EVALUATION OF LARGE-SCALE RAINFALL TESTING FACILITIES

Authors Information:

Michael D. Robeson, P.E.
Technical Services Manager
Profile Products
4421 Sunridge Drive
Loveland, Colorado 80538
Phone: 970-481-6932 FAX: 970-797-0471
E-mail: mrobeson@profileproducts.com

Michael D. Robeson is Manager of Technical Services for Profile Products. Michael is a registered Professional Engineer (PE) and holds a BS in Civil Engineering and Masters Degree in Hydraulics from Colorado State University where he also working towards a PhD. He has extensive knowledge and experience in the testing and evaluation of high performance erosion control systems such as articulating concrete block systems and turf reinforcement mats. In addition, he has also worked as a liaison with numerous agencies and private clients in research programs to assess hydraulic designs, modeling and data collection.

Marc S. Theisen, M.S., CPESC
Director of Business Development
Profile Products
3118 Bee Tree Lane
Signal Mountain, TN 37377

Kevin Spittle
Vice President of Research and Development
Profile Products
18912 Peninsula Point Drive
Cornelius, NC 28031

Abstract:

Due to the large influx of erosion and sediment control manufacturers along with national pollutant discharge regulations, there are hundreds of erosion control products specifically designed to protect soil slopes from rainfall induced erosion. One of the most common methods to evaluate performance of erosion control products during rainfall events is to utilize a large-scale rainfall simulation testing facility. However, nearly all of the large-scale rainfall testing facilities within the U.S. operate under different testing or lab standards which utilize varying slopes, lengths, widths, rainfall drop sizes, drop heights and environmental conditions. Therefore, it is often difficult to distinguish or compare product performance due to variability in laboratory setups. This paper will discuss some of the key parameters associated with the simulation of rainfall erosion, review several large-scale testing facility setups and discuss potential changes to existing standards that would encourage the utilization of multiple rainfall testing facilities.

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erosion control rainfall testing, rainfall simulation, slope testing

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1 INTRODUCTION

Due to the large influx of erosion and sediment control manufacturers along with national pollutant discharge regulations, there are hundreds of erosion control products specifically designed to protect soil slopes from rainfall induced erosion. One of the most common methods to evaluate performance of erosion control products during rainfall events is to utilize a large-scale rainfall simulation testing facility. However, nearly all of the large-scale rainfall testing facilities within the U.S. operate under different testing protocol or lab standards which utilize varying slopes, lengths, widths, rainfall amounts and intensities, rainfall drop sizes, drop heights, test duration, and environmental conditions. Therefore, it is often difficult to distinguish or compare product performance due to variability in laboratory setups. This paper will discuss some of the key parameters associated with the simulation of rainfall erosion, review several large-scale testing facility setups and discuss potential changes to existing standards that would encourage the utilization of multiple rainfall testing facilities.

2 RAINFALL SIMULATION TESTING PARAMETERS

Rainfall simulators are research tools designed to apply water in a form similar to natural rainstorms. Simulators can be useful for various types of soil erosion problems. However, rainstorm characteristics must be simulated correctly, runoff and erosion data analyzed carefully, and results interpreted properly to obtain reliable information for the conditions to which the simulated rainstorms are applied.

The ideal rainfall simulator would be inexpensive to build and operate, would simulate rainfall perfectly, simple to move and could be used whenever and wherever needed. Most researchers realize that such a rainfall simulator does not exist. Therefore, different rainfall simulators are designed with different characteristics to reach unique research goals. According to many researchers such as (Lal, 1994), the most important natural rainfall parameters to be closely simulated for erosion control research are raindrop size distribution, raindrop impact velocity and appropriate rainstorm intensities. These three characteristics can be considered key factors in soil detachment, soil surface sealing, and resulting runoff. These parameters and other desirable characteristics for rainfall simulators include the following (from Lal, 1994):

- Drop size distribution near that of natural rainstorms. Natural rainfall consists of a wide distribution of drop sizes that range from near zero to about 7 mm in diameter. The median diameter is between 2 and 3 mm for erosive rainstorms and increases with rainfall intensity.
- Drop impact velocities near those of natural raindrops. Raindrop fall velocities vary from near zero for mist-sized drops to more than 9 m/s for the largest sizes. For example, a common-sized raindrop of 2 mm falls at a velocity of 6 to 7 m/s in natural conditions.
- Intensities in the range of storms for which results are of interest. Intensities of natural rainfall vary from near zero to a couple hundred millimeters per hour. Generally, very low intensities are not of major interest for erosion. Intensities between 25 and 180 mm/hr (approximately 1 to 7 inches/hr) are usually of greatest importance.
- Research area of sufficient size to represent the treatment and conditions being evaluated. Rainfall simulators should be capable of applying rainfall to plots that are large enough for a realistic test of treatment characteristics. Square-meter plots and smaller plots may be sufficient for studying raindrop impact (interrill) erosion, but longer plots are necessary for evaluating scour and transport by runoff. Experience has shown that 5 m is the minimum slope length that will adequately represent a rill and interrill erosion system (Lal, 1994).
- Drop characteristics and intensity of application need to be uniform over the study area.
- Raindrop application needs to be continuous throughout the study area.
- Angle of impact not greatly different from near vertical for most drops.

- Simulators must have the capability of applying the same simulated rainstorm(s) repeatedly.
- Rainstorm conditions must be repeatable when used during common field conditions such as high and low temperatures and winds.
- The ability to simulate rainfall events under controlled and documented conditions.

2.1 PARAMETER FOR COMPARING SIMULATED RAINFALL WITH NATURAL RAINFALL

Researchers have regularly sought a parameter to indicate how closely the simulated rainfall attained the characteristics of natural rainfall. The most widely used parameter has been kinetic energy of raindrops at impact. Basic physics suggests that kinetic energy should be an important parameter. The area over which this energy is dissipated at impact is also important. For example (from Lal, 1994), eight drops 2 mm in diameter equal the mass of one 4 mm drop, but the horizontal cross section of eight 2 mm drops is twice that of a 4 mm drop. The kinetic energy of the 2 mm drop is lower than the 4 mm drop and will be dissipated over twice the area. Thus, the erosiveness of a large drop will be much greater than smaller drops with the same total kinetic energy. Therefore, Lal (1994) suggests that both the drop-size distribution and drop-fall velocity of natural rainfall should be simulated as closely as possible.

2.2 FIELD PARAMETERS FOR EROSION CONTROL PRODUCT APPLICATIONS

When attempting to simulate rainfall, one of the key parameters to consider is the real world application for which the products are being applied. The applications for erosion control products vary considerably across the country and world. However, from a design perspective, it is critical to attempt to determine product limits during laboratory testing in order to effectively apply these products in the field. Listed below are some common applications and conditions for erosion control products on slopes that experience rainfall.

- Varied soil types including ranges from sand to clay.
- Varied slopes from flat up to 1H:1V (Horizontal: Vertical) and occasionally steeper.
- Varied rainfall intensities from less than 25 mm/hr to as much as 180 mm/hr.
- Varied raindrop sizes from less than 1 mm to as much as 7 mm diameters.
- Varied environmental conditions ranging from extreme cold to extreme heat and highly variable wind conditions.
- Varied soil conditions
    - From loose soils to highly compacted soils.
    - Soil moisture ranging from nearly dry to fully saturated
    - Ambient soil temperatures
    - Soil surface conditions ranging from smooth to extremely rough

2.3 TYPES OF RAINFALL SIMULATORS

During that last 50 years, a wide range of equipment and techniques have been utilized to simulate rainfall. The major methods used to produce simulated raindrops for erosion research can be grouped into three broad categories:

1. Sprinkler irrigation equipment that distributes water droplets into the air which fall on the plot. These types of simulators have been found to be less successful in achieving natural rainfall characteristics, especially drop size distribution and uniformity of application (Lal, 1994). In addition, Holland (1969) concluded that sprinkler heads positioned 3 m above the plot surface only approximated 50 percent of the kinetic energy developed by natural rainfall.
2. Nozzles from which water is forced at a significant velocity by pressure downward toward the plot. Nozzles produce a wide range of drop sizes, but the large orifices necessary to obtain large drops usually require that the nozzle spray intermittently to reduce application rates to simulate typical rain intensities.

3. Drop emitters where drops form and fall from a tip starting at essentially zero velocity. Drop emitters produce a limited range of sizes and require higher starting heights to obtain proper impact velocities.

3 RAINFALL TESTING LABORATORIES

During the last 30 years in the erosion control industry, many rainfall product performance tests have been performed. These performance tests have ranged from simple garden hose and sprinkler setups to full scale documented field studies. In the middle of the performance test range are large-scale testing facilities. There are several large-scale rainfall testing facilities in the United States. However, there are only a handful of facilities that are commonly used by erosion control manufacturers to regularly evaluate products. This paper will provide facility setup information and discussion of the following large-scale rainfall facilities. Figures 1 and 2 show photographs of typical outdoor and indoor large-scale laboratory setups.

- San Diego State University - Soil Erosion Research Laboratory, San Diego, California
- Utah State University - Utah Water Research Laboratory, Logan, Utah
- Texas Transportation Institute - Erosion and Sediment Control Laboratory, College Station, Texas
- American Excelsior Company – Erosion Lab, Rice Lake, Wisconsin
- TRI/Environmental - Denver Downs Research Farm, Anderson, South Carolina

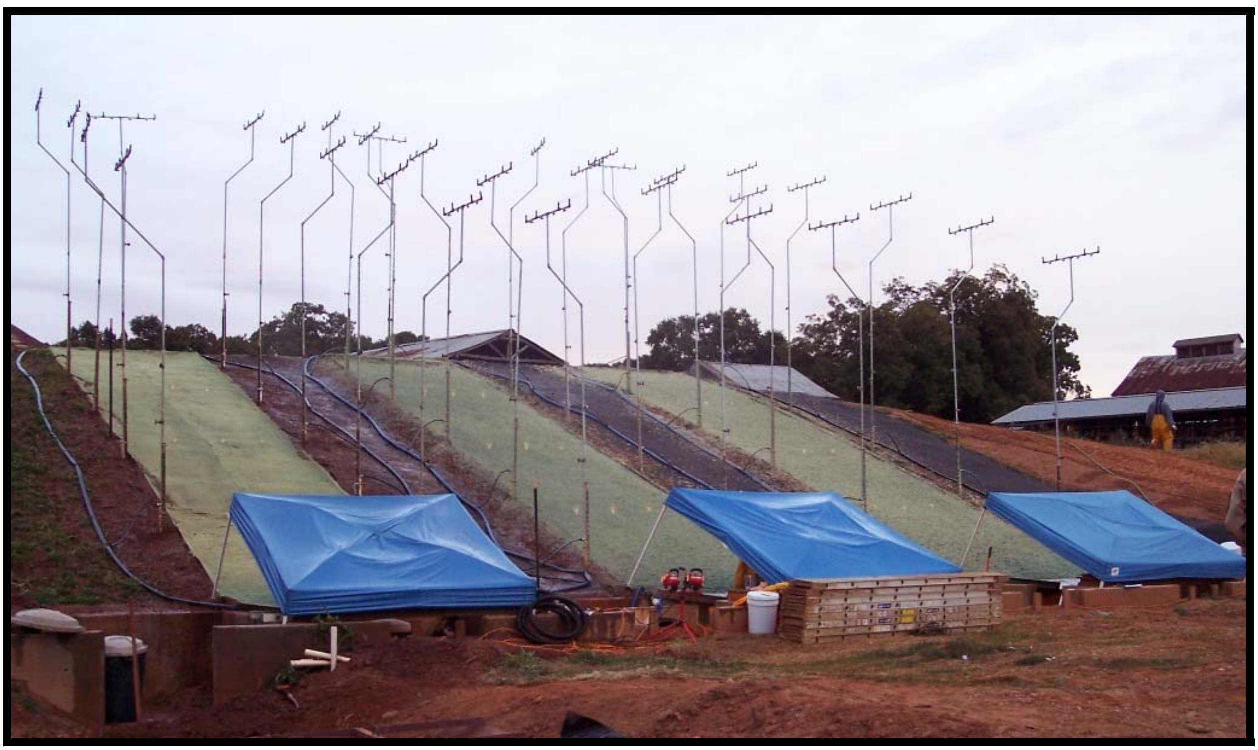

Figure 1: Photograph of Typical Large-Scale Outdoor Facility

Figure 2: Photograph of Typical Large-Scale Indoor Facility

In an effort to provide a basis for discussion, a summary was generated providing some common information available from each of the rainfall facilities as presented in Table 1.

Table 1: Summary of Common Facility Setup Information

Laboratory Location	Simulator Type	Plot Width	Plot Length	Maximum Plot Gradient	Plot Location	Drop Height	Soil Types
(state)		(m)	(m)	(H:V)		(m)	(USDA)
UT	Drop emitter	1.22	5.94	1.5H:1V	Indoor	3.4	Sandy Loam
TX	Drop emitter	1.83	9.14	1H:1V	Indoor	4.3	Sand, Clay
WI	Sprinkler	2.44	12.19	3H:1V	Outdoor	4.3	Sand, Loam, Clay
SC	Sprinkler	2.44	12.19	3H:1V	Outdoor	4.3	Sandy Loam
CA	Nozzle	1.98	7.92	2H:1V	Indoor	2.5	Loamy Sand

As can be observed in Table 1 above, there is considerable variability in many of the facility setups. Plot widths range from 1.22 m to 2.44 m; lengths range from 5.94 m to 12.19 m; indoor facilities have adjustable slopes and the outdoor facilities are typically used at a fixed relatively mild slopes; some are located indoors and some outdoors; each utilizes slightly different soil types; drop heights vary from 2.5 to

4.3 m; and three different rainfall simulator types are represented. Each of the facilities is capable of providing varying levels of rainfall intensities. The maximum listed rainfall intensities for each facility are:

- California: Up to 135 mm/hr
- Wisconsin: Up to 254 mm/hr
- South Carolina: Up to 180 mm/hr
- Utah: Up to 380 mm/hr
- Texas: Up to 102 mm/hr

3.1 KINETIC ENERGY

In addition to the variability of setup between facilities, there is considerable variability in the amount of kinetic energy imparted to the soil. The kinetic energy of a raindrop can be computed as follows:

$$KE = 0.5\ mV^2$$

Where:
KE = kinetic energy of each drop (N-m)
m = mass of drop (kg)
V = velocity of drop (m/s)

Table 2 presents a summary of the variability in drop kinetic energy for a constant drop height of 4.3 m using raindrop sizes from 1 mm to 6 mm. As can be observed in Table 2, the kinetic energy imparted to the soil by a 6 mm raindrop is 850 times greater than a 1 mm raindrop.

Table 2: Summary of Kinetic Energy Calculations for Various Raindrop Sizes

Drop Size (mm)	Drop Height (m)	Drop Velocity (m/s)	Terminal Velocity (m/s)	Mass of Drop (kg)	Kinetic Energy Energy of a Drop (N-m)*1000
1	4.3	4	4	5.2E-07	0.004
2	4.3	6	6.5	4.2E-06	0.08
3	4.3	6.8	7.9	1.4E-05	0.3
4	4.3	7.4	8.5	3.3E-05	0.9
5	4.3	7.7	9	6.5E-05	1.9
6	4.3	7.8	9.3	1.1E-04	3.4

4 POTENTIAL MODIFICATIONS TO EXISTING STANDARDS

The current ASTM standard for evaluating rolled erosion control products during rainfall events is ASTM D6459-07, entitled “Standard Test Method for Determination of Rolled Erosion Control Product (RECP) Performance in Protecting Hillslopes from Rainfall-Induced Erosion”. It was recently re-approved, however several notes were added in an attempt to address concerns pertaining to the standard. Listed below is a summary of the notes that were added to the standard.

- The effect of variations in test plot width, length, gradient and drainage conditions are currently being evaluated.
- Standardized, quantified soil compaction rate is being evaluated.

- Variations in wind speed and direction may affect outdoor test results and should be examined on a case-specific basis.
- Distribution of rain drop size and intensity over the plot may affect results and needs to be evaluated on a case-specific basis.

In reviewing the notes recently added to this standard, in conjunction with the information presented within this paper, and an effort to include most of the currently utilized large-scale testing facilities, a list of recommended changes to the ASTM D6459 standard are presented below.

- In order to accommodate all of the facilities, minimum flume width should be set to 1.22 m
- Minimum flume length should be set to 5.94 m, in an effort to accommodate all of the facilities. This length is supported by research to be sufficient for the development of rill and interrill erosion.
- Minimum flume slope should be set to 3H:1V. However, it should be noted as pointed out during the section on field parameters, that many erosion control products are utilized on slopes much steeper than 3H:1V. Therefore, it would be advisable to test products on as close as possible to slope gradients where their usage is intended.
- Both indoor and outdoor laboratories can be utilized, provided that the effects of wind and other weather challenges can be properly dealt with. The use of wind shields for all outdoor facilities should be required and the maximum wind speed allowed should be re-examined. Currently, the wind speed allowed is up to 8 km/hr (ASTM D6459). Testing should be performed and documented showing that wind speeds up to 8 km/hr do not affect the fall of raindrops or distribution across the plot. It is quite possible that this limit will need to be lowered.
- The current standard allows raindrops between 1 and 6 mm and given that there is 850 times more kinetic energy between the 6 mm and 1 mm drop sizes, this range needs to be narrowed. A drop size range between 2 and 6 mm would yield a difference of 43 times more kinetic energy. A drop size range between 2 and 5 mm would yield a difference of 24 times more kinetic energy.
- If a facility tests at varying rainfall intensities, it must be verified that raindrop sizes increase with increasing intensity. This phenomenon has been observed in nature and needs to be properly represented by the rainfall facilities.
- Drop heights should be maintained at a minimum of 2.5m to accommodate all of the currently utilized facilities. This can be justified as long as the kinetic energy is properly reported for each laboratory.
- One or two consistent soil types should be selected for use by all laboratories. Ideally an ASTM classified sand (highly erodible) and then another more erosion resistant soil that is also ASTM classified and readily available should be considered.
- Once a common set of soil types has been agreed upon, a standard compaction rate representative of typical field conditions should be selected and verified for all tests.
- Soil preparation techniques need to be further clarified and documented to present one uniform way of preparing each of the slopes within the different rainfall facilities. In particular, all of the indoor laboratories utilize a soil box of a specified depth that has an open mesh bottom covered with filter fabric to facilitate internal drainage while the two outdoor facilities are using a full earth embankment. There are likely differences between the two different general techniques. To be consistent, this issue should be further examined and a consistent procedure developed that minimizes any differences between the facilities.
- All test slopes should be prepared to be geotechnically stable. This condition is assumed to be the case for the use of nearly all erosion control products on hillslopes in the field and should be represented in the laboratory. Due to lack of internal drainage, the geotechnical stability of the outdoor labs is a potential issue during heavy rainfall testing. According to Lal (1994), for erosion experiments where runoff and soil loss are the primary indicators of differences in treatments, an open mesh bottom covered with a filter cloth is used to allow free passage of soil water.
- Consideration should be given to both smooth bed and rough bed preparation techniques. This is recommended due to the fact that field conditions consist of both techniques.
- Each facility needs to report a proper representation of the kinetic energy imparted to the soil during each test. Given that there are such large differences of kinetic energy for raindrop sizes, this information is going to be essential for reporting purposes.

- A common analysis procedure should be developed once changes have been made to the standard in an effort to allow testing data obtained at one laboratory to be properly compared with another laboratory. It is quite likely that in order for this to occur, substantial round robin testing involving all interested laboratories will be necessary.

5 CONCLUSION

This paper has discussed key parameters associated with the simulation of rainfall induced erosion on slopes, A review of several large-scale testing facilities and their setups has demonstrated a lack of consistency in how rainfall induced erosion is simulated and eventually evaluated. There are differences in slope gradients, soil types, methods of soil compaction, drainage techniques, rainfall simulator devices, rainfall intensities, raindrop sizes, duration of simulated rainfall events and other testing attributes. This paper has discussed and offered potential changes to existing standards that would encourage the utilization and standardization of multiple rainfall testing facilities.

6 REFERENCES

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