RESEARCH, DEVELOPMENT AND IMPLEMENTATION OF TEST PROTOCOLS FOR RAINFALL EROSION FACILITIES (REFS)

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ABSTRACT

Scientific means to evaluate the effectiveness of erosion control Best Management Practices (BMPs) for nonpoint source pollution has become the focus of a number of industry-related activities during the past several years, including the efforts of leading industry associations, governmental agencies, universities and commercial laboratories. To develop meaningful performance data on slope applications and to provide some measure of comparability, rainfall simulation has become the standard method for evaluation of erosion control products and installation techniques by many of these organizations.

Modeling of rainfall to simulate natural weather events and environmental forces, and to predict sediment loss, has continually evolved since the early 1930s. A wide variety of rainfall simulation mechanisms, including rotating sprayers, horizontal drip pans and low height sprinklers have been constructed for this purpose. Most tests using these devices have evaluated cover material performance and soil erosion, based solely on collection of the quantity of sediment captured. The means for collecting, capturing and measuring sediment have also varied considerably, as have the statistical, engineering and scientific reliability of the reported results.

This paper summarizes an extensive research effort which was used to develop a comprehensive, state-of-the-art test protocol for a rainfall erosion testing facility located in Rice Lake, Wisconsin. A brief discussion of the facility is provided, as well as a discussion of key equipment selection. Analytical techniques for system start-up and simulator calibration is described, including determination of rainfall intensity, uniformity of rainfall coverage, rainfall drop size distribution, velocity estimation, kinetic energy created and erosive power generated. Plot preparation activities and documentation are discussed, including test bed veneers, subgrade compaction, soil preparation and treatment of vegetation. Data collection techniques to be conducted during testing operations are identified, including measurements of sediment loss, runoff and infiltration. Post-test analysis to determine USLE/RUSLE C-factor and SCS Curve Number parameters are presented. Finally, evaluation of the results, using generally-accepted statistical principles, is also presented.

INTRODUCTION

Documentation of product performance has become an issue of paramount importance in the erosion and sediment control industry. End-users and designers are more frequently requesting this information to provide the basis for construction project designs, specifications and installations. Performance data are also valuable to manufacturers, so that they can provide accurate data to meet end-user, designer, and installer expectations. This 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 for American Excelsior Company's development of *The ErosionLab* Rainfall Erosion Facility (REF). Aside from the materials themselves, related aspects of installed systems, such as soil preparation, anchor patterns, application rates, and termination details will also be evaluated. And finally, the desire to improve existing products and to innovate new materials and solutions for erosion control applications is a major objective.

The REF and all hillslope erosion testing facilities have two fundamental requirements: 1) the ability to simulate natural rainfall events under controlled and documented conditions, and; 2) the ability to accurately capture, collect and measure soil loss as a result of simulated rainfall events. These two requirements must be achieved using generally accepted engineering principles, scientific procedures, analytical methods and statistical standards.

The test method was limited to evaluation of non-vegetated conditions since: 1) all Best Management Practices (BMPs) applied to hillslope conditions must initially perform in a non-vegetated condition to control erosion and retain seed; 2) the variables associated with performance of BMPs vary greatly depending on climatic and local agronomic conditions, and; 3) considerable time constraints are involved when attempting to evaluate vegetated conditions. By evaluating BMPs in unvegetated conditions, a conservative or “worst case scenario” was applied. Testing methodologies for evaluation of vegetated BMPs in controlled conditions may be developed at a later date.

RAINFALL SIMULATION HISTORY

Rainfall simulators have been used for many years in the study of soil erosion, runoff characteristics, infiltration rates, and erosion control product performance. Numerous types and sizes of simulators have been developed for a variety of studies since the 1930's. Some of the early studies using rainfall simulators were conducted by Lowdermilk (1930), Duley and

Hays (1932), Nichols and Sexton (1932), Hendrickson (1934), Diseker and Yoder (1936), Woodruff, Smith, and Whitt (1938), Neal (1938), and Borst and Woodburn (1938) to name a few. There was little knowledge of the physical characteristics of natural rainfall at the time of these first studies. Rainfall characteristics were first studied in the early 1940's. Laws (1941) studied the raindrop fall velocity as influenced by drop size and distance of fall. Laws and Parsons (1943) related raindrop size distribution to rainfall intensity. This early work on natural rainfall characteristics formed the basis on which rainfall simulators have developed to date.

Some of the more notable designs used hanging yarn (Ellison and Pomerene, 1944) and small gauge glass tubing (Ekern, 1951) to produce drops. The primary use of the early simulator designs were in detailed, small scale laboratory research to study the effect of a particular rainfall characteristic on soil erosion, runoff, infiltration, or material performance. The limitations of these early simulators included: 1) the need to move the simulator or the erosion plot so that drops do not all fall on the same point on the plot, 2) small plot size, 3) effects of wind, 4) clogging of the small tubes, 5) limited drop size distribution, and 6) low kinetic energy depending on the fall height.

Early studies conducted on a variety of spray nozzle configurations showed that they were the most promising in the duplication of the drop size distribution of natural rainfall and are also suited for large plot research. The most notable research was the type F nozzle (Wilm, 1943) which produced a drop size distribution similar to that of high intensity rainfall. The following paragraphs highlight some of the more notable simulators that were developed using nozzles and, in later studies, sprinklers.

The first suitable nozzle for rainfall simulation was the Spraying Systems Company 80100 VeeJet tested and used by Meyer and McCune (1958) on the simulator they termed the “Rainulator.” The nozzle sprayed down, and at a line pressure of 6 psi and a fall height of 8 ft, produced a drop size distribution similar to natural rainfall at a kinetic energy approximately 80% of natural rainfall. The major limitations of the Rainulator was the high flow rate of the nozzle and the expense and complexity of the apparatus. Moving the Rainulator was very labor intensive and thus limited the practical number of plots that could be tested in a short amount of time.

Swanson (1965) developed a trailer-mounted, rotating boom type simulator to overcome some of the limitations of the Rainulator. This device used the same nozzles as the Rainulator which were mounted on ten concentric booms that rotated at a constant rate. The simulator produced intensities of 2.5 or 5 inches per hour depending on the number of nozzles that were operating, with kinetic energy about 77% of natural rainfall. Some inherent limitations of the rotating-boom simulator included the cycling of the simulated rainfall over a plot, the difference in nozzle heights over sloping test plots, and the distribution of rainfall in a circular pattern, requiring protection for adjacent plots. Even though the rotating boom was more portable, it still required considerable labor to set up or to dismantle for transporting.

Holland (1969) developed a rainfall erosion facility at Colorado State University that utilized Rainjet 78C sprinkler heads that sprayed upwards and were positioned approximately 10 ft above the plot surface. Intensities ranged from 0.54 in/hr to 4.24 in/hr depending on the riser configuration, with kinetic energy approximating 50% of natural rainfall. This system could be taken down and moved easily and, excluding the pump, contained no moving parts.

From this past research and development of rainfall simulators, a suitable simulator needs to closely approach certain characteristics of natural rainfall in order to produce reliable indications of natural rainfall effects. Some of the more important characteristics are drop-size distribution and fall velocities similar to those of natural rainfall at similar intensities. It is also important to be able to reproduce intensities in the range of storms producing medium to high rates of runoff and erosion since it is these storms that cause major erosion and will severely test the performance of erosion control products. The plot size must be large enough for satisfactory representation of alternative treatments and natural erosion characteristics, such as rill formation. The rainfall should be uniform over the plot in both intensity and drop characteristics and the application should be nearly continuous across the plot. The angle of impact should not vary significantly from vertical and the simulator must operate satisfactorily in mild winds, and be completely portable.

The objective of this comprehensive literature search was to guide the design and development of *The ErosionLab* REF and test protocol to conform with the important elements determined from historic rainfall simulation and soil erosion research.

FACILITY DESCRIPTION

The ErosionLab REF is located near Rice Lake, Wisconsin, and covers a site approximately 100 feet wide by 300 feet long (see Figure 1). A berm with a south-facing, 3H:1V slope was built to simulate conditions found on typical construction projects involving large-scale land disturbance activities and heavy earthwork requirements, such as highways, landfills, mines, pipelines, land developments, etc. (see Figure 2). Standard excavation, placement and compaction techniques were employed to construction the embankment.

Three different veneer soils (sand, clay and silt loam) were placed on top of the berm to a depth of approximately 46 centimeters (18 inches). Twelve test plots 2.4 meters (8 feet) wide by 12 meters (40 feet) long were located on the berm. Each plot totaled 32 square meters (320 square feet) or approximately 0.3 percent of a hectare (0.7 percent of an acre). A separation distance of 4.8 meters (16 feet) was used between each plot to assure independent results and each plot was surrounded by a surface water barrier to assure that no intrusion of outside surface water (i.e., “run-on”) occurred.

A moveable catchment trough was custom-manufactured to collect sediment from the test plot. All sediment-laden runoff is routed by flashing into the

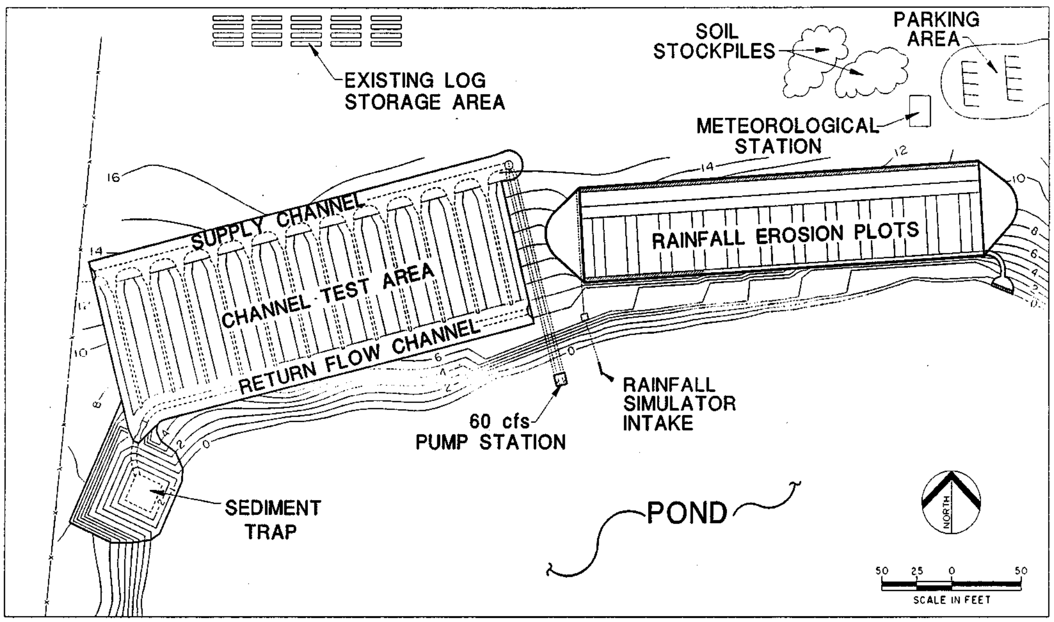

Figure 1. Overall site layout of *The ErosionLab.*

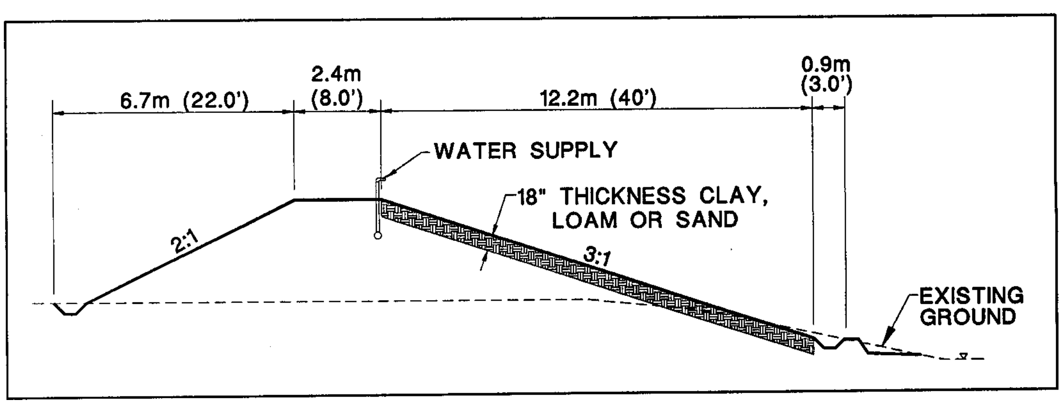

Figure 2. Profile through erosion test plot.

catchment trough and is then pumped into a large polyethylene collection tank for temporary storage.

EQUIPMENT SELECTION

The key equipment for the REF included sprinkler heads, sprinkler risers, valves, pressure gauges, water distribution systems, pumps, intake manifold, and collection troughs. To assure similarity to natural raindrop size, Rainjet *RS-10H* (half-circle pattern) and *RS-30ES* (rectangular pattern) sprinkler heads were selected. These heads produce a discharge of about 7.5 to 11 liters per minute (2 to 3 gallons per minute) at an operating pressure of 207 kPa (30 pounds per square inch). This results in a typical drop size of approximately 4 to 6 millimeters in diameter using a "rotating pendulum" method to form the drops.

To allow the simulated rainfall to approach terminal velocity and to approximate the kinetic energy of natural events, the sprinkler heads were mounted on sprinkler risers or "trees" placing the discharge point approximately 3 meters (10 feet) above the ground (see Figure 3). The "throw" or peak trajectory of the sprinkler heads adds approximately 1.2 meters (4 feet) of additional height to the simulated raindrops for a total fall height of approximately 4.2 meters (14 feet). From this height, the simulated raindrops reach a

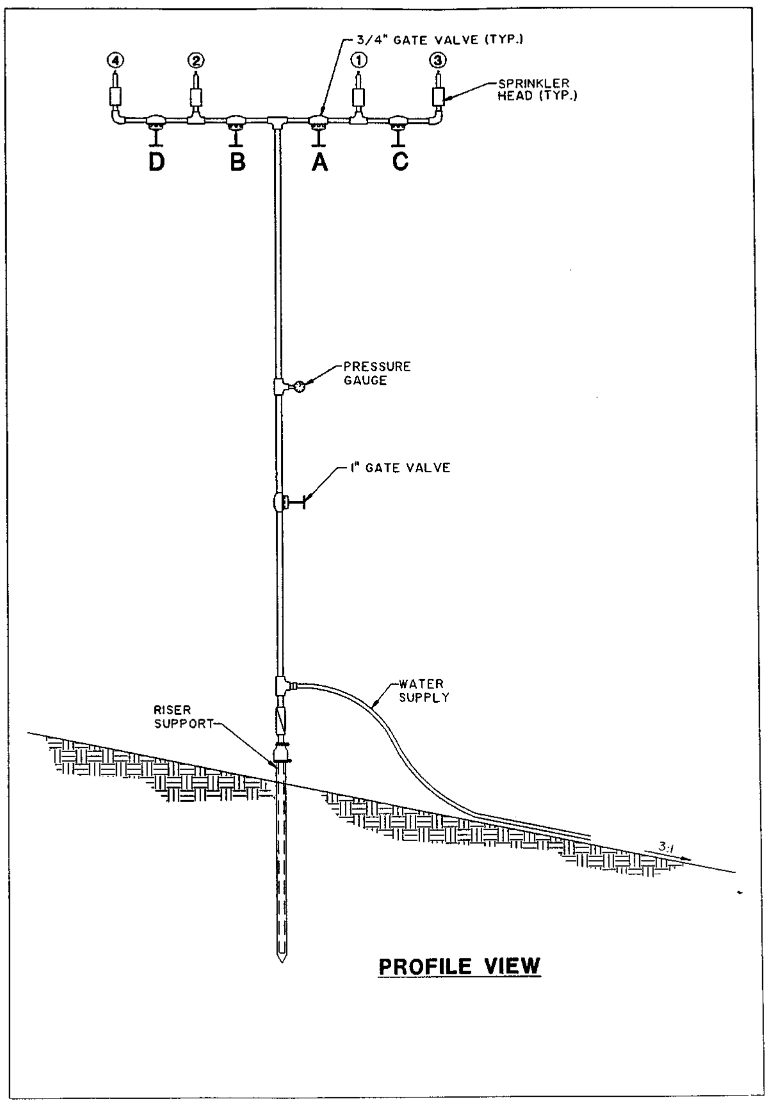

Figure 3. Riser assembly.

velocity of approximately 7.5 meters per second (25 feet per second) resulting in approximately 70 to 75 percent of the kinetic energy of natural rainfall.

Four sprinkler heads were mounted on each riser and eleven risers were positioned around the test plot to assure uniform coverage. Gate valves were used to control the flow of water to each of the sprinkler heads. With only one sprinkler head per riser turned on and with the maximum recommended operating pressure, a rainfall intensity of approximately 6.3 centimeters per hour (2.5 inches per hour) can be achieved. With all four sprinkler heads per riser turned on and with the maximum operating pressure, a rainfall intensity of approximately 25 centimeters per hour (10 inches per hour) is achieved. To assure proper operating conditions, pressure gauges were mounted on each sprinkler riser, and a fully looped water distribution system was employed.

SYSTEM START-UP AND INITIAL CALIBRATION

To assure the integrity of the rainfall simulation system, a procedure for start-up and calibration was developed. The objectives of this procedure were: 1) initiate operation of the rainfall simulators to determine if the equipment is functioning within specifications and meets design requirements; 2) calibrate the simulator to ensure that uniform areal coverage is achieved at all design intensities, and; 3) make the needed adjustments to the system so that repeatable results can be obtained. This procedure for system startup and initial calibration will be conducted each spring prior to the initiation of tests.

The initial startup procedure assures that all the equipment is in proper operating condition before performing the initial system calibration. This includes all of the supply hoses and pipe, booster pumps, water supply intake unit, plot frame and flashing, rain gauges, and the runoff collection trough, pump, and storage tank. The risers are plumbed in a semi-permanent fashion using the layout shown on the design plans (see Figure 4). The initial calibration process may require that the risers be repositioned to establish the most optimum rainfall uniformity. For subsequent startup and calibration processes, the risers will be installed in the permanent locations that were established from the first calibration. If the optimum uniformity has been established during the first calibration process, there will be no need for further repositioning of the risers unless major changes in the experimental design are desired.

The soil surface in and around the plot area is covered with plastic sheeting to minimize the amount of mud and erosion generated during the initial startup and calibration process. The plastic sheeting is removed when testing commences. Since this condition produces the maximum amount of runoff, the procedure will also test the capacity of the catchment trough and evacuation pump system. In preparation for this initial calibration process, the sprinkler gate valves are closed so that only one head per riser is in operation. The main control gate valves on each riser are then adjusted to achieve the standard operating pressure of 207 kilopascals (30 pounds per square inch) at the gauge.

The purpose of the initial calibration process is to determine: 1) the rainfall intensity; 2) the uniformity of rainfall application across the plot, and; 3) the drop size distribution for each design intensity. Calibrations and testing are not conducted when the wind velocity is greater than 8 kilometers per hour (5 miles per hour), so that repeatable results can be achieved. Calibration of the simulators is conducted once, during system start-up, at the beginning of each testing season.

Ideally, the rainfall simulators distribute water at a uniform depth over the entire plot area for all design intensities. Since the sprinkler heads specified for the simulators produce partial circle and rectangular patterns, the objective of this procedure is to achieve a sprinkler overlap pattern to produce a rainfall coverage as uniform as possible given the types and spacing of sprinkler heads.

According to the sprinkler manufacturer's literature, the risers are spaced so that the sprinklers produce a uniform application at the design pressure. Uniformity is calculated by conducting a test using a network of 20 rain gauges laid out over the test plot. This calibration process involves varying the pressure within the operating range [173 to 242 kPa (25 to 35 psi)] and measuring the resulting rainfall pattern and rate to achieve the optimal operating pressure. The duration of this test is approximately 15 minutes, recorded to the nearest second, so that the rainfall intensity can be determined.

The uniformity is calculated using the Christiansen Uniformity Coefficient (James 1988). When the areal coverage represented by each observation point (rain gauge) are equal, the Christiansen Uniformity Coefficient (C_u) is calculated using the following formula:

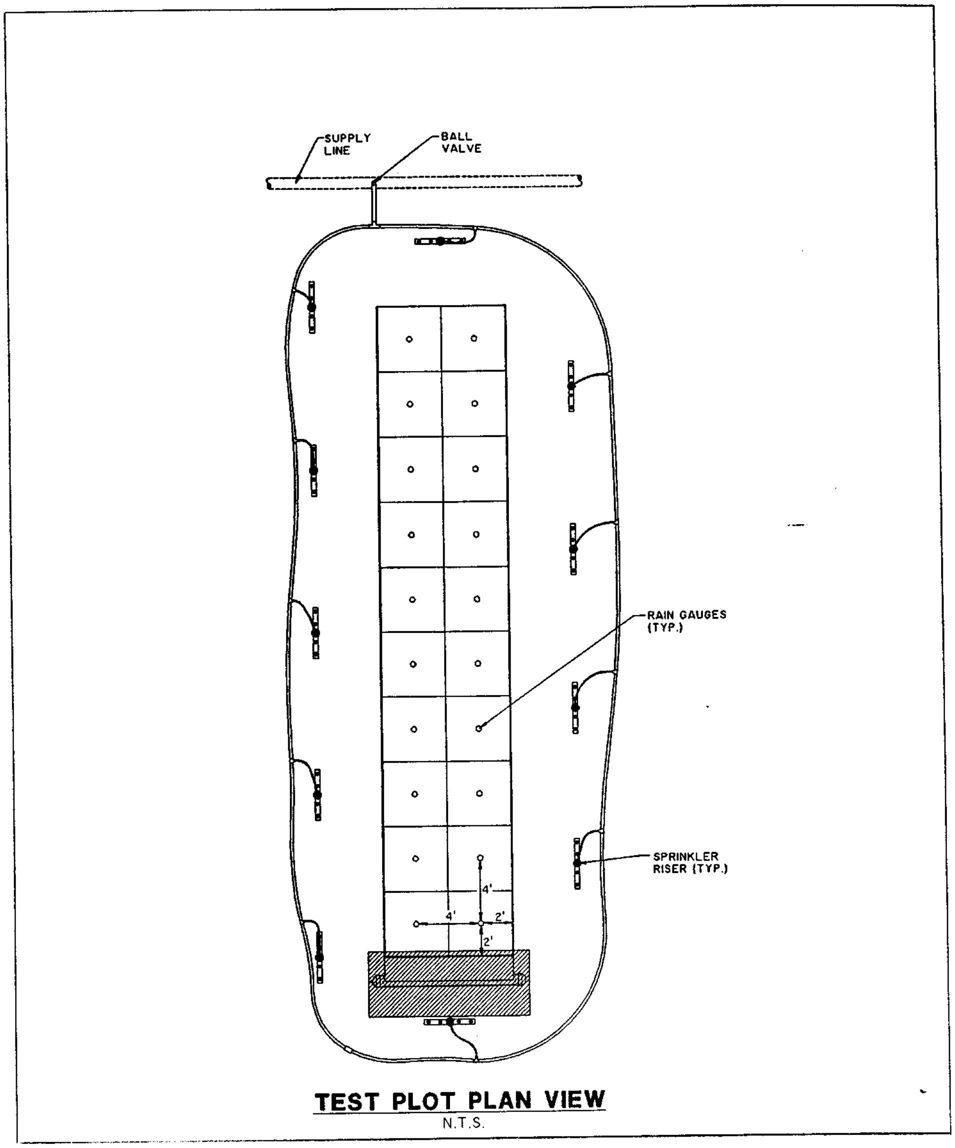

Figure 4. Test plot layout.

$$C_u = 100\left(1.00 - \frac{\sum |d|}{n\overline{X}}\right)$$

Where:

- C_u = Christiansen Uniformity Coefficient
- d = $X_i - \overline{X}$
- n = number of observations (20 in this case)
- $\overline{X}$ = average depth caught
- X_i = depth caught in each rain gauge i

The average rainfall intensity over the entire test plot is the average depth of rainfall divided by the elapsed time of the test. The formula to calculate intensity, in centimeters per hour, is:

$$i = 60\,\frac{\sum_{j=1}^{j} Pj}{Jt}$$

Where:

- i = rainfall intensity (cm/hour)
- Pj = Depth of rainfall (cm)
- J = Number of rain gauges (20 in this case)
- t = Time of test (minutes)

Repositioning the risers, if necessary, to obtain a uniform coverage is impossible to describe on a step-by-step basis. Good judgment must be used by the researcher to establish the best riser locations which yield the highest uniformity coefficients, considering all target intensities.

Natural rainfall, at a given intensity, exhibits a range of drop sizes; moreover, the drop size distribution varies with intensity. Studies have shown that the drop size of natural rainfall is highly variable, but the proportion of large size drops generally increases with intensity. Figure 5 shows the raindrop size distribution by volume for selected intensities, as documented by Laws and Parsons (1943).

To measure drop size distribution, three labeled pie pans are completely filled with sifted flour, struck off with a ruler to produce a smooth, uncompacted surface, and covered. The pans are placed on top of one-gallon cans to eliminate splash from raindrops hitting the surrounding ground surface. The bottoms of the pans are in a horizontal attitude (i.e., not parallel to the ground surface). At the desired intensity, the covers are briefly removed so that drops impinge on the flour to form pellets. The pans are re-covered after a few seconds and before the drops start to touch each other. This procedure is repeated for each desired intensity.

The flour pellets are air dried for a minimum of 12 hours. Each sample of these semi-dry pellets is screened by emptying the entire contents of one pan onto a 70 mesh sieve to carefully remove as much loose flour as possible. The remaining pellets are then transferred to evaporating dishes and heated in an

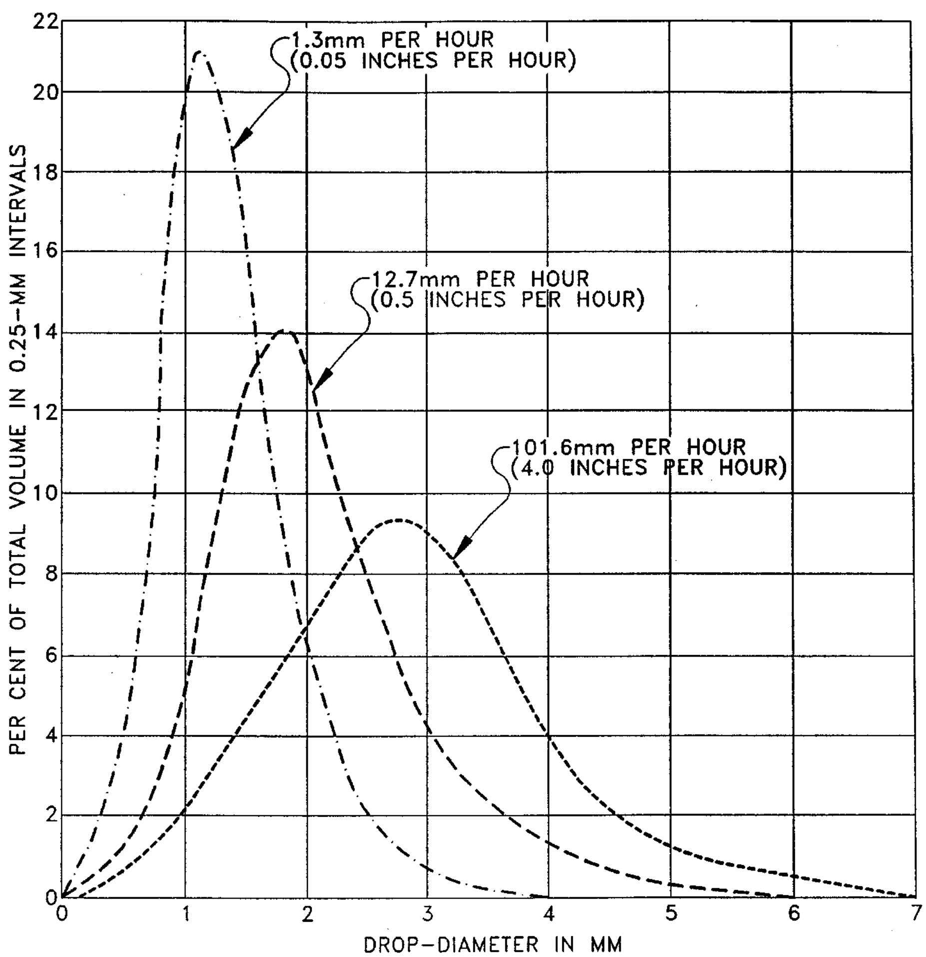

Figure 5. Raindrop size distribution for selected intensities.

oven at 43° C (110° F) for 2 hours. The total weight of the hard flour pellets is recorded. The pellets are sieved through standard soil sieves by shaking the stack of sieves for 2 minutes. Foreign matter and any double pellets are culled from each sieve and the total weight and pellet counts for each sieve are recorded. This calibration procedure is repeated a minimum of three times for each design intensity.

A water drop approaches terminal velocity as it falls vertically in still air. Terminal velocity varies with drop size. Figure 6 shows the relation of distance of fall to drop velocity (Laws 1941) and Figure 7 shows terminal velocity as a function of raindrop size (Gunn and Kinzer 1949). To determine drop velocity, the average height of the drop trajectory is measured using a surveyors rod for each desired intensity. The rod is held vertically into the spray of a single riser and the wetted height is measured. As with the other calibration routines, the measurement is repeated for each desired intensity.

For a given drop size, the percentage of terminal velocity achieved by the rainfall simulators at the soil surface can be determined from the calibration data. The total raindrop kinetic energy at the soil surface, for each target intensity, is determined by summing the kinetic energy of each drop size class multiplied by the relative percentage of that drop size, as determined by the distribution data. The kinetic energy represented by each size class is:

$$KE = 0.5mv^2$$

Where:

KE = kinetic energy of drop size class
m = mass of drop
v = velocity of drop at the soil surface

A more useful measure of the erosive power of rainfall is the Erosion Index (*EI*), which is utilized in both the Universal and Revised Universal Soil Loss Equations, as described in Agriculture Handbook No.

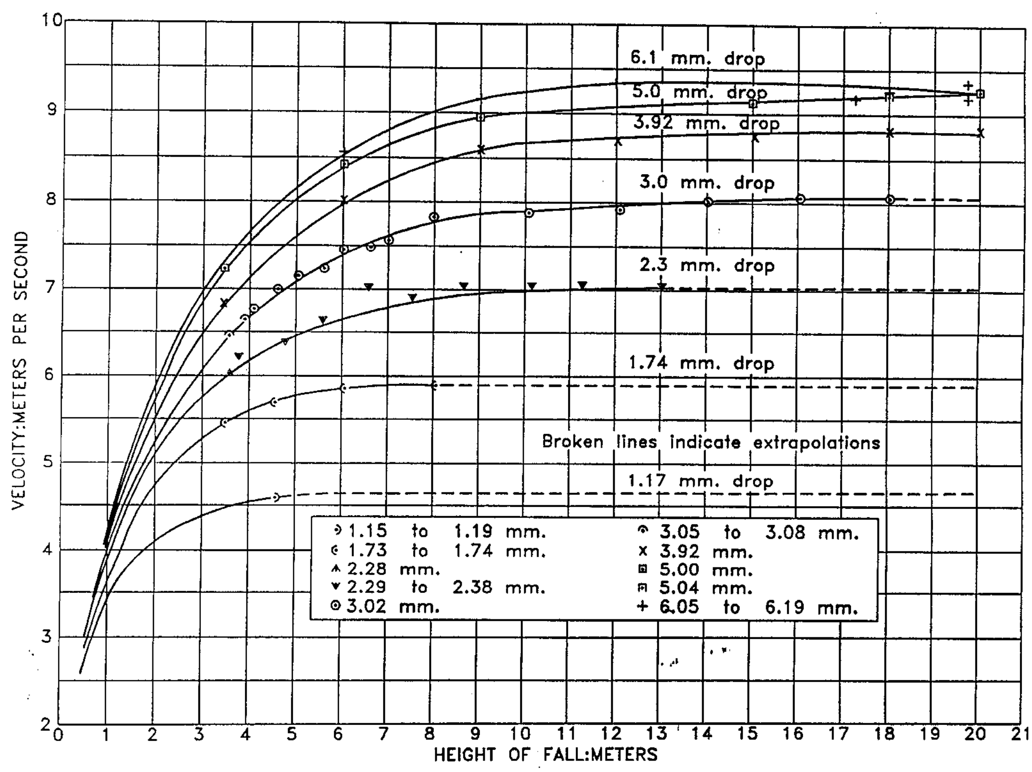

Figure 6. Fall velocity of 7 sizes of water drops (after Laws, 1941).

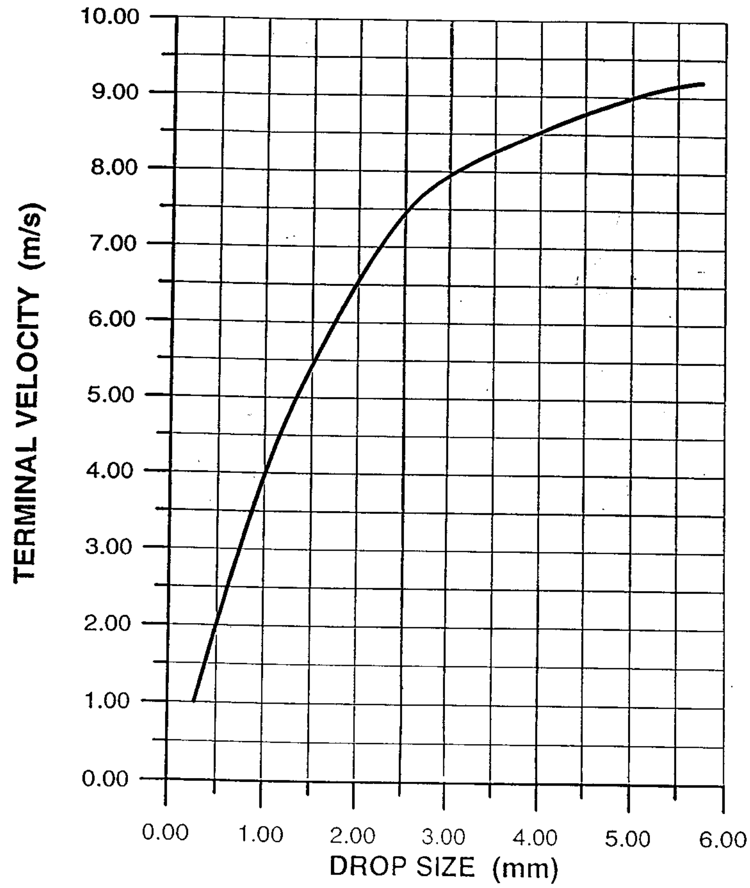

Figure 7. Terminal velocity of distilled water droplets in still air (Gunn and Kinzer, 1949).

537, "Predicting Rainfall Erosion Losses," and Agriculture Handbook No. 703, "Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation." The *EI* value for a single test at constant intensity, *I*, can be calculated as

$$EI = I \times 1099 \times [1 - 0.72 \exp(-1.27 \times I)]$$

Where:

EI = erosion index, as used in USLE and RUSLE

I = rainfall intensity, inches/hr

One intensity/uniformity check is conducted every other month, or after about 8 to 10 test runs, whichever comes first. This check is done using the intensities most frequently utilized in the testing program. Recalibration of the simulator is also conducted when there is a change in equipment (e.g., sprinkler heads, pumps, etc.).

PRE-TEST DOCUMENTATION

A test folder is maintained for each test run, including information on: 1) site conditions; 2) geotechnical and soil conditions; 3) meteorological data, and; 4) material type and description. The site information is subjective and includes the following: general visual conditions of the plot to be tested, general meteorological information, plot treatment, photographs, and any supplemental information that is not included in the following sections but is felt to be of interest to the test. The geotechnical and soils information includes: standard proctor moisture-density relationship, soil texture (USCS classification), and gradation (including hydrometer test for the P200 fraction). The meteorological information includes: all data from the on-site weather for the 30-day period prior to the test (i.e., ambient air temperature, wind movement in kilometers per day, and natural rainfall amounts). The material type and description information includes: manufacturers name (when applicable), product name, product description, product specifications, product size, and a sample of material, if practical.

TEST SET-UP

The test set-up includes the plot preparation and material installation for a rainfall erosion test. To obtain repeatable results, each plot is prepared in a standardized fashion prior to each test. Each test plot is tilled to a depth of approximately 10 cm (4 inches) prior to the placement of erosion control products. The tilled plot is raked smooth with a steel hand rake and lightly compacted with a turf roller. There are no depressions, voids, soft or uncompacted areas. The plot is free from obstructions or protrusions, such as roots, large stones, or other foreign material. Any such problems are corrected before product installation can begin. For plots that have been tested previously, the sediment that was washed off the plot during the previous test is dried and broadcast over the entire plot prior to tilling.

The erosion control product is installed according to the manufacturer's specifications or common industry practice. In the case of rolled erosion products, this procedure documents such information as which side faces up, material orientation to slope, and how much overlap, if any, was provided between adjacent strips. The anchors, installation pattern and termination details are also recorded. In the case of blown-on or sprayed-on products, the total weight of the material applied to the plot is recorded and the method of application described. Regardless of the type of cover material, the material is placed or applied so that no gaps are present along the perimeter edging.

DATA COLLECTION

Test data include: operator name and title, operating pressure, open riser valves, time rainfall began, time runoff from the plot began, time rainfall stopped, time runoff stopped, and volume readings taken at intervals ranging from 30 seconds to 3 minutes (more frequent measurements are recorded at higher runoff rates). Runoff hydrographs are determined from this data.

Since determination of erosion control capabilities is a primary goal of this testing program, samples are collected to determine the total amount of sediment produced from the test plot and the time history of sediment concentrations in runoff during the course of the event. Total sediment from the plot tested is determined by allowing the water in the runoff collection tank to set for at least 1 hour after the conclusion of the test. Excess water is siphoned off and discarded, making sure that the sediment in the bottom of the tank is not disturbed. Depending on the amount of sediment produced during the run, either the entire amount of the settled sediment, or a representative sample, is collected in a labeled, 1-gallon freezer bag. The unsampled portion, if any, is weighed, recorded, and then dried and broadcast back onto the plot surface. Water content of the sampled sediment is determined gravimetrically. The total dry weight of sediment can then be determined by assuming that the entire sediment produced during the test exhibited the same moisture content as the sampled portion.

To determine sediment concentration, grab samples (200 ml) are taken at intervals of 30 seconds to 3 minutes depending on the runoff rate. Sampling commences when runoff starts and continues until runoff stops. Samples are taken from the plot apron in 200 ml laboratory-supplied sample bottles and analyzed for suspended sediment. Rainfall is not allowed to enter the bottle during filling by lifting the cover on the apron and collection trough just enough to gain access for sampling bottle. Each bottle has the sampling time labeled and is then placed in the laboratory-supplied cooler. Sediment concentration curves are then constructed from the laboratory results.

ANALYSIS AND INTERPRETATION OF DATA

Data from multiple tests utilize measured values of total runoff volume, peak runoff rate, time to beginning of runoff, time to peak runoff, and total sediment yield as the primary variables of interest in quantifying product performance. Since all present testing is performed in what we term a "Phase I" condition (i.e., unvegetated), no information regarding vegetation characteristics (e.g., density, type, biomass) is included (see Introduction). In addition, the data are used to determine relevant parameters typically used in hydrologic analysis and erosion control evaluation.

The following parameters are included in this evaluation:

From total runoff volume: Computation of the equivalent runoff Curve Number "CN" for determining total runoff volume as used with the SCS Curve Number method (Soil Conservation Service 1956).

From peak runoff rates: Computation of the rational runoff coefficient "C" used for the computation of peak discharge in the Rational Runoff Equation (Linsley, et al. 1972).

From sediment yield data, comparing bare soil control to various treatments: Computation of the equivalent cover factor "C" for use in the USLE and RUSLE (U.S. Department of Agriculture 1978 and 1997).

Statistical Analysis: Test data and calculated performance indicators, as described above are analyzed using standard statistical methods. Both parametric and non-parametric procedures are used to analyze for differences in means between treatment and control, or between treatments. The Student "t" test will be used for the parametric procedure and the Wilcoxen rank-sum test for the non-parametric procedure.

Values from computations are rounded off to the number of decimal places justified by the data. The answer can be no more accurate than the least accurate number in the data set. Rounding is done on final calculation results only, not on interim results. All calculations and reporting of experimental results adhere to the procedures described in "Experimental Methods for Engineers" (Holman 1984).

CONCLUSIONS

The test protocol for rainfall simulation of erosion control mechanisms described in this paper is based on generally-accepted engineering principles, scientific procedures, analytical methods and statistical standards. This methodology provides the ability to quantify the performance capabilities of a variety of Best Management Practices, including dry-blown straw, hydraulically-applied mulches, erosion control blankets and turf reinforcement mattings in a newly-installed condition. In addition, the application or installation methods of these BMPs can be evaluated to determine their effect on performance. Finally, the performance results can be compared to bare soil conditions to demonstrate the value of these BMPs in reducing soil loss, complying with regulatory requirements, improving water quality, and enhancing environmental conditions.

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EDITORIAL COMMENTS

This paper is based on *The ErosionLab* Rainfall Erosion Facility (REF) *Procedures Manual*, dated 6/97, which was developed and published by Ayres Associates, Fort Collins, Colorado, under contract to American Excelsior Company. This document has been reviewed recently by a number of practicing professionals in industry, academia, and government, and may be modified to reflect their recommendations and to improve the quality of these test protocols. As an ongoing process, comments, suggestions, constructive criticism and questions regarding these testing procedures are encouraged and should be directed to American Excelsior Company, P.O. Box 1067, Arlington, Tex. 76005-1067, Attn: Dwight A. Cabalka, P.E., National Applications Engineer.

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