QUANTITATIVE EROSION CONTROL PRODUCT TESTING UNDER SIMULATED RAINFALL

Justin J. Early, E.I.

Project Engineer

Paul E. Clopper, P.E.

Manager, Water Resources
Ayres Associates
3665 JFK Parkway, Building 2, Suite 200
Fort Collins, CO 80525

Tony Johnson

National Research Director
American Excelsior
PO Box 391
831 Pioneer Avenue
Rice Lake, WI 54868

BIOGRAPHICAL SKETCHES

Justin J. Early, E.I.

Justin Early received his B.S. degree in Civil Engineering from Colorado State University in 2001. Mr. Early is currently working as a project engineer for Ayres Associates in Fort Collins, Colorado. Justin has been involved with various types of projects dealing with stable channel design, erosion and sediment control, channel restoration, and 1- and 2-dimensional hydrodynamic modeling.

Paul E. Clopper, P.E.

Paul Clopper is employed by Ayres Associates in Fort Collins, Colorado, where he manages the Water Resources Division. He has a B.S. degree in Civil Engineering from the University of California (Davis), a Master's degree in Civil Engineering (Hydrology & Water Resources) from Colorado State University, is a registered professional engineer and has 23 years of consulting experience in water resources. His work experience includes applied research in the fields of erosion and sediment control, and is responsible for the analysis and design of projects involving surface and ground water hydrology and hydraulics. He currently serves as the chairman for ASTM subcommittee Section D-18.25.04, Articulating Concrete Block Revetment Systems.

Anthony Johnson

Anthony Johnson is employed as the national research director for the American Excelsior Company, Arlington, Texas. He previously served as manager of the American Excelsior Company's *ErosionLab*, a large-scale erosion control testing facility located in Rice Lake, Wisconsin. He has a B.S. degree in Reclamation and Environmental Management from the University of Wisconsin-Platteville and has work experience with the USDA-National Resource Conservation Service on erosion control, streambank stabilization, and soil survey projects. He currently serves as chairman for ASTM Subcommittee Section D-18.25.02, Erosion Control Blankets, and is active in many other industry organizations.

QUANTITATIVE EROSION CONTROL PRODUCT TESTING UNDER SIMULATED RAINFALL

Justin J. Early, E.I.

Project Engineer

Paul E. Clopper, P.E.

Manager, Water Resources
Ayres Associates
3665 JFK Parkway, Building 2, Suite 200
Fort Collins, CO 80525

Tony Johnson

National Research Director
American Excelsior
PO Box 391
831 Pioneer Avenue
Rice Lake, WI 54868

ABSTRACT

It is widely accepted that human activities can cause environmental degradation. Construction and land reclamation sites have historically contributed polluted and sediment-laden storm water to local streams and rivers, degrading water quality and altering natural riverine processes. With heightened public awareness and increasing government regulation, designers, civil engineers, and landscape architects are accordingly eager for information that can help them minimize negative environmental impacts from projects that involve land disturbance.

Until recently, industry has generally applied erosion control materials to sites without the benefit of quantitative data describing the performance of the specific material on the specific soil type. This paper provides quantitative data on the performance of various erosion control Best Management Practices (BMPs). We describe a series of tests conducted at American Excelsior Company's *ErosionLab* Rainfall Erosion Facility (REF). Selected BMPs were tested in a controlled environment that simulates "real world" rainfall conditions. Performance results (soil loss and sediment concentration data) were compared to a baseline condition of bare, unprotected soil.

Data sites from this study were analyzed and interpreted within the framework of the Revised Universal Soil Loss Equation (RUSLE), which incorporates both intensity and depth of rain to determine the erosive energy of rainfall and overland flow. The erosive energy is used as a baseline to compare soil loss from hillslope test plots during simulated rainfall of various intensities and durations. The results of this study are being used to develop standards by which BMPs can be selected, designed, and installed.

1. INTRODUCTION

Over the past thirty years, there has been an increasing awareness of the harmful effects of human-induced environmental degradation. Nonpoint discharge of sediment-laden storm water from construction sites and land reclamation activities represents one such environmental problem created by man. There have been a number of regulatory programs that have brought much-needed attention to these situations. One such program is the National Pollutant Discharge Elimination System (NPDES) Phase II program. This program requires permit coverage for construction activities that disturb areas greater than 1 acre in size.

As a result of these programs, documentation of product performance has become an issue of paramount importance in the erosion and sediment control industry. Information regarding product performance is more frequently being required as a basis for design, specification and installation of Best Management Practices (BMPs) on construction projects. Performance data are also valuable to manufacturers, in order to provide accurate data not only meeting their expectations, but also the expectations of the designers, installers and project owners. Performance information is also central to product research and development; sales and marketing activities; installation guidelines; and product certification. Establishing carefully quantified data on erosion control product performance in typical hillslope applications is the fundamental purpose of the American Excelsior Company's *ErosionLab* Rainfall Erosion Facility (REF). Located in Rice Lake, Wisconsin, the *ErosionLab* is owned and operated by American Excelsior Company's Earth Science Division. Quality Assurance/Quality Control (QA/QC) supervision, data analysis, and reporting are provided by Ayres Associates.

2. PROCEDURE

The *ErosionLab* REF consists of 12 test plots constructed of three common soil types (sand, loam, and clay), with four test plots dedicated to each soil type. The test plots consist of an 18 in layer of test soil. This veneer overlies native Chetek sandy loam soil. The well-drained soil is fine to medium grained, non-cohesive, and exhibits rapid infiltration rates. Each rectangular plot is on a 3H:1V (33 percent) slope and measures 2.4 m wide by 12.2 m long (8 ft by 40 ft). Overspray from adjacent plots is prevented by accessways that provide a 16 ft separation distance between plots.

The plots are tested individually with a network of portable rainfall simulators. The design and spacing of the simulators result in near uniform rainfall distribution over the test plot at target intensities of 51, 102, and 152 mm/hr (2, 4, and 6 in/hr). For each test, six rain gauges are placed to obtain representative rainfall depths on the upper, mid, and lower third of each plot. Water is supplied to the simulators from a nearby pond that is fed by shallow ground water. The equipment is calibrated on a periodic basis according to a peer-reviewed procedure manual (Ayres Associates, 1998). Each plot is prepared using standardized procedures. These include tilling the plot to a depth of approximately 10 to 15 cm (4 to 6 in). The tilled plot is then raked smooth with a steel hand rake and lightly compacted with a turf roller. The plot can be tested under bare soil (control) conditions, or with an erosion control BMP. After the plot is prepared, it is covered with polyethylene sheets to provide protection until testing commences.

During the testing procedure, all runoff and associated sediment is captured in a collection trough. A metal collection apron with a protective cover is fitted to the downstream end of the plot to aid in the runoff collection. The water is then decanted and pumped into a portable, graduated polyethylene collection tank. The saturated sediment from the collection trough is transferred to five gallon buckets and weighed. The total dry unit weight of the sediment is then determined. Grab samples of the runoff is taken at 3 minute intervals to determine total sediment concentration. This is done throughout the entire test until runoff stops. Test samples are then analyzed to determine total sediment concentration.

The testing methodology follows ASTM D-6459, "Standard Test Method for Determination of Erosion Control Blanket (ECB) Performance in Protecting Hillslopes from Rainfall-Induced Erosion."

3. THE REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE)

The framework within which the data from the rainfall tests are analyzed is based on the Revised Universal Soil Loss Equation (RUSLE) (USDA-ARS Agricultural Handbook 703). The RUSLE was first released in 1992 after 56 years of ongoing efforts to quantify and predict the processes involved in soil erosion by rainfall. Its foundation lies in the Universal Soil Loss Equation (USLE), developed in 1956. The Revised Universal Soil Loss Equation is represented by:

$$A = RK(LS)CP$$

Where:

A = Soil loss averaged over a unit area, in the units selected for K and the period selected for R. When estimating average annual rates of soil loss, the units are typically expressed as ton-acre^{-1}-year^{-1}. In this study, R corresponds to a single storm event and is analyzed in increments during the storm; therefore, for any storm increment, A is reported in units of ton-acre^{-1}.

R = Rainfall-runoff erosivity factor, expressed in units of 100 ft-ton-acre^{-1}-in-hour^{-1}. R represents the cumulative erosive effect of multiple rainstorms, or of within-storm increments of essentially uniform intensity, using a measure of energy times intensity, over a defined period of time.

K = Soil erodibility index, expressed in units of ton-acre-hour (100 ft-ton-acre-in)$^{-1}$. K represents the ease with which a particular soil matrix is eroded when exposed to rainfall and runoff corresponding to a given R factor.

LS = Slope length and steepness factor, dimensionless. LS represents the ratio of soil loss on a hillslope with horizontal length L and slope S to the soil loss on a standard plot, defined as one with a 72.6 ft length and a 9 percent slope.

C = Cover-management factor, a dimensionless ratio ranging from 0 (complete protection, no erosion) to 1.0 (no protection). C represents the ratio of soil loss from an area with specified cover and management to the soil loss from a bare, unprotected, uncovered slope (e.g., tilled, continuous fallow).

P = Support practice factor, a dimensionless ratio ranging from 0 (complete control, no erosion) to 1.0 (no additional erosion control). P represents the ratio of soil loss from an area with a support practice like contouring, stripcropping, or terracing to the soil loss from an area with straight-row farming up and down the slope.

3.1. Rainfall-Runoff Erosivity Factor "R"

Erosion is caused both by the energy of rainfall itself, and by overland flow runoff. The rainfall-runoff erosivity factor "R" estimates the erosive forces of rainfall and its associated runoff, and is directly related to the intensity and depth of rainfall. A baseline measure of erosive energy is therefore essential when comparing soil loss from hillslope plots during tests at different intensities and durations. Calculation of the rainfall-runoff erosivity factor R of the RUSLE method is performed for each discrete increment of a storm event. The numerical value of R essentially normalizes the variation in actual intensities and durations exhibited by different storm events. The following method is used:

$$R = \sum EI_{30}\left(10^{-2}\right)$$

Where:

R = rainfall-runoff erosivity

E = total storm kinetic energy

I_{30} = maximum 30 min rainfall intensity

$$EI_{30} = \left(\sum_{k=1}^{m} e_r \Delta V_r\right) I_{30}$$

Where:

e_r = rainfall energy per unit depth of rainfall per unit area (ft • ton • acre^{-1} • in)

ΔV_r = depth of rainfall for the rth increment of the storm hyetograph which is divided into m parts, each with essentially constant rainfall intensity (in)

Unit energy, e, is a function of rainfall intensity and is computed as

$$e_r = 1099\left[1 - 0.72e^{(-1.27i_r)}\right]$$

and:

$$i_r = \frac{\Delta V_r}{\Delta t_r}$$

Where:

Δt_r = duration of the increment over which rainfall intensity is considered to be constant (h), and

I_r = rainfall intensity (in/hr).

$$\mathbf{I}_{30} = \left(7.4\,\text{in/hr} * \frac{0.333\,\text{hrs}}{0.5\,\text{hrs}}\right) + \left(4.5\,\text{in/hr} * \frac{(0.5 - 0.333)\,\text{hrs}}{0.5\,\text{hrs}}\right) = 6.4\,\text{in/hr}$$

The maximum 30 minute rainfall intensity, I_{30}, is calculated from the test data by one of the following two methods:

1. Multiply the rainfall intensity times its corresponding duration (usually 20 minutes) divided by 30 minutes, and add the product of the previous test intensity times the amount of additional time needed to equal 30 minutes total duration (e.g., 10 minutes).

   Example:

   - Rainfall intensity = 7.4 in/hr for 20 minutes (0.333 hrs).
   - Preceding intensity = 4.5 in/hr for 0.333 hrs.

2. If the duration of the test is greater than or equal to 30 minutes, the actual measured intensity is used.

3.2. Soil Erodibility Factor "K"

The RUSLE soil-erodibility factor K is determined from bare soil control tests for a specific soil type. The K factor is determined for each increment of a storm based on the corresponding measured amount of erosion A.

Typically, the test plots exhibit no cover-management factor or support practice improvements. Therefore, both C and P of the RUSLE are numerically equal to 1.0 by definition. For a standardized hillslope length of 40 feet on a uniform 33 percent slope, the LS factor of RUSLE is numerically equal to 2.78 (USDA-ARS Agriculture Handbook 703). The following method can be used:

$$K = \frac{A}{R(LS)CP} = \frac{A}{R(2.78)(1.0)(1.0)} = \frac{A}{2.78R}$$

Where:

A = Cumulative measured amount of erosion in tons/acre

R = Cumulative rainfall-runoff erosivity factor, calculated as described above

This method can be used to determine a soil erodibility K-value for each uniform-intensity increment of a storm.

An alternative method of calculating the soil erodibility factor K is to plot the measured amount of erosion "A" in tons/acre as the dependent variable, versus the rainfall-runoff erosivity factor "R" as the independent variable. The slope m of a least-squares regression line fitted through the origin is thus:

$$m = K(LS)CP$$

or, rearranging for K,

$$K = \frac{m}{(LS)CP} = \frac{m}{(2.78)(1.0)(1.0)} = \frac{m}{2.78}$$

3.3. Cover-Management Factor "C"

Determining the value of the cover-management factor C for any erosion control BMP requires a comparison of soil loss that occurs both with and without the BMP in place. Once the soil-erodibility factor K has been determined for each soil type, the cover-management factor can be determined for each product tested on that soil.

As a linear regression technique is used to determine the soil erodibility factor for the bare soil control data, a similar technique is used to determine the cover-management factor for the surface treatment. Again, the amount of soil erosion "A" in tons/acre is plotted against the rainfall-runoff erosivity factor "R." The slope m of a least-squares regression line fitted through the origin is used to determine the "C" factor for the BMP being tested, given that the "K" factor for the soil has already been determined. In this case, the value of the soil erodibility factor "K" is assumed to be independent of the surface treatment, and numerically equal to the value derived from the bare soil tests. The support practice factor “P” is still equal to 1.0 by definition.

Now, rearranging for C,

$$C = \frac{m}{(LS)KP} = \frac{m}{2.78(K)(1.0)} = \frac{m}{2.78K}$$

Thus, a regression-based determination of the soil erodibility factor “K” yields a similarly derived cover-management factor “C” within the framework of the RUSLE, for each BMP tested. Figure 1 provides an illustration of this analytical method using actual data collected from the *ErosionLab* for bare soil and for an Erosion Control Blanket referred to as “Type 1 ECB.”

4. HYDROLOGIC PARAMETERS

In typical rainfall-runoff analysis associated with erosion and sediment control design, hydrologic parameters such as the Soil Conservation Service (SCS) curve number (CN) and the rational method runoff coefficient (C) need to be quantified in order to fully evaluate a product’s performance. The SCS curve number is used for estimating runoff volume. Both infiltration and surface storage are included in this single watershed parameter (Noventy and Olem, 1994). The rational runoff coefficient (C) is used to determine the peak rate of runoff given the rainfall intensity and watershed area for a given soil type and land use.

Computation of the runoff curve number (CN) is performed by initially solving the following equation for the soil storage parameter S:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Where:

Q = runoff (inches) = Total water volume collected ÷ plot area

P = rainfall (inches) = Measured intensity times rainfall duration

S = potential maximum storage depth (inches)

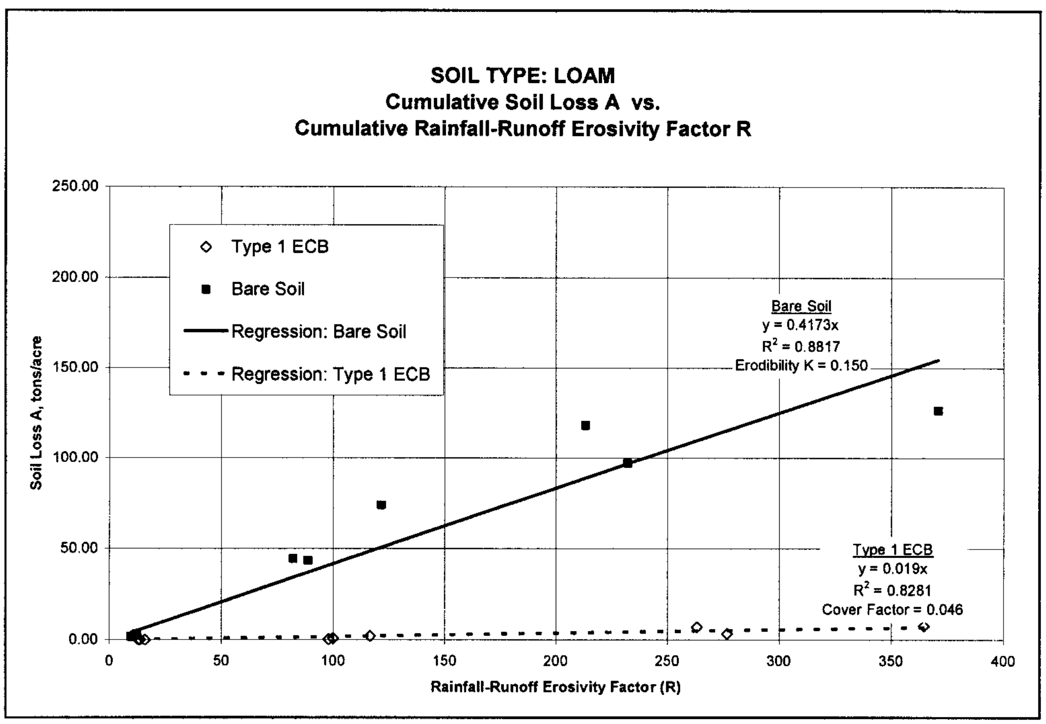

Figure 1. Determination of RUSLE parameters “K” and “C” for a specified soil type (loam) and BMP (erosion control blanket).

The Curve Number "CN" is calculated using the following equation:

$$CN = \frac{1000}{S + 10}$$

Calculation of the runoff curve number for each product provides a series of values that can be associated with rainfall and runoff volumes. BMP performance is determined by comparison to a bare soil control by plotting the cumulative runoff vs. cumulative rainfall. Examination of the plot indicates the overall effectiveness of the product in reducing the runoff volumes for a given soil type. An example is provided in Figure 2.

The rational method relates the peak runoff discharge to the rainfall intensity. The peak discharge rate associated with any given erosion control product can be estimated by determining the rational runoff coefficient C. This is done using the following equation:

$$Q = F(CiA)$$

Where:
Q = peak discharge rate (ft^3/s)
F = units conversion factor = 1.008 for English units
i = rainfall intensity (in/hr)
A = plot surface area (acres)

The rational runoff coefficient is also compared to bare soil control tests. A graphical example of such a comparison is provided below.

The runoff discharge rate Q in ft^3/s is plotted as the dependent variable versus rainfall intensity i in (in/hr) as the independent variable. A least squares regression line is fitted through the origin and the corresponding slope provides the following relation:

$$m = FCA$$

Where:
m = slope of the regression line
F = 1.008, the conversion constant of the Rational Method equation for use with English customary units
C = the Rational Method Coefficient (dimensionless)
A = drainage area in acres

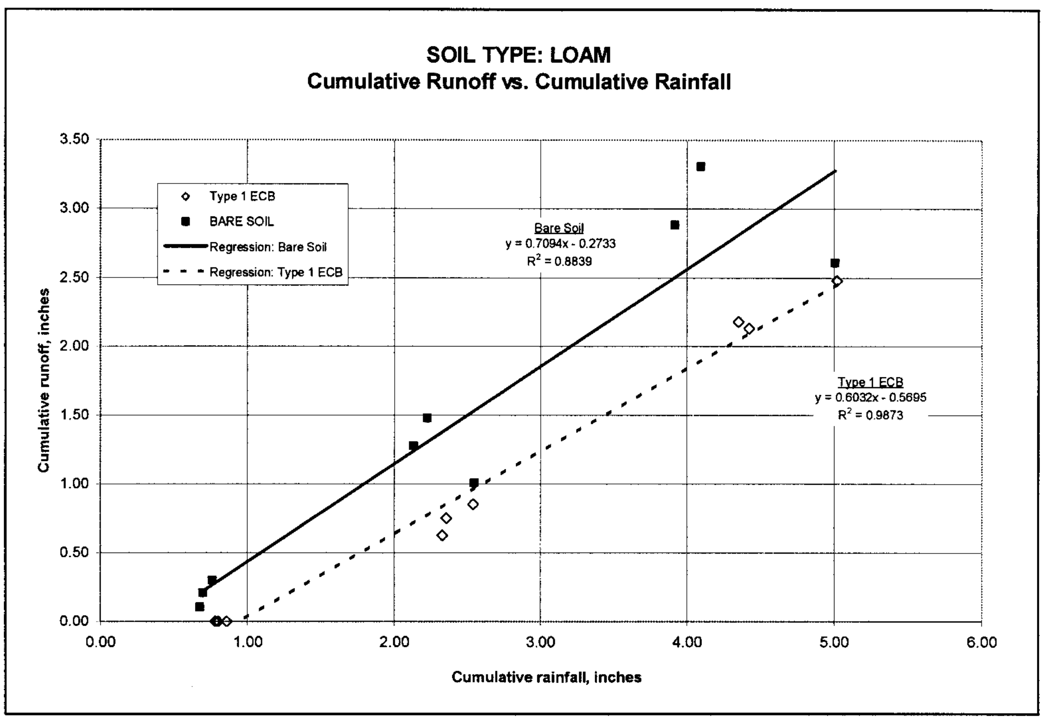

Figure 2. Runoff volumes for bare loam soil vs. ECB-protected loam.

Calculation of the Rational Coefficient C from the regression relationship is readily performed by rearrangement:

$$C = \frac{m}{FA}$$

An adjustment for the infiltration capacity of the soil is not directly incorporated since the Rational Method for discharge estimation is a simplified model of the rainfall-runoff process.

Table 1 provides a summary of the data that is presented in Figures 1, 2, and 3. The values shown in this table are the actual measured results for bare soil control testing and an Erosion Control Blanket referred to as "Type 1 ECB."

5. CONCLUSIONS

Increased erosion due to rainfall is an undesirable result of construction activity and other projects that involve land disturbance. The need for improved and more efficient erosion control products and methods continues to grow, and regulatory requirements continue to become more stringent. Progressive research to aid in the selection, design, and installation of Best Management Practices (BMPs) is essential to achieve the goal of minimizing sediment-laden discharges to receiving waters.

American Excelsior's *ErosionLab* Rainfall Erosion Facility (REF) allows detailed, quantitative analysis on the performance of erosion control BMP products and materials. Important hydrologic design parameters, such as the SCS curve number and the Rational Method runoff coefficient, can be quantified for any BMP product or material. The performance can also be related to each of three common soil types (sand, loam, and clay). Most importantly, the use of the Revised Universal Soil Loss Equation (RUSLE) provides a framework within which the test data can be assessed. The methods described in this paper allow prediction of BMP performance in reducing rainfall erosion for single or multiple storms, an essential step in the selection of an appropriate and cost-effective BMP for a particular application.

6. REFERENCES

American Society for the Testing of Materials (ASTM). 2000. "ASTM D-6459: Standard Test Method for Determination of Erosion Control Blanket (ECB) Performance in Protecting Hillslopes from Rainfall-Induced Erosion." ASTM, West Conshohocken, Penn. January.

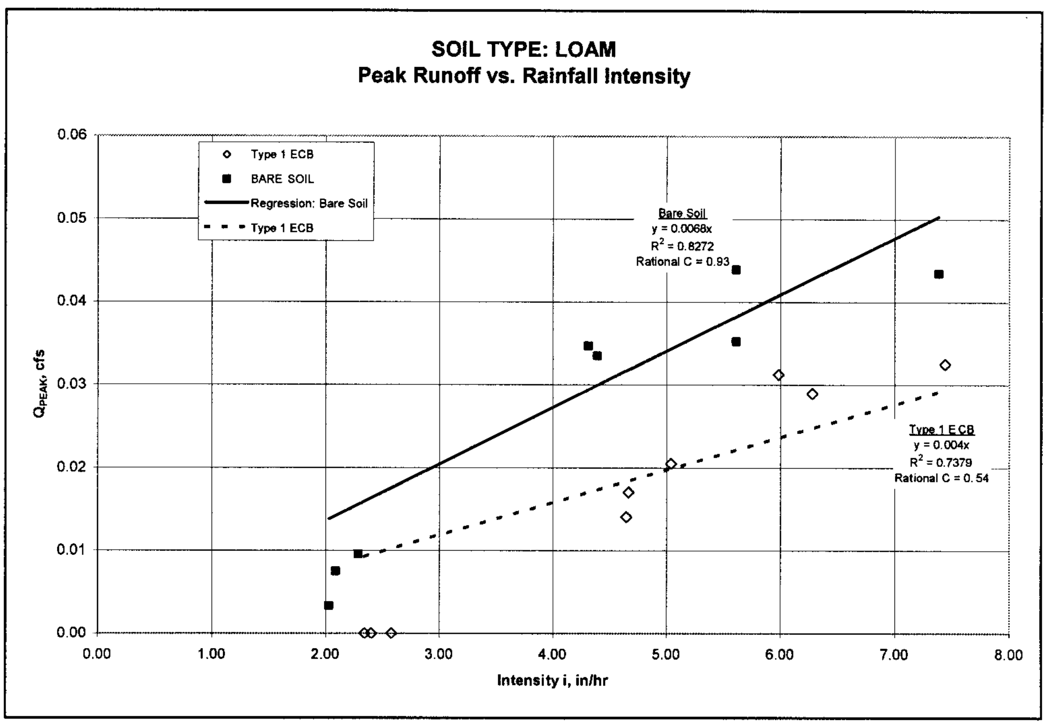

Figure 3. Peak runoff rates for bare loam soil vs. ECB-protected loam.

Table 1. Summary of Test Results for Bare Loam and "Type 1 ECB."

	Cumulative Soil Loss, A (tons/acre)[1]	Rainfall-Runoff Erosivity Factor, R[1]	Measured Peak Runoff, (cfs)[2]	Measured Rainfall Intensity, (in/hr)[2]	Cumulative Runoff, (in)[1]	Cumulative Rainfall, (in)[1]
Bare Loam						
Test 1 – 2 in/hr	1.75	9.49	0.003	2.0	0.105	0.68
Test 1 – 4 in/hr	44.57	82.10	0.035	5.6	1.008	2.55
Test 1 – 6 in/hr	118.21	213.28	0.044	7.4	2.612	5.01
Test 2 – 2 in/hr	1.50	10.09	0.010	2.3	0.301	0.76
Test 2 – 4 in/hr	43.58	88.77	0.034	4.4	1.479	2.22
Test 2 – 6 in/hr	97.09	232.13	0.044	5.6	3.309	4.09
Test 3 – 2 in/hr	3.31	12.23	0.008	2.1	0.211	0.70
Test 3 – 4 in/hr	73.93	121.71	0.035	4.3	1.278	2.13
Test 3 – 6 in/hr	126.59	370.82	0.045	5.4	2.883	3.92
Type 1 ECB						
Test 1 – 2 in/hr	0	15.8	0	2.6	0	0.86
Test 1 – 4 in/hr	2.14	116.57	0.021	5	0.85	2.54
Test 1 – 6 in/hr	7.68	364.46	0.033	7.4	2.48	5.02
Test 2 – 2 in/hr	0	13.61	0	2.4	0	0.8
Test 2 – 4 in/hr	0.78	99.94	0.017	4.7	0.75	2.36
Test 2 – 6 in/hr	7.14	263.2	0.031	6	2.18	4.35
Test 3 – 2 in/hr	0	12.91	0	2.3	0	0.78
Test 3 – 4 in/hr	0.29	97.92	0.014	4.6	0.63	2.33
Test 3 – 6 in/hr	3.28	276.71	0.029	6.3	2.13	4.42

1) Values represent cumulative storm amounts.
2) Values reported for individual storm increments.

Ayres Associates. 2000. "A Quantitative Assessment of Erosion and Sediment Control Best Management Practices—Rainfall-Runoff Erosion on Hillslopes: Bare Soil Control Testing." Prepared for the American Excelsior Company by Ayres Associates, Fort Collins, Colo. Project No. 26-0132.00, September.

Ayres Associates. 1998. "Procedures Manual: *ErosionLab* Rainfall Erosion Facility." Prepared for the American Excelsior Company by Ayres Associates, Fort Collins, Colo. Project No. 34-0335.00, April.

Chow, V. T. 1964. *Handbook of Applied Hydrology*. McGraw-Hill Book Company, New York, N.Y.

Holland, M. E. 1969. Design and Testing of Rainfall System, prepared for U.S. Department of the Interior Office of Water Resources Research (Matching Grant No. B-030-COLO) and CSU Experiment Station, Fort Collins, Colo.

Kelsey, K. L. 2002. Use of the Revised Universal Soil Loss Equation (RUSLE) to Predict Event Soil Loss. *Thesis*. University of Wisconsin-Stevens Point. Stevens Point, Wisconsin.

Sutherland, R. 1997. Written communication to the American Excelsior Company re: review comments on Procedures Manual review draft, July.

U.S. Department of Agriculture, Agricultural Research Service. 1978. "Predicting Rainfall Erosion Losses." Agriculture Handbook No. 537, Washington, D.C.

U.S. Department of Agriculture, Agricultural Research Service. 1997. "Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation." Agriculture Handbook No. 703, Washington, D.C.