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Silt Fences: An Economical Technique for Measuring Hillslope Soil Erosion

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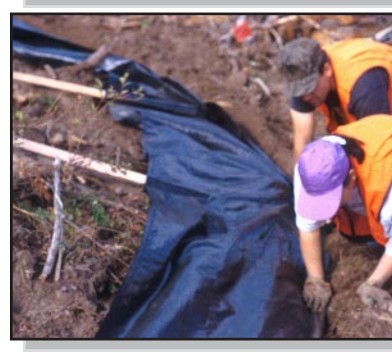

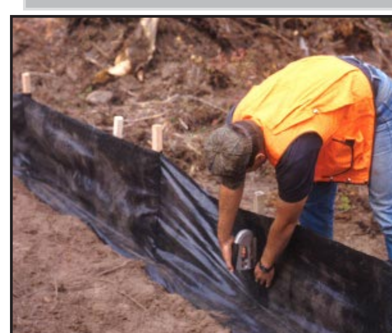

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Abstract—Measuring hillslope erosion has historically been a costly, time-consuming practice. An easy to install low-cost technique using silt fences (geotextile fabric) and tipping bucket rain gauges to measure onsite hillslope erosion was developed and tested. Equipment requirements, installation procedures, statistical design, and analysis methods for measuring hillslope erosion are discussed. The use of silt fences is versatile; various plot sizes can be used to measure hillslope erosion in different settings and to determine effectiveness of various treatments or practices. Silt fences are installed by making a sediment trap facing upslope such that runoff cannot go around the ends of the silt fence. The silt fence is folded to form a pocket for the sediment to settle on and reduce the possibility of sediment undermining the silt fence. Cleaning out and weighing the accumulated sediment in the field can be accomplished with a portable hanging or platform scale at various time intervals depending on the necessary degree of detail in the measurement of erosion (that is, after every storm, quarterly, or seasonally). Silt fences combined with a tipping bucket rain gauge provide an easy, low-cost method to quantify precipitation/hillslope erosion relationships. Trap efficiency of the silt fences are greater that 90 percent efficient, thus making them suitable to estimate hillslope erosion.

Keywords—silt fence, erosion, erosion rate, sediment, measurement techniques, monitoring

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Many individuals assisted in installation of silt fences over the years. This includes personnel from the Soil and Water Engineering Project as well as various National Forest personnel. David Turner, Statistician with the Rocky Mountain Research Station, provided statistical assistance.

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Introduction

Soil erosion is a major land management issue due to stringent regulations on water quality and efforts to reduce the impact of various activities on sedimentation. Surface erosion is the movement of individual soil particles by a force, either by uniform removal of material from the soil surface (sheet erosion) or by concentrated removal of material in the downslope direction (rill erosion) (Foster 1982). Forces required to initiate and sustain the movement of soil particles can be from many sources, such as raindrop impact, overland flow, gravity, wind, and animal activity. Erosion is a natural process; however, human or natural disturbances on the landscape generally increase surface erosion over natural levels. Erosion is reduced by all material on or above the soil surface, such as naturally occurring vegetation, surface litter, duff, rocks, and synthetic materials such as erosion mats, mulches, and other barriers that reduce the impact of the applied forces (McNabb and Swanson 1990; Megahan and others 1986).

Erosion modeling techniques have been developed to predict erosion following common disturbances. Some of these models are not receiving widespread use probably because they were not developed or validated for a particular condition or treatment of interest. Therefore, many government agencies, farmers, industries, and consultants need an easy method to measure hillslope erosion to validate model results as well as need local information from their particular conditions.

Soil erosion measuring techniques can be costly and time consuming. Various techniques have been used including rainfall simulation, erosion bridges, Gerlach troughs, and small watershed measurement techniques. Dissmeyer (1982) developed a protocol to measure hillslope erosion with silt fences. His techniques have been utilized and improved upon in this document. Less expensive data recording equipment (such as, continuous recording tipping bucket rain gauges) has made it easier for land managers to obtain their own erosion rate data as well as information on the type of storms that caused the erosion. This information can be used for completing environmental assessment documentation.

Silt fences have been used to control surface erosion in the construction industry for several decades. Also, silt fences have been used for instream sediment control (Trow Consulting Engineers Ltd. 1996). A silt fence is a synthetic geotextile fabric that is woven to provide structural integrity (tensile strength 80 to 100 lb, 0.3 to 0.4 kN) with small openings (0.01 to 0.03 inch, 0.3 to 0.8 mm) that pass water but not sediment. Silt fences have low permeability rates, which make them suitable to form temporary detention storage areas allowing sediment to settle and water to pass through slowly.

Hydraulic performance of silt fences has been measured by several researchers using flume studies (Britton and others 2000, 2001; Jiang and others 1996). They concluded that the maximum flow rate through silt fences is a function of the head and is generally small (0.01 to 0.46 ft^3 sec^{-1} or 0.00028 to 0.013 m^3 sec^{-1}). Flume studies have shown silt fence trap efficiencies ranging from 68 to 98 percent (Britton and others 2000, 2001; Wishowski and others 1998; Wyant 1980). A field study of silt fence trap efficiency on an existing long-term hillslope erosion plot at the Agricultural Research Service Palouse Conservation Field Station in Washington with a Palouse silt loam soil indicated trap efficiency was 93 percent the first year when measured on a storm-by-storm basis and 92 percent efficient the second year when only measured at the end of the runoff season (Robichaud and others 2001) (tables 1 and 2).

This paper describes how erosion measurements can be made with silt fences. Installation procedures, statistical design, analysis methods, and equipment requirements are discussed. Silt fences can be used to compare erosion effects of silvicultural treatments, farming practices, grazing systems, road or skid trail erosion, vegetative or mechanical rehabilitation treatments, prescribed fires, and wildfires, as well as compare rates of naturally occurring erosion.

Table 1—First-year winter runoff and sediment data from a fallow agricultural plot with a silt fence. The silt fences were cleaned after each runoff event (Robichaud and others 2001).

	Flow thru to collection tank		Sediment collected		Sediment yield		
Storm date	Runoff (mm)	Sediment conc. (mg L^{-1})	Collection tank (kg)	Silt fence (kg)	Collection tank (Mg ha^{-1})	Silt fence (Mg ha^{-1})	Silt fence trap efficiency (%)
9 Dec 96	11.4	346	0.08	0.5	0.040	0.25	87
12 Dec 96	.9	825	.02	2.6	.008	1.29	99
2 Jan 97	19.3	210	.08	NA[a]	.041		
18 Feb 97	4.5	7230	.66	6.9	.326	3.43	91
19 Feb 97	1.2	6251	.16	7.1	.077	3.52	98
10 Mar 97	2.3	0	0	1.9	.0	.95	100
17 Mar 97	3.7	5312	.39	1.1	.196	.53	73
Season	43.3	NA	1.39	20.1	.687	9.97	93

[a] No sediment was observed trapped in the silt fence due to snow cover.

Table 2—Second-year winter runoff and sediment data from a fallow agricultural plot with a silt fence. The silt fences were only cleaned at the end of the runoff season (Robichaud and others 2001).

	Flow thru to collection tank		Sediment collected		Sediment yield		
Storm date	Runoff (mm)	Sed. conc. (mg L^{-1})	Tank (kg)	Silt fence (kg)	Collection tank (Mg ha^{-1})	Silt fence (Mg ha^{-1})	Silt fence trap efficiency (%)
10 Nov 97	1.8	0	0	not collected	0		
21 Nov 97	7.6	14,225	8.7	not collected	1.1		
26 Nov 97	5.1	11,930	4.8	not collected	.6		
17 Dec 97	6.1	11,434	5.6	not collected	.7		
8 Jan 98	6.4	17,224	8.9	not collected	1.1		
15 Jan 98	12.3	3,798	3.7	not collected	.5		
20 Jan 98	15.5	13,305	16.5	not collected	2.1		
30 Jan 98	7.4	19,403	11.4	not collected	1.4		
Season	62.2	NA	59.6	664	7.5	83.1	92

Site Selection

Silt fences work best when they are located on uniform slopes with minimal obstructions. The plots are located to collect a defined contributing area by natural features (break in slope, rock outcrop, and so forth) or introduced features such as a cross-felled log, roadway, or hand-dug trench. Properly installed silt fences will withstand creeping snow during the winter months. They can be on slopes ranging from 3 to 70 percent (2 to 35°). Study sites should be accessible so they can be easily maintained. Materials can be carried by ATVs, pack animals, vehicles, or backpack. Some of the locations where we have used silt fences receive more than 10 ft (3 m) of snow on a 60+ percent (31°) slope and have held up well for collecting sediment associated with snowmelt events.

Defining Contributing Areas to Silt Fence

Silt fences should only be used to determine natural or management-induced hillslope erosion rates. Silt fences are not designed to measure erosion rates in continuous flows such as first-order streams. The contributing area into a silt fence needs to be designed so it does not overwhelm or overtop the silt fence. The size of the contributing area varies depending on expected flow and sediment yield. It is sometimes difficult to determine the extent of the contributing area to a particular silt fence. Therefore, a boundary at the top of the plot is often needed. Typically, silt fences are between 10 and 50 ft (3 and 15 m) across the hillslope, and plot lengths upslope are 16 to 200 ft (5 to 61 m). Contributing areas vary from 160 to 10,000 ft^2 (15 to 930 m^2). Carpenter (1999) suggests contributing areas should not exceed 21,000 ft^2 (1950 m^2) for any application (such as construction sites) of silt fences. If the contributing area is large, a second silt fence located below the first silt fence may be used to trap any sediment that overflows the first silt fence. Typical plot layouts are provided in figure1. Appendix A provides calculated storage volume for various slopes, slope lengths, and silt fence width combinations. This can be helpful in determining silt fence size. Defining the contributing area allows for converting the amount of collected sediment to sediment volume-per-unit area (ft^3 ac^{-1} or m^3 ha^{-1}) or weight-per-unit area (t ac^{-1} or t ha^{-1}). When possible, use naturally occurring slope breaks or swales that define the area contributing to the silt fence installation. These can include insloped roads, rock outcrops, and ridgelines. In some cases, slightly convex heeled-in logs placed above the monitored area have been sufficient (fig. 1). There may be additional flow into the silt fence through, for example, snow bridging that is almost impossible to measure or prevent.

Some researchers measure hillslope erosion without a defined area. They measure the amount of erosion that would pass a particular location on the hillslope—that is, volume of sediment per unit width

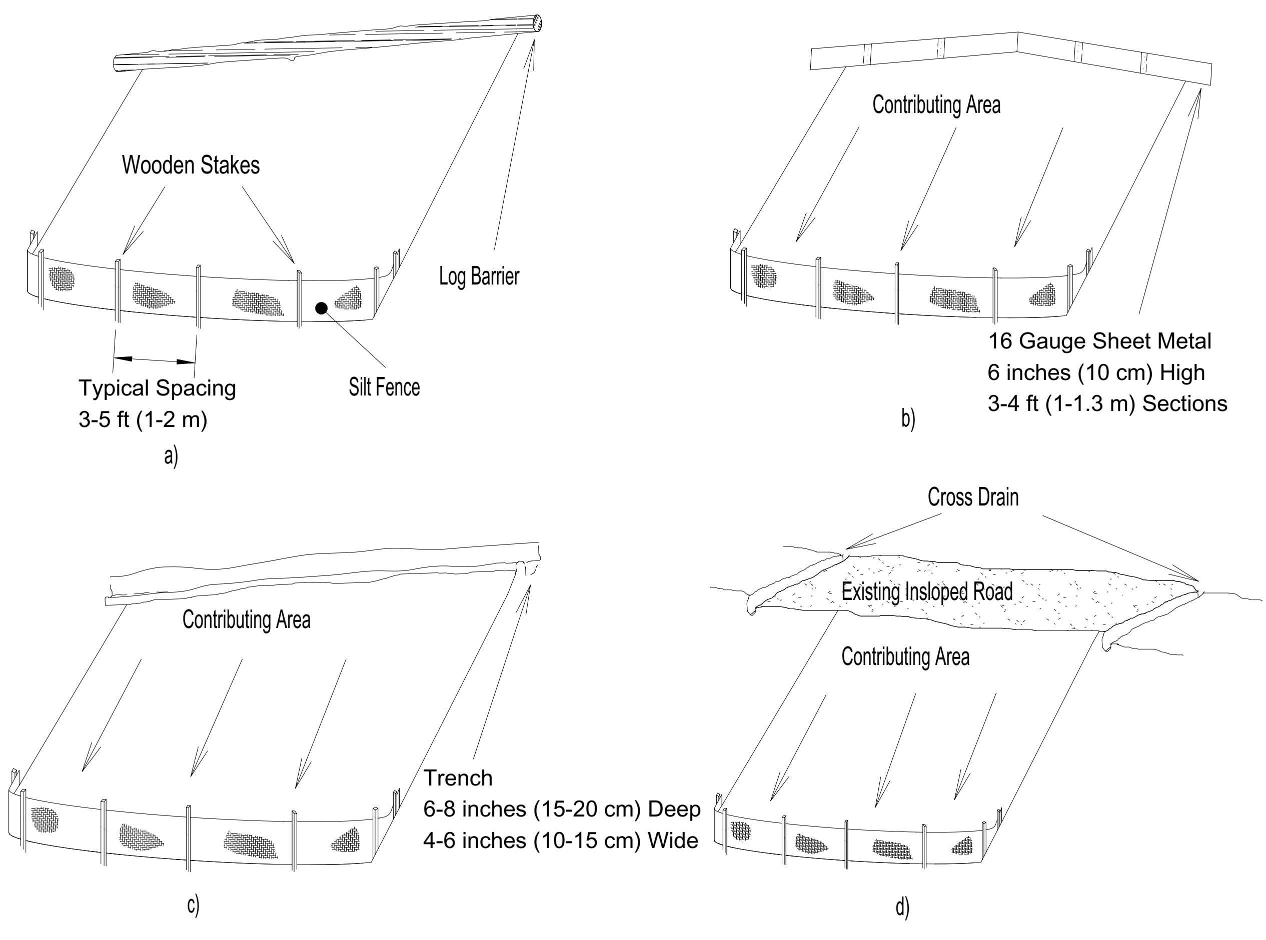

Figure 1—Typical plot layout showing contribution areas and silt fences. Various techniques to define the upper boundary of the contributing areas are shown: (a) log barrier, (b) sheet metal, (c) hand trench, and (d) existing inslope road.

($ft^3\ ft^{-1}$ or $m^3\ m^{-1}$) or weight per unit width ($t\ ft^{-1}$ or $t\ m^{-1}$). These measurements are used when reporting a sediment flux on a hillslope.

Silt Fence Plot Installation

Specifications for suitable silt fences are provided in appendix B. Silt fence fabric can be purchased at building supply stores, regional distributors, and Web-based suppliers (see appendix C).

The silt fences are installed at the base of the plots (fig. 1). Materials and tools needed for installations are provide in appendix D. A trench 6 by 10 inches (0.15 by 0.25 m) deep is dug along the contour with the ends of the trough gently curving uphill to prevent runoff from circumventing the silt fence (fig. 2). The trench can be dug with hand tools such as a Pulaski or a narrow blade shovel. The excavated material is placed on the downhill side of the trench for later use in backfilling. The silt fence is laid out along the trench covering the bottom and uphill side of the trench (fig. 2). The excavated soil is now used to backfill the trench. Tamping the soil along the entire length of the silt fence is necessary to compact the soil against the silt fence, thus preventing the silt fence from being pulled out by the flowing water. Fold the silt fence downslope 6 to 12 inches (0.15 to 0.3 m) over the compacted soil to form a pocket for sediment storage.

Install wooden stakes or alternatively #3 re-bars or metal fence stakes such that 18 to 30 inches (0.46 to 0.76 m) of the silt fence will be against the upright stake so it can be fastened securely. The stakes should be driven at least 12 inches (0.3 m) deep and should be spaced 3 to 5 ft (0.9 to 1.5 m) apart. If the silt fence has sewn-in loops for wooden stakes, additional stakes can be located between them. The silt fence can be attached to the stake with 0.5 inch (13 mm) staples through a protective strip of asphalt paper 2 inches (50 mm) wide by the length of the exposed stake to reduce tearing or by using roofing/siding insulation nails with plastic washers (fig. 2). Staples should be placed diagonally covering multiple horizontal fabric strands to minimize tearing. Alternatively, wire or plastic zip ties can be used. They should also straddle multiple strands.

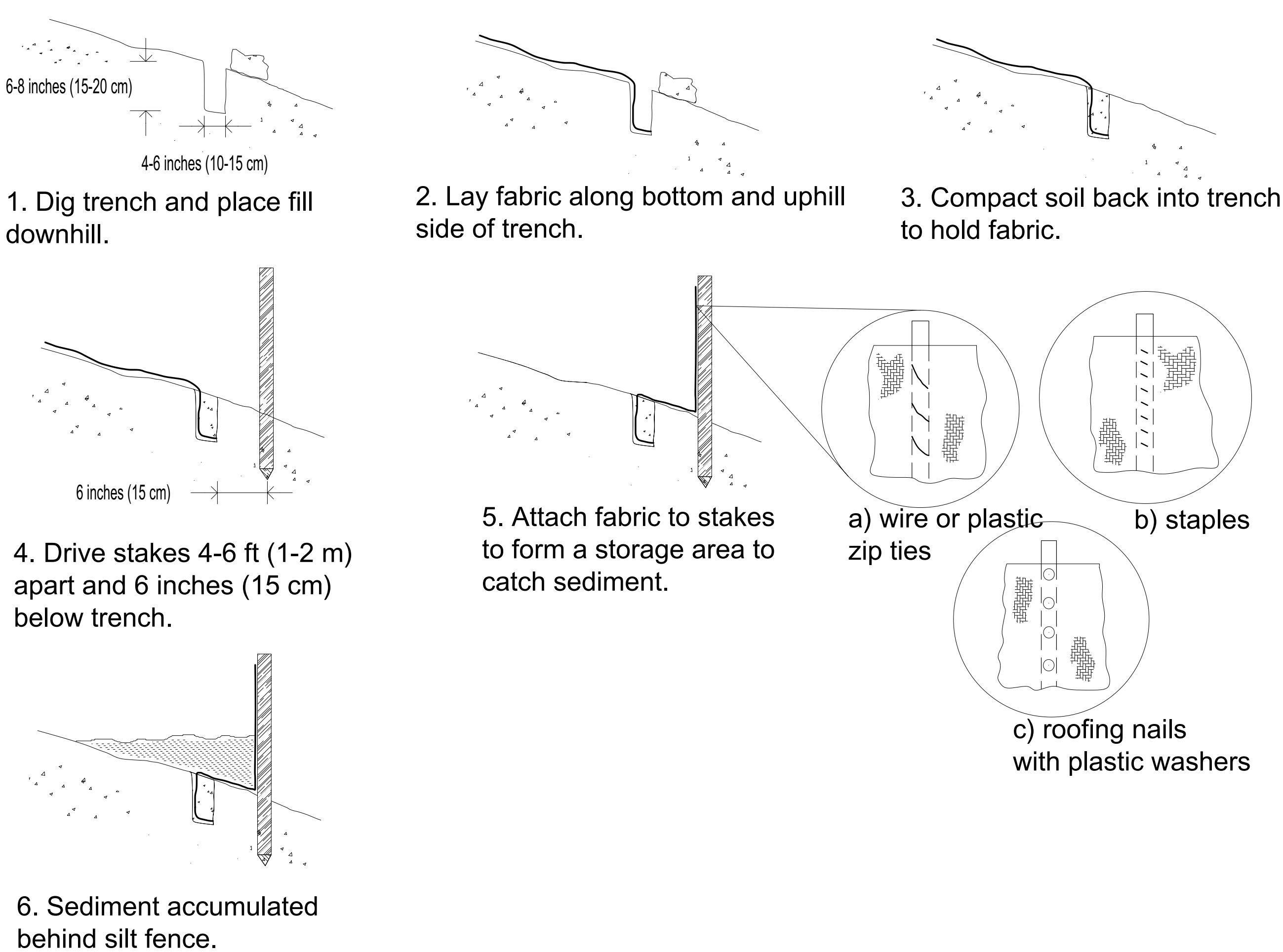

Figure 2—Step-by-step installation procedure for silt fences.

Caution should be urged when using this connection method to prevent large gaps and tears. If gaps or tears occur, attach a patch of fabric over the problem area and seal with construction adhesive or silicon. Staples or notches cut into the wooden stakes prevent the ties from slipping downward. Additional stakes can be added to reinforce and stabilize the silt fence especially in suspect locations. If high snow loads are expected, cross-braces between the vertical stakes can be used.

Remove any remaining loose soil on the uphill side of the silt fence and in the pocket that was formed and smooth out the existing soil. This will ensure that the existing soil surface is easily identifiable when cleaning the trapped sediment. Construction or plumber chalk is often used on the compact soil above the silt fence to aid in defining the boundary between the native ground surface and the deposited sediment. Red chalk sprinkled over the potential deposit area so that the ground surface appears red has shown the best results for most soil types.

Cleanout, Maintenance, and Schedule

Periodic cleanout of the silt fences is required to obtain reliable measurements of erosion. Depending on the need for accuracy, one can clean out silt fences after each storm, monthly, or twice a year. Cleaning the silt fences following every storm improves the prediction accuracy of the storms that produce erosion.

Noticeable degradation of the fabric from sunlight in harsh environments can occur after 2 or 3 years. These erosion measuring structures are temporary and can only be expected to perform properly for a maximum of 3 to 5 years depending on weather conditions.

After numerous trials of different sediment measurement techniques, including accumulation survey methods and sediment bulk density measurements, we have concluded that the direct measurement of the total weight of the sediment is the most accurate (see appendix D for materials and tools needed for cleanout). The sediment is weighed and recorded in the field using a plastic bucket (5 gal, 19 l). A sample data collection sheet is in appendix E. A hoe or hand trowel is used to scrape the deposited sediment into the container, discarding large sticks, cones, and other organic debris. Care must be used when cleaning the silt fence pocket to not tear or puncture the fabric. Also, careful scraping is needed to prevent removing native soil. Dig down to the colored soil, if chalk was used at installation or during last cleanout. Place the sediment into the container and weigh in the field with a hanging or platform parcel scale (scale with 0.5 or 1 lb, 0.2 to 0.4 kg) increments with a maximum capacity of 80 to 100 lb (36 to 45 kg). Weigh each bucket and place a subsample (0.1 lb, 50 g) into a soil tin or recloseable plastic bag for water content determination in the office or laboratory. The remaining material can be discarded downhill of the silt fence study area. Use a hand brush or broom to clean all sediment from the silt fence pocket.

The water content of the sediment needs to be subtracted from the field-collected sediment weight to obtain the corrected dry weight. Back at the office or laboratory, preferably on the same day, record wet weights of the subsample using a scale with an accuracy of tenths of grams or one-hundredths of ounces (laboratory scale or a postal scale). The subsamples can then be dried in an oven at 221 °F (105 °C) for 24 hours. Weigh the dry subsample and calculate gravimetric water content as shown in appendix F. If additional nutrient, organic matter, or particle size information on the sediment is desired, take additional subsamples for later processing.

Additional Data Collection

Precipitation Measurements

Precipitation collection methods can vary from expensive to low cost. Only low-cost methods will be discussed in this paper. A tipping bucket rain gauge provides information on the rainfall intensity and amount (fig. 3). A storage-type rain gauge provides cumulative precipitation only. For snow zone application, an antifreeze-filled siphon attachment can be added to the top of a tipping bucket rain gauge. Antifreeze can also be added to the storage-type rain gauge. The antifreeze will melt the snow and provide the snow water equivalent. Windscreens or windshields are appropriate for open areas to aid in an accurate catch of precipitation. In forested areas they are generally not needed because the horizontal wind component is subdued due to standing timber. Rain gauges are installed near the silt fence erosion plots (less than 500 ft, 160 m away) so they will be above estimated winter snowpack depth and not directly under tree canopy.

Tipping bucket rain gauges with a data pod (data logger) became available in 2001 for under $300 and provide excellent records of the rainfall intensity, event amount, and time of the event (fig. 3). Commercial software included with the rain gauge makes downloading and displaying this information easy. Tipping bucket rain gauges are usually installed on a stump, metal pole (1 inch, 2.5 cm diameter), wooden post (4 by

Figure 3—Three commercially available tipping bucket rain gauges (see appendix B for suppliers).

4 inches, 10 by 10 cm), or a polyvinyl chloride (PVC) pipe (4 inches, 10 cm diameter) standing on end with a metal platform on top on which to install the rain gauge. The other end is buried in the ground at least 2 ft (0.6 m).

Storage-type rain gauges are installed similarly to tipping bucket rain gauges. Alternatively, a section of 4 to 8 inches (10 to 20 cm) diameter PVC pipe, edge sharpened on one end and capped on the other, can be a low-cost storage rain gauge (fig. 4). The PVC pipe needs to be at least 2 ft (0.6 m) longer than predicted snow depth, and a PVC cap glued in place on the bottom needs to be water tight. PVC pipe can be attached vertically to a stump or a set post. Either type of storage gauge should be filled about one-third full with a 50:50 mix of nontoxic, recreational vehicle (RV) type antifreeze and a thin skin (1⁄8 inch, 3 mm) of mineral oil placed on the surface to reduce evaporation losses. Amounts of antifreeze will vary depending on predicted precipitation amounts and expected low temperatures. Depth changes from the top of the rain gauge to the surface of the fluid provide the precipitation amounts. Intervals of measurement can vary depending on the application but should be at least semiannual and perhaps as frequently as each storm event.

Tipping bucket rain gauge data can be summarized by counting the number of tips (rainfall depth) for various time intervals. Typical intervals include 5, 10, 30, and 60 minutes of maximum rainfall intensity during a given rainfall event. This information can be obtained by counting the maximum number of tips for that time interval (see example in appendix G). Most tipping bucket rain gauge software provides a time stamp with the number of tips occurring during that interval (for example, five tips in 1 minute, three tips for the next 1-minute interval, seven tips for the next 1-minute interval, two tips for the next 1-minute interval, and three for the next 1-minute interval for a total of 20 tips in

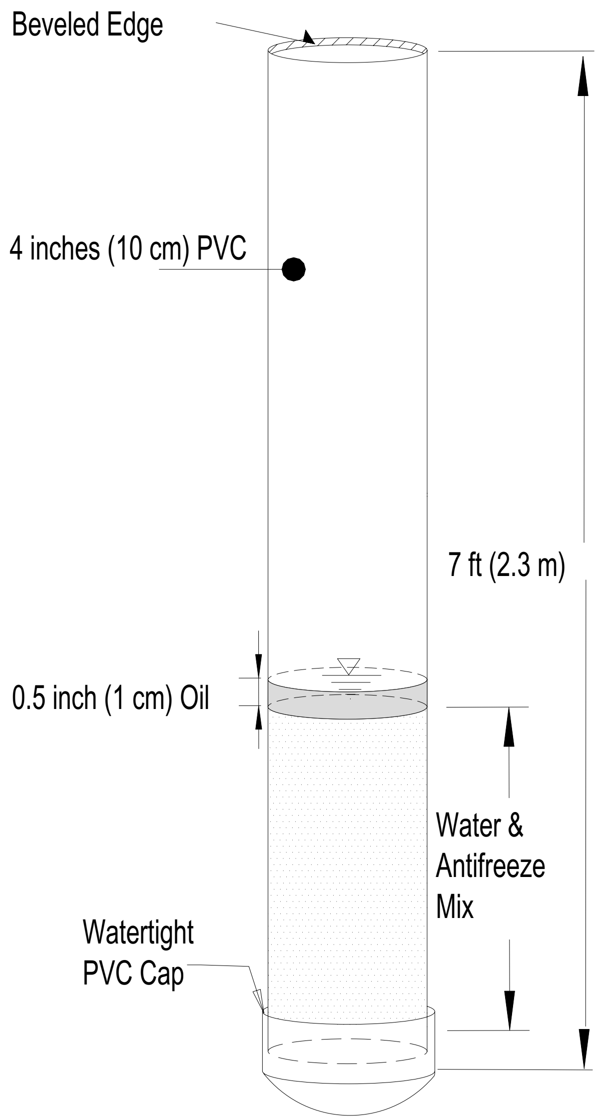

Figure 4—A hand-built storage-type rain gauge.

5-minute interval). The maximum intensity is calculated by adding the number of tips for the desired interval converting the tips to depth of rainfall (inches or mm).

Ground Cover Measurements

Exposed bare soil on the hillslope is the most important soil factor affecting erosion rates. It is important to measure bare soil exposed or conversely ground cover, especially if the study is addressing vegetation recovery or seeding effectiveness. Bare soil exposed and ground cover can be measured with various techniques. Chambers and Brown (1983) described these techniques in detail. Ocular measurements are estimated directly or divided into percentage classes (0 to 15, 15 to 30, 30 to 50, 50 to 70, 70 to 90, greater than 90 percent) of the area of interest, such as $1/100^{th}$ acre (0.004 ha) subplots.

Gridded metal or wooden frames are used for the point-quadrant method. They usually have intersecting lines (string or twine) at 4 to 6 inches (10 to 15 cm) intervals for a 10 ft^2 (1 m^2) area (thus, for a 4 by 4 inch grid in a 3 by 3 ft frame, there are 64 intersecting lines excluding the frame). The frame is randomly located (three to seven times) within the contributing area of interest. The corners of the frame can be marked with wood stakes or re-bar so the frame can be placed in the same location during subsequent measurements. Alternatively, the line-intercept method can be used. However, this technique is generally used for larger areas. Typical ground cover classes include bare soil, litter, duff, gravel, rock, live vegetation, stumps, and logs.

Data Analysis and Interpretation: Statistical Design

Achieving a sound statistical design for silt fence erosion plots is difficult due to high variability. Nearing and others (1999) concluded that variability in erosion plot data increases as the magnitude of the soil loss increases. Thus, a few large events make comparison between treatments difficult.

The number of replications needed to detect significant differences in treatment effects depends on several factors, including the inherent variability of the site; natural variability (that is, microtopography, microscale burn severity differences, root holes, soil texture, rock content, and so forth); the allowable type I error (usually $\alpha = 0.05$ or $\alpha = 0.10$); the probability of accepting a false hypothesis, known as power of the test and denoted by $1 - \beta$; the magnitude of differences to be detected; and the distribution of the data (normal distribution). Most common analyses begin by assuming normally distributed data. For silt fence erosion data, this is generally not a reasonable assumption for two reasons: first the data are often highly skewed to the right (a few large events); secondly, there may be many zeroes (rain events that did not produce any sediment). Such departures from normality suggest log transformation of the data before analysis. Alternatively, nonparametric procedures, for nonnormal data distributions, may be more appropriate for testing the equality of medians (middle value of the data), rather than the more usual t-test or analysis of variance for means, (see appendix H).

If there are few zeros, departures from normality may be helped by log transformation of the data before analysis. A better choice may be nonparametric procedures, more appropriate for testing the equality of median (middle value of the data), rather than more familiar t-test or analysis of variance of means. An easily implemented nonparametric analysis for silt fence erosion data is the Kruskal-Wallis rank sum test (equivalent to a one-way analysis of variance on the ranks of the original data) (Ott 1988; Walpole and Myers 1985). This tests the equality of medians for several treatments.

Most erosion scientists use five to seven replications for erosion plot studies. Nearing and others (1999) suggest comparing only treatments that will have large differences in soil loss because small differences would require too many replications to be practical. They suggest five replications per treatment as a minimum. If comparing two treatments, then nine replications per treatment would be needed. The number of replications is based on the expected magnitudes of the mean differences between treatments as well as the underlying variability (measured by the variance) for the particular sites, soils, and treatments under consideration.

We have developed suggestions for various scenarios that may be of interest assuming similar landscape, soils, elevation, slope, and topography. Generally, silt fences will be monitored for 2 to 3 years, thus changes in erosion rates over time can also be detected.

Scenario 1—Timber Harvesting Effects: To determine erosion amounts for various activities within a timber sales unit, identify the various activities (treatments) that occur within the sale boundary. These could include log-landing areas, haul road, repeatedly used skid trail, few pass skid trail, and control (undisturbed) areas. One would need to reduce the number of treatments to two and a control to be able to make a reasonable statistical design. For example, nine silt fences on the haul road; nine silt fences on the repeatedly used skid trail, and the remaining nine silt fences for the control. The total of 27 silt fences would be monitored for 3 years.

Scenario 2—Testing Seeding Mixes Post Wildfire: To determine erosion rates for two seeding mixes (seed mix A and seed mix B) and a control (no seeding) after a wildfire. In this scenario, ground cover would also need to be measured (described in the "Additional Data Collection" section). Thus, nine replications of each treatment would be needed. The total of 27 silt fences would be monitored for 3 years.

Scenario 3—Comparing Prescribed Fire or Wildfire Erosion Rates: To determine erosion amounts from a prescribe fire or wildfire and a control (no fire). Thus, five replications of each treatment would be needed. This total of 10 silt fences would be monitored for 2 years.

Silt fence data can be organized and analyzed using a computer spreadsheet (appendix F). Calculate the sediment amounts for each collection period and convert to weight per area. Determine rainfall amounts and rainfall intensity for that collection period. Compare sediment yields with rainfall amounts and/or intensity, remembering that rainfall can vary over short distances. Variability in the data is to be expected; there are inherent variations in soils, below ground organic matter, and so forth, that can influence sediment output. That variability, combined with the effects of the treatment, can make interpreting the results challenging. If a statistically designed layout was used then it will be easier to develop and run a statistically valid analysis. Each collection period may be a "repeated measure" for the same silt fence during the study period.

Summary

Silt fences are an economical method to obtain hillslope erosion measurements. They can be installed with a small field crew and maintained at various time intervals, depending on the storm production accuracy of the information that is desired. When installed and maintained properly, they can trap and store sediment until it is cleaned out and measured. Erosion measurements from silt fences can be used to validate model estimates, demonstrate treatment or management practice effects, and compare seeding treatments on hillslope erosion.

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Appendix A—Volume of Silt Fence Storage Capacity For Various Configurations of Ground Surface Slope, Silt Fence Height, and Width

Silt fence		Silt fence maximum holding capacities (ft^3) Ground surface slope (%)													
Height ft	Width ft	5	10	15	20	25	30	35	40	45	50	55	60	65	70
1.5	10	177	88	59	44	35	29	25	22	20	18	16	15	14	13
1.5	20	353	177	118	88	71	59	50	44	39	35	32	29	27	25
1.5	30	530	265	177	133	106	88	76	66	59	53	48	44	41	38
1.5	40	707	353	236	177	141	118	101	88	79	71	64	59	54	50
1.5	50	884	442	295	221	177	147	126	110	98	88	80	74	68	63
2.0	10	314	157	105	79	63	52	45	39	35	31	29	26	24	22
2.0	20	628	314	209	157	126	105	90	79	70	63	57	52	48	45
2.0	30	942	471	314	236	188	157	135	118	105	94	86	79	72	67
2.0	40	1,257	628	419	314	251	209	180	157	140	126	114	105	97	90
2.0	50	1,571	785	524	393	314	262	224	196	175	157	143	131	121	112
2.5	10	491	245	164	123	98	82	70	61	55	49	45	41	38	35
2.5	20	982	491	327	245	196	164	140	123	109	98	89	82	76	70
2.5	30	1,473	736	491	368	295	245	210	184	164	147	134	123	113	105
2.5	40	1,963	982	654	491	393	327	280	245	218	196	178	164	151	140
2.5	50	2,454	1,227	818	614	491	409	351	307	273	245	223	205	189	175

Silt fence		Silt fence maximum holding capacities (m^3) Ground surface slope (%)													
Height (m)	Width (m)	5	10	15	20	25	30	35	40	45	50	55	60	65	70
0.45	3	5	2	2	1	1	1	1	1	1	0.5	0.5	0.5	0.5	0.5
.45	6	10	5	3	2	2	2	1	1	1	1	1	1	1	1
.45	9	14	7	5	4	3	2	2	2	2	1	1	1	1	1
.45	12	19	10	6	5	4	3	3	2	2	2	2	2	1	1
.45	15	24	12	8	6	5	4	3	3	3	2	2	2	2	2
.60	3	8	4	3	2	2	1	1	1	1	1	1	1	1	1
.60	6	17	8	6	4	3	3	2	2	2	2	2	1	1	1
.60	9	25	13	8	6	5	4	4	3	3	3	2	2	2	2
.60	12	34	17	11	8	7	6	5	4	4	3	3	3	3	2
.60	15	42	21	14	11	8	7	6	5	5	4	4	4	3	3
.75	3	13	7	4	3	3	2	2	2	1	1	1	1	1	1
.75	6	27	13	9	7	5	4	4	3	3	3	2	2	2	2
.75	9	40	20	13	10	8	7	6	5	4	4	4	3	3	3
.75	12	53	27	18	13	11	9	8	7	6	5	5	4	4	4
.75	15	66	33	22	17	13	11	9	8	7	7	6	6	5	5

Appendix B—Common Silt Fence Specifications

The following terms are used for silt fence specifications related to the trap efficiency (ASTM 1995, 1996). Table B1 provides specifications for various silt fences. These silt fences should perform well for most soil conditions. Generally, lower permittivity valued silt fences will trap more sediment but water flow rates are also reduced.

Permittivity

Permittivity of geotextiles is a measurement of the amount of water per unit cross-sectional area per unit head that flows through the geotextile, without any extra force on the water (laminar flow conditions). It is an indicator of the quantity of water that can pass through a geotextile in an isolated condition. Because there are geotextiles of various thickness, evaluation in terms of the permeability can be misleading. It is more significant to evaluate the quantity of water that will flow through the material under a given head over a particular area; this is expressed as permittivity. The units of permittivity are sec^{-1}. This is derived from the formula for permittivity:

$$\text{Permittivity} = Q/(h*A*t)$$

Where Q is the quantity of water flow through silt fence fabric ($inch^3$, mm^3), h is the head of water on the silt fence (inch, mm), A is the cross-sectional area ($inch^2$, mm^2), and t is the time for flow, Q, (sec).

Water Flow Rate

The Water Flow Rate of a geotextile is a measurement of the volume of water that will pass through the material per unit time per unit area. The units are (commonly) gal min^{-1} ft^{-2} (L min^{-1} m^{-2}). Unlike permittivity, this value will be affected by thickness of the fabric and other factors such as apparent opening size (AOS).

Apparent Opening Size (AOS)

The AOS of a geotextile is a property that approximates the largest particle that will effectively pass through the fabric. It is figured by using the geotextile as a filter and sifting various (standardized) sizes of glass beads through the material. This is an important characteristic when designing silt fences because it is crucial that the AOS be small enough that it will hold back nearly all of the sediment, while at the same time not clog easily and allow water to pass through. The AOS is measured in a standard U.S. Sieve number (20 to 80) with 20 being a large opening and 80 being small. Equivalent values include:

Sieve number equivalencies

Sieve	Opening size	
no.	inch	mm
20	0.033	0.840
30	.023	.590
40	.017	.420
50	.012	.297
60	.010	.250
70	.008	.210
80	.007	.177

Table B1—Specifications related to trap efficiency of silt fences. Typical strength characteristics are also provided.

Manufacturor and Product Design	Permittivity (sec^{-1})	Water Flow Rate ($gal\ min^{-1}\ ft^{-2}$)	($L\ min^{-1}\ m^{-2}$)	AOS (US Sieve)	(mm)
Agri Drain					
Biotech 760	0.45	30	1225	20	0.850
NILEX					
2130 (Amoco Fabric)	0.05	10	405	30	0.600
910 (SI Industries)	0.20	15	610	20	0.850
915 (SI Industries)	0.40	25	1020	40	0.425
Amoco					
Style 2130	0.05	10	405	30	0.600
Exxon					
GTF 100S	NA	125	5095	50-70	.40-.20
ADS					
ADS 3302WP / 3302WT	0.01	50	2035	20	0.840
TC Mirafi					
Silt Fence (stakes attached)	0.10	10	405	30	0.600
100X	0.10	10	405	30	0.600
LINQ Indust. Fabrics					
GTF 170	0.05	20	815	20	0.850
GTF 180	0.05	7	285	20	0.850
(GTF 170 and 180 differ in strength)					
GTF 190	0.07	12	490	30	0.600
GTF 200S	0.07	12	490	50	0.300
Belton Industries (available in 3 different colors)					
751 / 894 / 897 (dimensions differ)	0.10	15	610	30	0.600
755 / 890 (dimensions differ)	NA	25	1020	30	0.600
806 / 810 (dimensions differ)	0.20	20	815	20	0.850
DGI Industries					
P - Series	0.10	10	405	30	0.600
BIG R					
(Mutual Industries Fabric) Mutual MISF180	NA	30	1225	40	0.425
Typical					
Burst Strength	160-400 Psi (100-2760 Kpa)				
Puncture Strength	25-90 lbs (0.11-0.40 kN)				
Tensile Strength	80-180 lbs (0.35-0.80 kN)				

Appendix C—List of Suppliers for Silt Fences and Rain Gauges

This list of products and businesses is provided as an information tool only and does not imply endorsement by the Forest Service or the U.S. Department of Agriculture. All listed prices were as of 2002.

Silt Fence Distributors

ACF Environmental (Amoco Fabrics)
2831 Cardwell Road
Richmond, VA 23234
Toll free: 1-800-448-3636
Web: www.acfenvironmental.com

Big R Manufacturing & Distributing (Mutual Industries Distributor)
P.O. Box 1290
Greeley, CO 80632-1290
Toll free: 1-800-234-0734
Fax: (970) 356-9621
Web: www.bigrmfg.com/construc.htm

Cobb Lumber Co. (LINQ Industrial Fabrics Distributor)
P.O. Box 808
Timpson, TX 75975
Toll free: 1-888-322-2622
Fax: (936) 254-2763
Web: www.cobblumber.com

Liberty Equipment Co. (Belton Industries Distributor)
10879 Houser Drive
Fredericksburg, VA 22408
Tel: (540) 898-8933
Fax: (540) 898-8650
Web: www.libertyequipment.com

Nilex Corp. (Amoco & SI Fabrics with custom stakes)
15171 E. Fremont Drive
Englewood, CO 80112
Tel: (303) 766-2000
Edmonton (780) 463-9535
Calgary (403) 543-5454
Vancouver (604) 420-6433
Winnipeg (204) 925-4466
Web: www.nilex.com

Silt Fence Manufacturers

Advanced Drainage Systems, Inc. [a]
3300 Riverside Drive
Columbus, OH 43221
Tel: (614) 457-3051
Fax: (614) 538-5204
Web: www.ads-pipe.com

Agri Drain Co. [a]
Toll Free: 1-800-232-4742
Fax: 1-800-282-3353
Web: www.agridrain.com

Belton Industries, Inc. [a]
8613 Roswell Rd.
Atlanta, GA 30350
Tel: (770) 587-0257
Toll Free: 1-800-225-4099
Fax: (770) 992-6361
Toll Free: 1-800-851-4029
E-mail: engineeringsales@beltonindustries.com
Web: www.beltonindustries.com

DGI Industries [a]
P.O. Box 70
Bennington, NH 03442
Tel: (603) 641-2850
Toll Free: 1-888-745-8344
Fax: (603) 669-6991 (24 hour)
Web: www.dgiindustries.com

Exxon Chemical Americas
2100 River Edge Parkway, Suite 1025
Atlanta, GA 30328-4654
Toll Free: 1-800-543-9966

LINQ Industrial Fabrics, Inc.
2550 West Fifth North Street
Somerville, SC 29483-9699
Tel: (843) 873-5800
Toll Free: 1-800-445-4675
Fax: (843) 875-8111
E-mail: linq@linqind.com
Web: www.linqind.com

Mutual Industries, Inc. [a]
707 W. Grange St.
Philadelphia, PA 19120
Tel: (215) 927-6000
Toll Free: 1-800-523-0888
Fax: (215) 927-8888
E-mail: team1@mutualindustries.com
Web: www.mutualindustries.com

SI Geosolutions
6025 Lee Highway, Suite 435
Chattanooga, TN 37421
Toll Free: 1-800-621-0444
Fax: (423) 899-7619
Web: www.fixsoil.com
Database of representatives on Web site

TC Mirafi
Lake Forest, CA
Tel: (949) 859-2850
Web: www.tcmirafi.com
Database of representatives/distributors on Web site

Note: Many of the companies listed sell silt fences with stakes preattached, sometimes at buyer's specified intervals; otherwise they are generally 4 to 10 ft (1.2 to 3 m) apart. Additional stakes can easily be added between the preattached stakes.

Local lumberyards or building suppliers may have silt fence fabric or can obtain it.

[a] *Sells factory direct*.

Rain Gauges

Onset Computer Corp.
P.O. Box 3450
Pocasset, MA 02559-3450
Tel: (508) 759-9500
Toll Free: 1-800-564-4377
Fax: (508) 759-9100
E-mail: sales@onsetcomp.com
Web: www.onsetcomp.com (Online ordering available)

Data Logging Rain Gauge Model RG2 (English version) and RG2-M (metric version) are fully self-contained, battery-powered rainfall data collection and recording systems. They include a HOBO Event data logger integrated into a tipping-bucket rain gauge. The RG2 automatically records up to 80 inches (160 cm for the RG2-M) of rainfall data that can be used to determine rainfall rates, times, and duration. A time and date stamp is stored for each 0.01 inches (0.2 mm for the RG2-M) tip event for detailed analysis. Price: $380 (2002). HOBO Event Logger Price: $85 (2002) (can be attached to RainWise Rain Gauge, as well as Davis Instruments Rain Collector).

Required Software: Boxcar Pro or Boxcar 3.0+ starter kits include software, PC interface cable and manual. Price: Boxcar Pro 4.0 Windows Starter Kit $95 (2002), Boxcar 3.7 Windows Starter Kit $14 (2002). Boxcar Pro for MAC OS free on Web site, Mac Interface Cable $9 (2002).

RainWise Inc.
25 Federal Street
Bar Harbor, ME 04609
Tel: (207) 288-5169
Toll Free: 1-800-762-5723
Fax: (207) 288-3477
E-mail: sales@rainwise.com
Web: www.rainwise.com (Online ordering available)

RainWise provides a large selection of rain gauges and data loggers that can be purchased as a single unit or bought separately then assembled. They are capable of recording 0.01 inch of rainfall as well as putting a time and date stamp at specified intervals during an event. Total System (rain gauge and built-in logger): Rain Logger Price: $295 (2002), Tipping Bucket Rain Gauge (wired) Price: $69.95 (2002), Data Logger Price: $120 (2002).

A PC interface cable and necessary software is included with the Rain Logger and the information can easily be exported into a spreadsheet for graphing and other data analysis. Also, software is available for download from the RainWise Web site.

Spectrum
23839 W. Andrew Rd.
Plainfield, IL 60544
Tel: (815) 436-4440
Toll Free: 1-800-248-8873
Fax: (815) 436-4460
E-mail: info@specmeters.com
Web: www.specmeters.com (Online ordering available)

Spectrum's Data Logging Rain Gauge provides high accuracy with a low-maintenance tipping bucket design. The logger records accumulated rainfall during each interval, maximum of 2.55 inches per interval. User selected intervals are 1, 5, 10, 15, 30, 60, and 120 minutes. Logger capacity is 7,000 intervals.

Use with SpecWare 6 Software for analysis and reporting. WatchDog rain collectors and SpecWare Software can be programmed to record rainfall in either English (inches) or metric (mm) units. The rain gauge and data logger may also be purchased separately and assembled.

Total System (gauge and built-in logger): Data Logging Rain Gauge Price: $199 (2002), Digital Tipping Bucket Rain Gauge Price: $74.95 (2002), WatchDog-115 Rain Logger Price: $85 (2002).

Required Software: Specware 6.0 Software (includes PC interface cable) Price: $99.

Davis Instruments
4701 Mount Hope Drive
Baltimore, MD 21215
Tel: (410) 358-3900
Toll Free: 1-800-988-4895
Fax: (410) 358-0252
Toll Free Fax: 1-800-433-9971
E-mail: sales@davisontheweb.com
Web: www.davis.com

The Rain Collector II measures rainfall in 0.01 inch increments in the English version and 0.2 mm in the metric version. Can be outfitted with data logger (see Onset Inc. for HOBO even logger). Davis Rain Collector II-English or Metric Rain Collector II Price: $75 (2002).

Ben Meadows Company (Distributor)
Subsidiary of Lab Safety Supply Inc.
P.O. Box 5277
Janesville, WI 53547-5277
Tel: (608) 743-8001
Toll Free: 1-800-241-6401
Toll Free Fax: 1-800-628-2068
E-mail: mail@benmeadows.com
Web: www.benmeadows.com (Online ordering available)

Ben Meadows is a distributor of different rain gauges and weather monitoring equipment. The Onset Data Logging Rain Gauge, the Rainwise Tipping Bucket Rain Gauge, the Davis Rain Collector, and the Onset HOBO Event Logger are available.

Appendix D—Equipment List

Silt Fence Installation Tools

- Shovels (square and round nosed type)
- Pulaski
- Hand trowels
- Claw hammer
- Sledgehammer
- Heavy-duty stapler
- Flagging
- Pin flags
- Measuring tape
- Steel cap for driving wooden stakes
- Caulking gun

Silt Fence Installation Supplies

- Wooden stake (2 by 2 inches by 4 ft, 5 by 5 cm by 1.2 m)
- Silt fence fabric (100 ft by 36 inches or 42 inches, 30 m by 0.9 or 1.1 m) rolls, 42 inch width preferred
- Staples (0.5 inch, 1 cm), or roofing nails (1 inch, 2.5 cm) with plastic washers, or 16-gauge wire or plastic zip ties (10 inches, 25 cm)
- Tar paper strips or plastic strips
- Red construction chalk (1 gal, 4 l)
- Construction adhesive or silicon

Sediment Cleanout Tools

- Hanging or platform scale (fish scale: capacity 50 lb with 1-lb increment, 22 kg with 0.2-kg)
- Shovel (square nosed)
- Hand brush or broom
- Hand trowel (it is best to round-over sharp corners and points with file or grinder, so it does not catch the fabric)
- Notebook/data sheets (waterproof) and pencils
- Red construction chalk (1 gal, 4 l)
- Tripod or tree branch or metal angle tied to tree for hanging scale
- Extra silt fence fabric (for repairs)
- Plastic wire ties (100)
- Construction adhesive or silicon caulk
- 4 plastic buckets (5 gal, 19 l)

Figure D1—Steel cap for pounding wooden stakes into the ground.

Appendix E—Example of Field Data Sheet

Silt Fence Cleanout Field Datasheet

Page 1 of 1

Date 12-Jul-01 Location Whitehorse #2, seeded Recorder John, Paul, Ringo

Contributing area 1/10 acre
Raingauge depth and tipping bucket data 2 ft 3 1/16 inches from top
Data downloaded from tipping bucket

field scale

Scale used Field 1 Scale units pounds

Bucket #	Tare weight
1	0.8
2	1.1
3	1.3
4	0.9
5	1.2

1	2	3	4	5	
Bucket sample #	Bucket used #	Tare + sediment	Tare wt	Wet sed wt	Subsample taken?
				col3-col4	
		field scale units			
1	1	16.2	0.8	15.4	✓
2	2	23.6	1.1	22.5	✓
3	3	17.8	1.3	16.5	✓
4	4	35.6	0.9	34.7	✓
5	5	12.4	1.2	11.2	✓
6	1	19.0	0.8	18.2	✓
7	2	26.8	1.1	25.7	✓
8	3	32.6	1.3	31.3	✓
9	4	41.0	0.9	40.1	✓
10	5	18.9	1.2	17.7	✓
11	1	15.4	0.8	14.6	✓
12	2	45.2	1.1	44.1	✓
13	3	29.7	1.3	28.4	✓
14	4	29.6	0.9	28.7	✓
15	5	34.0	1.2	32.8	✓
16	1	16.2	0.8	15.4	✓
17	2	19.4	1.1	18.3	✓
18	3	22.0	1.3	20.7	✓
19	4	26.8	0.9	25.9	✓
20	5	33.6	1.2	32.4	✓

Remarks: Include repairs needed and made. Supplies needed for next visit.

Need to bring more antifreeze and new dessicant. Shovel handle broke, need new shovel.

Still have small amount of snow in upper watershed. Rain guage had needles and dust accumulation.

Appendix F—Example of Field and Laboratory Spreadsheet

Silt Fence Cleanout Spreadsheet

Page 1 of 1

Date 12-Jul-01 Location Whitehorse #2, seeded Recorder John, Paul, Ringo

Contributing area 1/10 acre

Raingauge depth and tipping bucket data 2 ft 3 1/16 inches from top Data downloaded from tipping bucket

field scale

Scale used Field 1 Scale units pounds

lab/office scale

Scale used postal Scale units grams

Bucket #	Tare weight
1	0.8
2	1.1
3	1.3
4	0.9
5	1.2

Useful Conversions

1 lb = 454 grams	1 meter = 3.28 feet	1 acre = 43,560 square feet
1 lb = 0.454 kilograms	1 meter = 39.36 inches	1 hectare = 10,000 square meters
1 lb = 16 oz	1 cubic meter = 35.3 cubic feet	1 kilogram per hectare = 1.12 lbs per acre
1 oz = 28.4 grams	1cubic meter = 1.3 cubic yards	
1 kilogram = 2.205 lb	1 hectare = 2.47 acres	

Field Data Work Sheet

1 Bucket sample #	2 Bucket used #	3 Tare + sediment	4 Tare wt	5 Wet sediment wt **col3-col4**
		field scale units		
1	1	16.2	0.8	15.4
2	2	23.6	1.1	22.5
3	3	17.8	1.3	16.5
4	4	35.6	0.9	34.7
5	5	12.4	1.2	11.2
6	1	19.0	0.8	18.2
7	2	26.8	1.1	25.7
8	3	32.6	1.3	31.3
9	4	41.0	0.9	40.1
10	5	18.9	1.2	17.7
11	1	15.4	0.8	14.6
12	2	45.2	1.1	44.1
13	3	29.7	1.3	28.4
14	4	29.6	0.9	28.7
15	5	34.0	1.2	32.8
16	1	16.2	0.8	15.4
17	2	19.4	1.1	18.3
18	3	22.0	1.3	20.7
19	4	26.8	0.9	25.9
20	5	33.6	1.2	32.4

Office Data Work Sheet

6 Subsample #	7 Subsample wet weight	8 Subsample dry weight	9 Water weight **col7-col8**	10 Water content **col9/col8**	11 Dry sample weight **(1-col10)*col5**
	Office scale units				field scale units
1	69.0	50.4	18.6	0.37	9.7
2	126.0	89.5	36.5	0.41	13.3
3	142.0	113.6	28.4	0.25	12.4
4	106.0	88.0	18.0	0.20	27.6
5	61.0	54.3	6.7	0.12	9.8
6	123.0	108.2	14.8	0.14	15.7
7	137.0	111.0	26.0	0.23	19.7
8	80.0	62.4	17.6	0.28	22.5
9	96.0	82.6	13.4	0.16	33.6
10	104.0	87.4	16.6	0.19	14.3
11	104.0	74.9	29.1	0.39	8.9
12	76.0	54.7	21.3	0.39	27.0
13	134.0	109.9	24.1	0.22	22.2
14	114.0	99.2	14.8	0.15	24.4
15	86.0	63.6	22.4	0.35	21.3
16	100.0	74.0	26.0	0.35	10.0
17	62.0	45.3	16.7	0.37	11.5
18	75.0	54.8	20.3	0.37	13.0
19	66.0	53.5	12.5	0.23	19.8
20	115.0	82.8	32.2	0.39	19.8
			page 1	subtotal	356.5
			page 2	subtotal	
			page 3	subtotal	
				total	356.5

Multiply unit area (above) by total cumulative weight (field scale units) per unit area of plot. Use conversions above to give units of choice. 35.65 pounds/acre

Appendix G—Example Data Taken From Onset Rain Gauge Datalogger

Rainfall data summaries by given time interval. How many tips of the raingauge occurred by time interval? These are used to calculate maximum rainfall intensities by time interval.

Original data Date Time,1/100 INCHES OF RAIN	Parsed data by space and comma date	 time	 tips	10 minute summaries	30 minute summaries	60 minute summaries
06/23/99 09:00:00.0,0,Start						
06/23/99 14:44:42.5,1	6/23/99	14:44:42	1	1	1	1
06/23/99 14:47:01.0,2	6/23/99	14:47:01	2	2	2	2
06/23/99 14:47:02.0,3	6/23/99	14:47:02	3	**3**	3	3
06/24/99 04:15:32.0,4	6/24/99	4:15:32	4	1	1	1
06/24/99 04:48:11.5,5	6/24/99	4:48:12	5	1	1	2
06/24/99 04:53:36.5,6	6/24/99	4:53:37	6	2	2	3
06/24/99 04:56:09.5,7	6/24/99	4:56:10	7	3	3	4
06/24/99 05:04:53.5,8	6/24/99	5:04:54	8	2	4	5
06/24/99 05:05:54.0,9	6/24/99	5:05:54	9	3	5	6
06/24/99 06:09:10.5,10	6/24/99	6:09:10	10	1	1	3
06/24/99 06:09:11.0,11	6/24/99	6:09:11	11	2	2	4
06/24/99 06:19:26.0,12	6/24/99	6:19:26	12	1	3	3
06/24/99 06:21:56.0,13	6/24/99	6:21:56	13	2	4	4
06/24/99 06:22:56.5,14	6/24/99	6:22:56	14	3	5	5
06/24/99 06:25:14.0,15	6/24/99	6:25:14	15	4	6	6
06/24/99 06:27:21.0,16	6/24/99	6:27:21	16	4	7	7
06/24/99 06:28:35.5,17	6/24/99	6:28:35	17	5	8	8
06/24/99 06:29:32.5,18	6/24/99	6:29:32	18	5	9	9
06/24/99 06:31:43.0,19	6/24/99	6:31:43	19	6	10	10
06/24/99 06:33:40.0,20	6/24/99	6:33:40	20	6	11	11
06/24/99 06:37:12.5,21	6/24/99	6:37:12	21	5	12	12
06/24/99 06:39:24.5,22	6/24/99	6:39:24	22	5	11	13
06/24/99 06:41:50.5,23	6/24/99	6:41:50	23	4	12	14
06/24/99 06:45:41.5,24	6/24/99	6:45:41	24	4	**13**	15
06/24/99 06:50:39.5,25	6/24/99	6:50:39	25	3	13	16
06/24/99 06:53:30.0,26	6/24/99	6:53:30	26	3	12	17
06/24/99 06:58:12.0,27	6/24/99	6:58:12	27	3	11	**18**
06/26/99 16:49:33.0,28	6/26/99	16:49:33	28	1	1	1
06/26/99 16:57:51.0,29	6/26/99	16:57:51	29	2	2	2
06/26/99 20:00:30.5,30	6/26/99	20:00:31	30	1	1	1
07/03/99 10:21:11.5,31	7/3/99	10:21:12	31	1	1	1
07/03/99 10:22:12.0,32	7/3/99	10:22:12	32	2	2	2
07/03/99 11:36:24.0,33	7/3/99	11:36:24	33	1	1	1
07/03/99 11:37:15.5,34	7/3/99	11:37:15	34	2	2	2
07/03/99 11:39:32.0,35	7/3/99	11:39:32	35	3	3	3
07/03/99 11:42:16.0,36	7/3/99	11:42:16	36	4	4	4
07/03/99 11:44:48.5,37	7/3/99	11:44:49	37	5	5	5
07/03/99 11:48:07.0,38	7/3/99	11:48:07	38	4	6	6
07/03/99 11:53:28.5,39	7/3/99	11:53:28	39	3	7	7
07/03/99 11:58:19.0,40	7/3/99	11:58:19	40	2	8	8
07/03/99 12:00:21.5,41	7/3/99	12:00:21	41	3	9	9
07/03/99 12:07:29.0,42	7/3/99	12:07:29	42	3	8	10
07/03/99 13:12:34.0,43	7/3/99	13:12:34	43	1	1	1
07/03/99 13:24:45.5,44	7/3/99	13:24:45	44	1	2	2
07/03/99 13:25:46.0,45	7/3/99	13:25:46	45	2	3	3
		maximum of column		6	13	18

Maximum intensites by duration can be calculated using each of these compiled maximum tips by interval.

10 minute maximum intensity	6 tips in 10 minutes	30 minute maximum intensity	13 tips in 30 minutes
60 minutes/hour * 6 tips / 10 minutes * 0.01 inches/tip=0.36 inches/hour		60 minutes/hour * 13 tips / 30 minutes * 0.01 inches/tip=0.26 inches/hour	

60 minute maximum intensity	18 tips in 60 minutes
60 minutes/hour * 18 tips / 60minutes * 0.01 inches/tip=0.18 inches/hour	

Appendix H—Statistical Analysis Procedure

This section describes a simple approach to analyze silt fence erosion data. Additional statistical analysis can be performed on the data, but it may be necessary to consult statistical textbooks or get statistical assistance. This example should be viewed as a first approach for data analysis. The data represent five silt fences for a Burn Only treatment, four silt fences for Burn and Seed treatment, and three silt fences for the Control (no burn) treatment. Fifteen storm events were observed with some events producing no sediment. Generally it is best to analyze data after 15 to 20 storm events or a season.

A common occurrence with erosion or sediment yield data is that the underlying distribution is not normal or gaussian. This is due to a large number of zeroes (when there was no runoff) together with a few large values, indicating the underlying distribution is skewed to the right. For highly skewed data, the usual normality assumption is violated, and, consequently, the "usual" confidence intervals, t-tests, and analysis of variance procedures may not be appropriate. Instead, less restrictive nonparametric procedures should be used.

As with any data set, one should first explore the data to determine whether there are problems that could cause difficulties in statistical analysis. This can be accomplished by looking at the data graphically to determine whether there are unreasonable values, trends in the results, or outliers that do not fit the rest of the data. The outliers may to due to failure of the silt fences or contributing areas greater than expected. Graphs can include sediment yield between treatments (line or bar graphs), sediment yields versus rainfall intensity/amounts, and sediment yields versus ground cover amounts (X-Y graphs).

The data are entered into a spreadsheet program, such as Microsoft Excel, as follows in sheet 1, Original Sediment Yield Data (fig. H1).

Column A contains the sampling date (preferably the storm date) and is labeled "Date."

Column B contains the 10-minute maximum precipitation.

Column C identifies the group or treatment a particular observation comes from.

Columns D through H contain sediment values from fences 1 through 5 for the Burn Only treatment, 1 through 4 for the Burn and Seed treatment, and 1 through 3 for the Control or untreated group. This is an unequal design.

Column I contains the average sediment collected across all fences for each storm within each treatment. These values are computed by entering the formula "=AVERAGE(D4:H4)" into cell I4. This cell is then copied (move the cursor to cell I4, then **EDIT/COPY**) to cells I5 through I60. Note that each silt fence is observed after each storm. This analysis will focus on these averages rather than the individual storm/fence observations.

A first step in the analysis is to provide descriptive measures for each group. When data are highly skewed, the median rather than the arithmetic average is usually a better representation of a typical value. Although the median (the 50^{th} percentile) is often of interest, occasionally other percentiles such as the 75^{th} or 67^{th} may be useful. If p is the proportion of interest (p = 0.50 for the 50^{th} percentile, p = 0.75 for the 75^{th}, and so forth), a confidence interval for p may be constructed as follows (see Hahn and Meeker 1991: 82):

1. Highlight the averages for data from one of the groups (for the Burn Only group this would be the averages in cells I4:I22) and press **EDIT/COPY**. Move to cell J4 and press **EDIT/PASTE SPECIAL**, select the "**Values**" button and then "**ENTER**." This copies the values, instead of the formulas, into cells J4:J22.
2. In cell K4 add the label "Median." In cell L4 entering the formula "=MEDIAN(I4:I22)" indicates the Burn Only group median is 0.1 t ha^{-1}. To find an upper confidence limit for the median perform the next two steps.
3. If cells J4:J22 are not highlighted, do so and press **DATA/SORT**, select "**Continue with the current selection**" option and then press **Sort** and then press the "**OK**" button on the Sort menu window. This sorts the average values from smallest to largest. Add the label "Sorted Average" to cell J3.
4. Place the labels "Confidence [Interval]," "n," "Percentile," "Order Statistic," "Upper Confidence Limit" in cell K5 through K9. In cell L5 enter the desired confidence level; for this example we used 0.95. In cell L6 enter the number of storm dates (or silt fence cleanout dates); for this example we had 19 storm dates. In cell L7 enter the proportion for the desired percentile; for this example we used 0.50. This value may be changed as one compares various percentiles (such as, "there is a 50 percent chance that we will . . ."). In cell L8 use the formula "=CRITBINOM(L6,L7,L5)," which returns the smallest value for which the cumulative ranked averages is greater than or equal to a criterion value or rank of sediment yield. This integer

(13 for the current example) is the index of the order statistic that will provide a 95 percent upper confidence interval for the 50th percentile. Finally, in cell L9 enter the formula "=INDEX(J4:J22,L8,1)," which returns a reference to a value from within the ordered sediment averages (J4 thru J22). For this example, an upper 95 percent confidence limit for the 50^{th} percentile or median is the 13^{th} smallest observation or the 13th order statistic. With this data set, there are two zeros in the ordered list; therefore, it will be the 12^{th} smallest observation or the 12^{th} order statistic, which is 0.128 t ha^{-1}.

Following similar steps for the other two groups indicates that we are 95 percent certain that the 50^{th} percentile (the median) is less than 0.133 t ha^{-1} for the Burn and Seed group and 0.093 t ha^{-1} for the Control group. To find upper confidence limits for other percentiles we need only change the 0.5 in cells L7, L26, and L45 to the desired proportion. For example, entering the formula "=2/3" in cell L7 indicates that we are 95 percent certain that at least 67 percent of the observations lie below 0.164 t ha^{-1}, the 15^{th} order statistic. Figure H1 shows the Excel spreadsheet containing the raw data, the averages, and the confidence limits discussed above. This spreadsheet may be downloaded from http://forest.moscowfsl.wsu.edu/engr/siltfence.

Many investigators want to test for a significant difference between groups. Again, the usual testing procedures may not be appropriate because silt fence sediment yield data are often highly skewed. A simple nonparametric alternative, the Friedman test (Conover 1971: 299), is equivalent to performing a randomized complete block analysis of variance on the ranks of the averages of silt fences (Conover and Iman 1981). This analysis is accomplished by the following steps:

1. Using data from Original Sediment Yield Data sheet, copy columns containing dates, groups and averages (columns A, C, and I) to another page (sheet 2, Rank Analysis of Sediment Yield) of the spreadsheet (fig. H2-columns A, B, and C).
2. Highlight cells A1:C58 and press **DATA SORT**, sort by "**Average**" and then press "**OK**" button on the **SORT** menu window. This sorts the average values from smallest to largest.
3. Ranks of averages are computed by entering the formula "=RANK(C2,C2:$C:58)" into cell D2. This formula is then copied into cells D2:D58.
4. Unfortunately Excel does not handle tied observations correctly. There are 12 zeroes that are the 12 smallest observations in the data set. Excel gives each a rank of 1 that need to be replaced with the average of ranks 1 through 12 which is 6.5. There are four 0.1 averages that are replaced with the average of their ranks, (30+31+32+33)/4 = 31.5. The two ranks of 40 are replaced with 40.5, likewise the two 46s are replaced with 46.5. Replacing the two ranks of 52 with 52.5 completes the correct ranking of the data.
5. Copy the columns "Date," "Group," "Averages," and "Ranks" (A1:D58) to cell F1 by pasting the values using **EDIT/PASTE SPECIAL** checking "**Values**."
6. Now the corrected ranks have to be sorted into the original order. Highlight cells F1:I58, press **DATA SORT**, sort by "**Group**" then "**Date**" then press the "**OK**" button on the **SORT** menu window. This sorts by date for each group.
7. Now build a table for analysis. Label cells K1 "Date," L1 "Burn," M1 "Burn and Seed," and N1 "Control." Copy cells I2:I20 then paste to cell L2, copy cells I21:I39 then paste to cell M2, copy cells I40:I58 then paste to cell N2 to complete the table for analysis.
8. Now the built-in function "Anova: Two-Factor Without Replication" is applied to the ranks by clicking **TOOLS/DATA ANALYSIS** and selecting the "**Anova: Two-Factor Without Replication**" from the menu. The block K1:N20 is selected for the "**Input Range**" and cell K22 is selected as the beginning of the output range, the "**Labels**" box is checked and "**Alpha**" is set to 0.05, press "**OK**" (fig. H3). Then block K22:P56 will contain the output.

Figure H2 displays the output. The *p*-value for testing the equality of columns (groups Burn, Burn and Seed, Control) is 4.25E-05 (cell P53), which is highly significant. This indicates there is a difference by group. A *p*-value smaller than 0.05, generally, is considered significant. By inspection, the average rank of the control group is 20.1 (cell N47), while the average ranks of the two burned groups are 32.6 (cell N45) and 34.3 (cell N46) respectively.

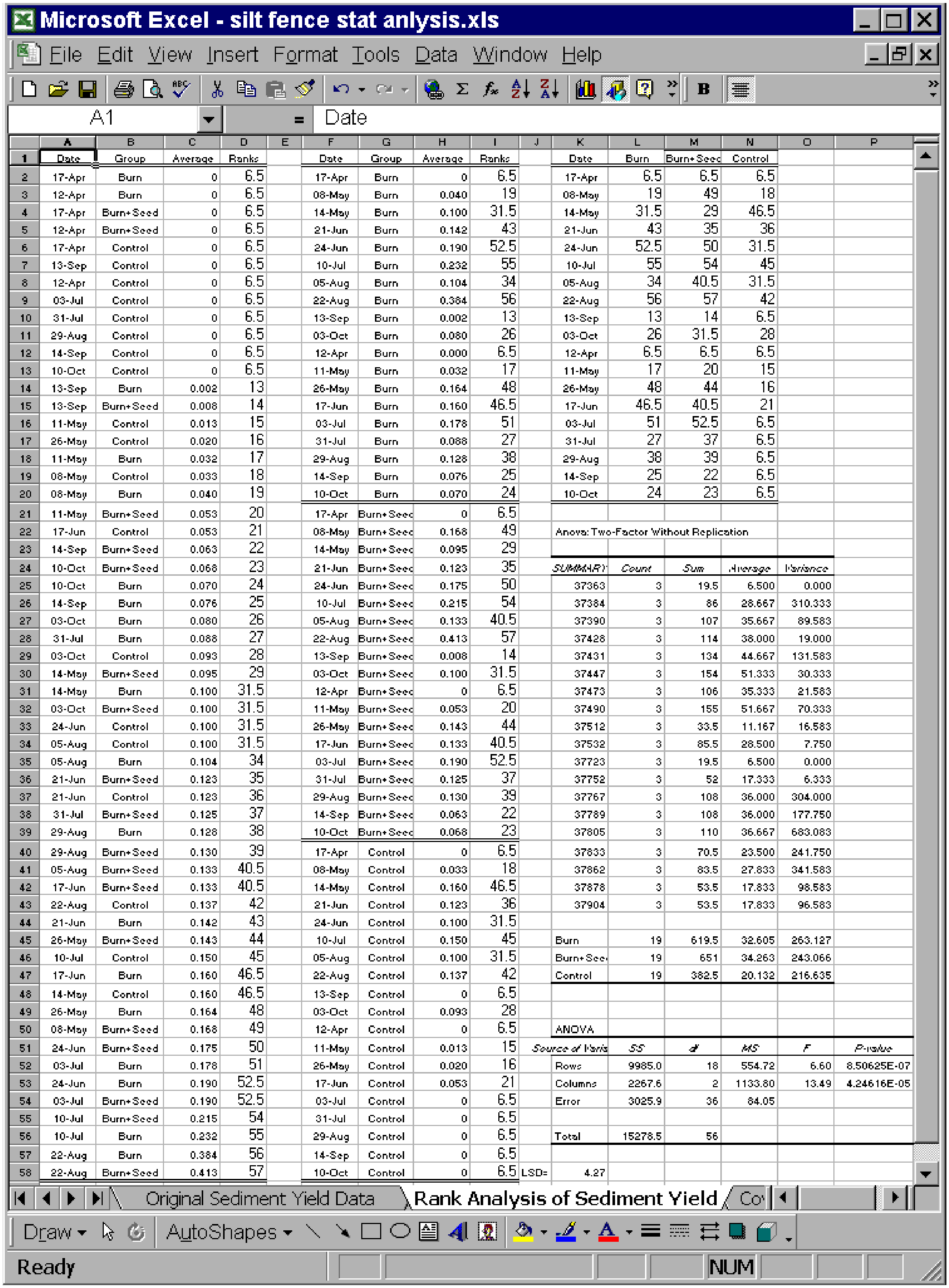
To determine which groups are different, label cell J58 "LSD" and perform a Least Significant Difference (LSD) test of the ranks. This is computed in cell K58 by entering the formula "=TINV(0.05,M54) *SQRT(N54/L47)" giving 4.27, where cell M54 contains the degrees of freedom for the error mean square, cell N54 contains the error mean square, and cell L47 contains the number of observations in each of the group means. This implies that the average of the ranks for any two groups must differ by at least 4.27 to be significantly different. Hence, the control group is significantly less than Burn, and Burn and Seed groups. However, there is no significant difference between the Burn, and Burn and Seed groups because the difference between their mean ranks is less than the LSD value. The analysis also implies that there is a significant difference by rows (date). The *p*-value was 8.50E-07 (cell P52) showing storm (date) differences.

Microsoft Excel - silt fence stat anlysis.xls

	A	B	C	D	E	F	G	H	I	J	K	L
1		10-min										
2		max. rain			Sediment yield (t ha^{-1})					Sorted		
3	Date	(mm hr^{-1})	Group	Fence #1	Fence #2	Fence #3	Fence #4	Fence #5	Average	Average		
4	17-Apr	0	Burn	0	0	0	0	0	0	0	Median	0.100
5	08-May	0	Burn	0	0	0	0.2	0	0.040	0	Confidence	0.95
6	14-May	6	Burn	0.09	0.19	0.11	0.1	0.01	0.100	0.002	n	19
7	21-Jun	9	Burn	0	0.08	0.23	0.17	0.23	0.142	0.032	Percentile	0.5
8	24-Jun	4	Burn	0.14	0.24	0.18	0.22	0.17	0.190	0.040	Order Stat	13
9	10-Jul	18	Burn	0.12	0.22	0.25	0.28	0.29	0.232	0.070	Upper Conf	0.142
10	05-Aug	5	Burn	0.16	0.23	0	0.01	0.12	0.104	0.076		
11	22-Aug	26	Burn	0.22	0.34	0.25	0.53	0.58	0.384	0.080		
12	13-Sep	1	Burn	0	0	0	0.01	0	0.002	0.088		
13	03-Oct	8	Burn	0.16	0.01	0.01	0.17	0.05	0.080	0.100		
14	12-Apr	0	Burn	0	0	0	0	0	0	0.104		
15	11-May	0	Burn	0	0	0	0.16	0	0.032	0.128		
16	26-May	14	Burn	0.2	0.16	0.11	0.18	0.17	0.164	0.142		
17	17-Jun	9	Burn	0.16	0.18	0.05	0.19	0.22	0.160	0.160		
18	03-Jul	26	Burn	0.19	0.18	0.22	0.15	0.15	0.178	0.164		
19	31-Jul	10	Burn	0	0.14	0.14	0	0.16	0.088	0.178		
20	29-Aug	13	Burn	0.19	0.05	0.14	0	0.26	0.128	0.190		
21	14-Sep	30	Burn	0.1	0.11	0.1	0.01	0.06	0.076	0.232		
22	10-Oct	23	Burn	0.17	0.08	0.03	0.03	0.04	0.070	0.384		
23	17-Apr	0	Burn+Seed	0	0	0	0		0	0	Median	0.125
24	08-May	0	Burn+Seed	0.18	0.17	0.19	0.13		0.168	0	Confidence	0.95
25	14-May	6	Burn+Seed	0.07	0.06	0.18	0.07		0.095	0.008	n	19
26	21-Jun	9	Burn+Seed	0.17	0.13	0.09	0.1		0.123	0.053	Percentile	0.5
27	24-Jun	4	Burn+Seed	0.17	0.15	0.18	0.2		0.175	0.063	Order Stat	13
28	10-Jul	18	Burn+Seed	0.28	0.13	0.2	0.25		0.215	0.068	Upper Conf	0.133
29	05-Aug	5	Burn+Seed	0.11	0.18	0.19	0.05		0.133	0.095		
30	22-Aug	26	Burn+Seed	0.27	0.52	0.4	0.46		0.413	0.100		
31	13-Sep	1	Burn+Seed	0	0.01	0.01	0.01		0.008	0.123		
32	03-Oct	8	Burn+Seed	0.12	0.1	0.11	0.07		0.100	0.125		
33	12-Apr	0	Burn+Seed	0	0	0	0		0	0.130		
34	11-May	0	Burn+Seed	0.11	0.05	0.01	0.04		0.053	0.133		
35	26-May	14	Burn+Seed	0.15	0.14	0.17	0.11		0.143	0.133		
36	17-Jun	9	Burn+Seed	0.06	0.13	0.12	0.22		0.133	0.143		
37	03-Jul	26	Burn+Seed	0.17	0.18	0.22	0.19		0.190	0.168		
38	31-Jul	10	Burn+Seed	0.08	0.15	0.15	0.12		0.125	0.175		
39	29-Aug	13	Burn+Seed	0.07	0.16	0.25	0.04		0.130	0.190		
40	14-Sep	30	Burn+Seed	0.08	0.04	0.05	0.08		0.063	0.215		
41	10-Oct	23	Burn+Seed	0.07	0.06	0.06	0.08		0.068	0.413		
42	17-Apr	0	Control	0	0	0			0	0	Median	0.020
43	08-May	0	Control	0	0	0.1			0.033	0	Confidence	0.95
44	14-May	6	Control	0.16	0.24	0.08			0.160	0	n	19
45	21-Jun	9	Control	0.08	0.04	0.25			0.123	0	Percentile	0.5
46	24-Jun	4	Control	0	0.27	0.03			0.100	0	Order Stat	13
47	10-Jul	18	Control	0.08	0.2	0.17			0.150	0	Upper Conf	0.093
48	05-Aug	5	Control	0.16	0.11	0.03			0.100	0		
49	22-Aug	26	Control	0	0.12	0.29			0.137	0		
50	13-Sep	1	Control	0	0	0			0.000	0.013		
51	03-Oct	8	Control	0.02	0.15	0.11			0.093	0.020		
52	12-Apr	0	Control	0	0	0			0	0.033		
53	11-May	0	Control	0	0.04	0			0.013	0.053		
54	26-May	14	Control	0	0.06	0			0.020	0.093		
55	17-Jun	9	Control	0	0.16	0			0.053	0.100		
56	03-Jul	26	Control	0	0	0			0	0.100		
57	31-Jul	10	Control	0	0	0			0	0.123		
58	29-Aug	13	Control	0	0	0			0	0.137		
59	14-Sep	30	Control	0	0	0			0	0.150		
60	10-Oct	23	Control	0	0	0			0	0.160		

Original Sediment Yield Data / Rank Analysis of Sediment Yield

Figure H1—Example spreadsheet for three groups (Burn, Burn and Seed, and Control) showing calculations of median and upper confidence limits for the median.



	A	B	C	D
1	Date	Group	Average	Ranks
2	17-Apr	Burn	0	6.5
3	12-Apr	Burn	0	6.5
4	17-Apr	Burn+Seed	0	6.5
5	12-Apr	Burn+Seed	0	6.5
6	17-Apr	Control	0	6.5
7	13-Sep	Control	0	6.5
8	12-Apr	Control	0	6.5
9	03-Jul	Control	0	6.5
10	31-Jul	Control	0	6.5
11	29-Aug	Control	0	6.5
12	14-Sep	Control	0	6.5
13	10-Oct	Control	0	6.5
14	13-Sep	Burn	0.002	13
15	13-Sep	Burn+Seed	0.008	14
16	11-May	Control	0.013	15
17	26-May	Control	0.020	16
18	11-May	Burn	0.032	17
19	08-May	Control	0.033	18
20	08-May	Burn	0.040	19
21	11-May	Burn+Seed	0.053	20
22	17-Jun	Control	0.053	21
23	14-Sep	Burn+Seed	0.063	22
24	10-Oct	Burn+Seed	0.068	23
25	10-Oct	Burn	0.070	24
26	14-Sep	Burn	0.076	25
27	03-Oct	Burn	0.080	26
28	31-Jul	Burn	0.088	27
29	03-Oct	Control	0.093	28
30	14-May	Burn+Seed	0.095	29
31	14-May	Burn	0.100	31.5
32	03-Oct	Burn+Seed	0.100	31.5
33	24-Jun	Control	0.100	31.5
34	05-Aug	Control	0.100	31.5
35	05-Aug	Burn	0.104	34
36	21-Jun	Burn+Seed	0.123	35
37	21-Jun	Control	0.123	36
38	31-Jul	Burn+Seed	0.125	37
39	29-Aug	Burn	0.128	38
40	29-Aug	Burn+Seed	0.130	39
41	05-Aug	Burn+Seed	0.133	40.5
42	17-Jun	Burn+Seed	0.133	40.5
43	22-Aug	Control	0.137	42
44	21-Jun	Burn	0.142	43
45	26-May	Burn+Seed	0.143	44
46	10-Jul	Control	0.150	45
47	17-Jun	Burn	0.160	46.5
48	14-May	Control	0.160	46.5
49	26-May	Burn	0.164	48
50	08-May	Burn+Seed	0.168	49
51	24-Jun	Burn+Seed	0.175	50
52	03-Jul	Burn	0.178	51
53	24-Jun	Burn	0.190	52.5
54	03-Jul	Burn+Seed	0.190	52.5
55	10-Jul	Burn+Seed	0.215	54
56	10-Jul	Burn	0.232	55
57	22-Aug	Burn	0.384	56
58	22-Aug	Burn+Seed	0.413	57

	F	G	H	I
1	Date	Group	Average	Ranks
2	17-Apr	Burn	0	6.5
3	08-May	Burn	0.040	19
4	14-May	Burn	0.100	31.5
5	21-Jun	Burn	0.142	43
6	24-Jun	Burn	0.190	52.5
7	10-Jul	Burn	0.232	55
8	05-Aug	Burn	0.104	34
9	22-Aug	Burn	0.384	56
10	13-Sep	Burn	0.002	13
11	03-Oct	Burn	0.080	26
12	12-Apr	Burn	0.000	6.5
13	11-May	Burn	0.032	17
14	26-May	Burn	0.164	48
15	17-Jun	Burn	0.160	46.5
16	03-Jul	Burn	0.178	51
17	31-Jul	Burn	0.088	27
18	29-Aug	Burn	0.128	38
19	14-Sep	Burn	0.076	25
20	10-Oct	Burn	0.070	24
21	17-Apr	Burn+Seec	0	6.5
22	08-May	Burn+Seec	0.168	49
23	14-May	Burn+Seec	0.095	29
24	21-Jun	Burn+Seec	0.123	35
25	24-Jun	Burn+Seec	0.175	50
26	10-Jul	Burn+Seec	0.215	54
27	05-Aug	Burn+Seec	0.133	40.5
28	22-Aug	Burn+Seec	0.413	57
29	13-Sep	Burn+Seec	0.008	14
30	03-Oct	Burn+Seec	0.100	31.5
31	12-Apr	Burn+Seec	0	6.5
32	11-May	Burn+Seec	0.053	20
33	26-May	Burn+Seec	0.143	44
34	17-Jun	Burn+Seec	0.133	40.5
35	03-Jul	Burn+Seec	0.190	52.5
36	31-Jul	Burn+Seec	0.125	37
37	29-Aug	Burn+Seec	0.130	39
38	14-Sep	Burn+Seec	0.063	22
39	10-Oct	Burn+Seec	0.068	23
40	17-Apr	Control	0	6.5
41	08-May	Control	0.033	18
42	14-May	Control	0.160	46.5
43	21-Jun	Control	0.123	36
44	24-Jun	Control	0.100	31.5
45	10-Jul	Control	0.150	45
46	05-Aug	Control	0.100	31.5
47	22-Aug	Control	0.137	42
48	13-Sep	Control	0	6.5
49	03-Oct	Control	0.093	28
50	12-Apr	Control	0	6.5
51	11-May	Control	0.013	15
52	26-May	Control	0.020	16
53	17-Jun	Control	0.053	21
54	03-Jul	Control	0	6.5
55	31-Jul	Control	0	6.5
56	29-Aug	Control	0	6.5
57	14-Sep	Control	0	6.5
58	10-Oct	Control	0	6.5

	J	K	L	M	N	O	P
1		Date	Burn	Burn+Seec	Control		
2		17-Apr	6.5	6.5	6.5		
3		08-May	19	49	18		
4		14-May	31.5	29	46.5		
5		21-Jun	43	35	36		
6		24-Jun	52.5	50	31.5		
7		10-Jul	55	54	45		
8		05-Aug	34	40.5	31.5		
9		22-Aug	56	57	42		
10		13-Sep	13	14	6.5		
11		03-Oct	26	31.5	28		
12		12-Apr	6.5	6.5	6.5		
13		11-May	17	20	15		
14		26-May	48	44	16		
15		17-Jun	46.5	40.5	21		
16		03-Jul	51	52.5	6.5		
17		31-Jul	27	37	6.5		
18		29-Aug	38	39	6.5		
19		14-Sep	25	22	6.5		
20		10-Oct	24	23	6.5		
21							
22		Anova: Two-Factor Without Replication					
23							
24		*SUMMARY*	*Count*	*Sum*	*Average*	*Variance*	
25		37363	3	19.5	6.500	0.000	
26		37384	3	86	28.667	310.333	
27		37390	3	107	35.667	89.583	
28		37428	3	114	38.000	19.000	
29		37431	3	134	44.667	131.583	
30		37447	3	154	51.333	30.333	
31		37473	3	106	35.333	21.583	
32		37490	3	155	51.667	70.333	
33		37512	3	33.5	11.167	16.583	
34		37532	3	85.5	28.500	7.750	
35		37723	3	19.5	6.500	0.000	
36		37752	3	52	17.333	6.333	
37		37767	3	108	36.000	304.000	
38		37789	3	108	36.000	177.750	
39		37805	3	110	36.667	683.083	
40		37833	3	70.5	23.500	241.750	
41		37862	3	83.5	27.833	341.583	
42		37878	3	53.5	17.833	98.583	
43		37904	3	53.5	17.833	96.583	
44							
45		Burn	19	619.5	32.605	263.127	
46		Burn+Seed	19	651	34.263	243.066	
47		Control	19	382.5	20.132	216.635	
48							
49							
50		ANOVA					
51		*Source of Varia*	*SS*	*df*	*MS*	*F*	*P-value*
52		Rows	9985.0	18	554.72	6.60	8.50625E-07
53		Columns	2267.6	2	1133.80	13.49	4.24616E-05
54		Error	3025.9	36	84.05		
55							
56		Total	15278.5	56			
57							
58	LSD=	4.27					

Figure H2—Example spreadsheet of ranked analysis of sediment yield data.

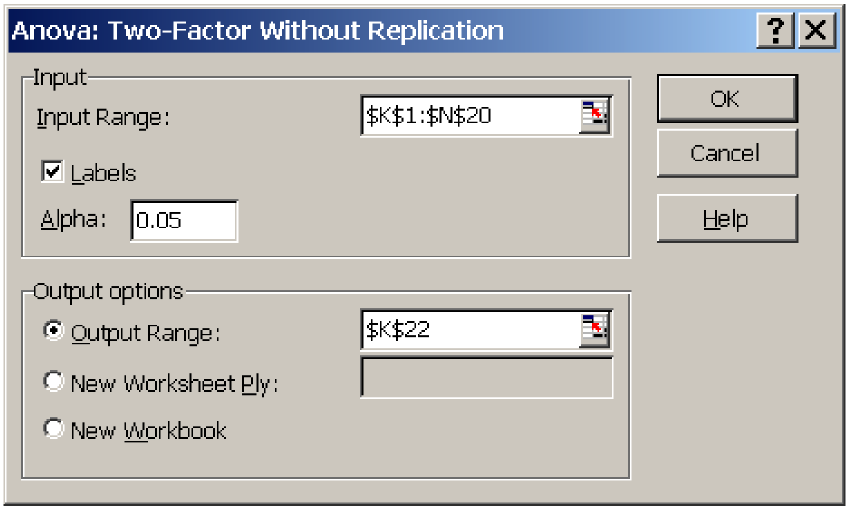


Figure H3—Example window from the Anova analysis.

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