs need to be tested when installed on top of a buffer strip.

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