### Design Considerations for a Prototype Erosion Control Testing Plot

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### **1. Introduction**

There are many erosion control products in the market. The concern for state DOTs is to determine which of the products is both effective and economical for a given situation. The information on the products may be of limited usefulness, if for example the soils for which it was tested differ greatly from the soils in the area of application. This problem is exacerbated as new erosion control products enter the market each year and older products become modified using new materials and new methods of manufacture. Large-scale performance testing is, at present, the only reliable method of evaluating a product, although rapid, small-scale tests continue to be developed and analyzed.

In the event that the New England States find it convenient and economical to develop individual or regional large-scale testing facilities, a design approach will be needed. Design considerations include characteristics of the soil to be tested as well as the physical arrangement of such things as test cell size, the rainfall simulators, collection provisions, and calibration and analysis methods. Ideally, the process will be reproducible from day to day and season to season, so that a product tested in one year will show comparable behavior at another time if it has been manufactured the same way. Handling and placing of the test soils is important, as well as maintenance and reuse of the plot. Protocol methodology concerning design of research testing must also be considered.

No report, however comprehensive, can cover all the possible methods of testing. The focus of this report is on methods of obtaining accurate, reproducible results. For this reason rainfall simulators are mentioned in the text and information on them is included in the Appendices. This information will be required when testing to compare products. Everything necessary to obtain quantitative results is mentioned.

Final design of a testing facility depends on local situations, including topography, drainage, etc. that cannot be foreseen by the authors for each and every situation. Nor can the authors identify the hardware and equipment suppliers in each area. Working from the schematics and other information provided, any reasonably experienced professional should be able to direct the construction of a test facility.

For some, qualitative results may suffice. There is no way to present standard test methods for this qualitative approach, since the investigation is dependent on the intuition of the investigator. This type of testing is beyond the scope of this research and report. The information in this report will be helpful to those wishing to use this approach. The size ranges of the test plots and the methods of collecting the samples etc., if desired, will be the same for any approach.

### 2. Literature Review

The U.S. Department of Agriculture has attempted to quantify soil loss for a given area under specific conditions (USDA, 1951). In 1940, the first quantitative equation was developed in the Corn Belt region (Wischmeier and Smith, 1978). It is known as the slope practice method and it estimates soil erosion based on length and percentage of slope. This method served as the foundation for further soil loss equations and was the predominant method of soil loss estimation until 1946. Subsequently, Musgrave (1947) performed an analysis of field measurements and observations in an effort to quantify factors that affect erosion including the amount and intensity of rainfall events. The Musgrave Equation(s) was changed into a graphical rather than analytical analysis of soil erosion by 1952. In 1954, the Universal Soil Loss Equation (USLE) was developed at Purdue University (Wischmeier and Smith, 1978) for agricultural applications. This was the first general equation for soil loss estimation on an annual basis and required three main parameters - a regional rainfall index, a soil erodibility factor, and a cropping and management component.

Rainfall simulators were developed as a means of improving the quality of field and laboratory data on soil erosion tests(Meyer, 1958; Meyer and Harmon, 1979; and Neibling et al, 1981). Simulators can duplicate regional rainfall conditions, such as raindrop size distribution and energy, and allow for repeatable and reproducible test results compared to natural rainfall. The improvements in soil erosion testing and data analysis has led to a revision of the USLE, now known as the Revised Universal Soil Loss Equation (RUSLE). All of the aforementioned methodologies played a role in the development of the RUSLE. The RUSLE operates under the same variables as the USLE except that the RUSLE accounts for seasonal fluctuations in erodibility as well.

Controlling soil erosion on construction sites has only been a concern during the last twenty five years or so (Israelson et al., 1980 a&b) because of its environmental impact on water quality. Erosion control during construction has been achieved by the application of many new geotextile products such as silt fence and erosion control blankets (Koerner, 1986). Recently, organic mulches and source–separated composts (CONEG, 1996) have been proposed for highway applications, and field measurements have shown that they perform well in erosion control (Demars and Long, 1998; Demars et al, 2000). The RUSLE equation has been adopted as the basis for evaluating the erosion control performance of these products.

Because of the proliferation of new erosion control products and the need for product testing, the American Society for Testing and Materials (ASTM) has developed a number of test standards (ASTM, 2004) to evaluate the properties and performance of synthetic and natural (including compost) products for erosion control on construction sites. The ASTM Standard Test Method D-6459 specifically deals with "Determination of Erosion Control Blanket (ECB) Performance in Protecting Hillslopes from Rainfallinduced Erosion" and provides excellent guidelines for testing erosion control products.

### 3. Mechanics of Erosion 3.1 Erosion Process Fundamentals

The RUSLE Equation accounts for the amount of soil eroded from an area of land depending on contributing factors of soil type, rainfall and land characteristics. The RUSLE estimates tons/acre of soil loss per annum. While it can predict both long- and short-term soil loss due to water erosion, it is not considered an accurate measure of erosion for periods less than a year because of climatic variations. These climate fluctuations are represented by the factor R, which considers the yearly rain characteristics. The RUSLE is used in many different ways by soil conservationists and geotechnical engineers to predict erosion and take steps to limit soil losses at agricultural, construction, and watershed sites.

The variables in the RUSLE were determined from an analysis of years of corresponding data (USDA, 1997). The RUSLE equation is written:

- *A* is the erosion loss given in terms of soil loss per unit area. The units of the R and K values define the units of the soil loss
- **R** is defined as the rainfall and runoff factor. The R factor is called the erosivity index and varies according to geographical location. The erosivity index is the annual summation of the energy supplied by all the rain drops in a given area times the maximum intensity over a 30-minute time interval. The energy supplied by a raindrop is dependent upon its size. Tables and maps for the entire United States have been created from compiled data of rainfall the R values from these tables are used in the RUSLE.
- *K* is the soil erodibility factor and is one of the most important variables in the RUSLE. If all the variables that make up the RUSLE were held constant, some soils will tend to erode more than other soils. The K value can be evaluated graphically using a soil erodibility nomograh (USDA, 1978) or by using the K value from Equation 3.10. The soil permeability, the percents of silt, clay and organic matter and the soil structure code are all incorporated in this equation (USDA 1978). The K factor can also be determined from experimental data on different soils while all other RUSLE variables are held constant.
- *L* and *S* are grouped together and referred to as the topographic factor. The L represents the length of the slope and S represents the incline of the slope. The velocity of water flow increases with the incline of the slope and the length of the area over which the water is flowing.
- *C* represents the crop- management or cover factor. In agricultural land this factor generally accounts for the "tillage management crop, seasonal EI-index distribution, cropping history and crop yield level" (USDA, 1997). The C factor

for bare soil is usually assumed to have a value of one. Obviously, there would be a difference in comparing an easily erodible soil, such as silt, with less erodible clay. Both of these "bare" soils will erode different amounts during the same storm event.

*P* is a factor takes into account methods of preventing erosion of tilled land by controlling the movement of water through such measures as proper drainage, contouring and blocking the flow of storm water with sod or other materials, etc. This factor is closely related to the C factor and overlaps its function.

While the RUSLE equation combines all of the variables that affect erosion, it has limitations when predicting the amount of erosion from a plot of land. Predictions are a problem because each variable is not directly related to erosion as the equation implies. Musgrave (1947) summarizes the efforts of researchers to quantify the effects of several variables. For example, the steeper (S) or longer (L) the slope, the more soil can be expected to erode. According to Musgrave, the erosion loss A in tons/acre, have the following relations based on extensive field measurements:

where S is the slope in feet per hundred, and

He also noted the rainfall effect for a given event was correlated with the maximum amount of rainfall occurring within any 30 minute period  $R_{30}$  as:

It would be desirable to control these 3 variables during a testing program that is performed in several different locations, if results are to be compared.

Erosion control products are used to provide short-term cover while vegetation is being established. The effect of these products on erosion is represented in the equation by C. When testing the effectiveness of a cover material in a large-scale test, the steepness and length of slope are constant and the same soil is used in the tests of bare and covered surfaces. Then if a storm of the same intensity and duration is applied to both areas, the ratio of the amounts eroded can be used to compute the cover factor thus:

Caution must be exercised when determining a value of C from the RUSLE. The use of Equation 3.2 may be somewhat appropriate for large-scale tests, when the applied intensity of rainfall approximates that received in a natural storm. Often erosion tests,

especially small-scale tests do not test the system with enough artificial-raindrop energy to calculate a true C. It would be advisable to avoid the use of C when reporting results from tests whose rainfall impact energies do not approach natural field conditions.

### **3.2 Flow Principles**

Both sheet flow on slopes and flow in channels can be analyzed with the Equation known as Manning's Formula (Daugherty and Ingersoll, 1954). This will be demonstrated with the formulas for uniform flow in open channels. The Manning's Equation relating the velocity of the water flow to the characteristics of the channel shape and surface, as well as the slope, can be written:

$$V = \frac{1.486}{n} \mathbf{R}^{2/3} \mathbf{S}^{1/2} \qquad (3.6)$$

where:

V= velocity of flow in ft/s n = roughness factor R= hydraulic radius in ft (area of flow/wetted perimeter) S= the soil slope

Equation 3.6 can be used directly for flow in channels. To use it for sheet flow on slopes, the hydraulic radius becomes the depth of flow, that is the height of water over the soil. The equation then becomes:

$$V = \frac{1.486}{n} \mathbf{H}^{2/3} \mathbf{S}^{1/2} \quad \dots \tag{3.7}$$

where:

H = the height of the water in ft.

The shear stress on the soil surface due to uniform water flow in a channel is given by the equation (Daugherty and Ingersoll, 1954):

 $\tau_{o} = \gamma_{w} R S.$ where :  $\tau_{o} = \text{shear stress}$  $\gamma_{w} = \text{unit weight of water}$ Other symbols as before (3.8)

For sheet flow the equation for shear stress becomes:

 $\tau_{\rm o} = \gamma_{\rm w} \, \mathrm{H} \, \mathrm{S}. \tag{3.9}$ 

Equations 3.6 through 3.9 can be used to estimate the flow and stress conditions that can occur during various storm events. For instance using Equation 3.6 one can estimate the

flow on the surface of a slope and obtain the velocity of the water as it proceeds down the slope and Equation 3.9 allows us to estimate the amount of shear stress being developed. Equations 3.6 and 3.9 allow these calculations for channels. These equations show that while the critical flow values can be obtained in large-scale tests one must be more creative in the small-scale tests.

#### **3.3 Soil Properties**

According to Musgrave (1947) the erodibility of different soils varies with their physical properties. The RUSLE equation accounts for soil effects with the factor K shown in Eq. 3.1. Also, testing of the effectiveness of an erosion control cover must also pay attention to the nature of the soil and its characteristics in addition to the C factor.

The Equation 3.1 must be used with caution. The assumption that the C factor for bare soil is always 1 carries the understanding that the K value predicts the erodibility of soil perfectly. There is limited experimental data that specifically looks at this question.

The USDA has tried to account for the soil factors that effect K using the equation:

 $100K = 2.1M^{1.14}(10^{-4})(12-a) + 3.25(b-2) + 2.5(c-3)$ (3.10)

where:

M is the particle size parameter = %(Silt+very fine sand)\*(100-%Clay), when %Silt < 70%

*a* is the percent of organic matter

**b** is the "soil-structure code" that is used in soil classification. Table 1 of USDA (1993) lists different shapes and size classifications that can be attributed to b values of 1-4 as shown on the soil erodibility nomograph.

c is the classification of the soil permeability where a value of 1-6 is assigned to c.

The application of Equation 3.10 appears to be becoming a lost art. Most soils in the USA have already been classified by the USDA, and the classification includes a value of the soil factor K. Therefore there is little need for members of the Soil Conservation Service to be fluent with the terms in Equation 3.10.

#### **3.4 Accounting for Frost**

New England soils will be subjected to freezing or frost action with the freeze zone extending 3 feet (1 m) or more below the surface. As the water in the soil pores freezes, it expands in volume and the soil volume increases by increasing its amount of voids. Thus the density of soil (mass/ volume) decreases. The volume change can be large if frost lenses develop due to high water table and capillary action in the soil. During the spring, the frost melts from the soil surface downward and the soil is especially loose/soft and vulnerable to erosion in a heavy rainstorm. Since each soil and site conditions create a different response to freezing, it is difficult to quantify the effects of frost action on erosion.

Equation 3.10 contains factors that are directly altered by frost action in soils. The primary effect of frost is to expand the grain structure, thus increasing the porosity and reducing the dry unit weight. This action will result in an increased soil permeability and is likely to alter the soil-structure. However, there is no information in the literature as to the effects of frost on the "b" and "c" parameters in Equation 3.10 but a looser (less dense) soil would be expected to be more erodible than a dense soil.

### 4. Field Test Site Design and Preparation

### 4.1 General

A test site must be selected based on the purpose and length of testing anticipated. If the tests are to be conducted by natural rainfall, it is very important that the site can be easily accessed after every rain event. In addition the site must be secure, since untended equipment tends to attract vandals. The size of the test site depends on the number of test cells to be run simultaneously. A desirable site might be adjacent to a State DOT facility.

### 4.2 Geometric Aspects to Consider

The tests will be best conducted on a slope, cut or fill. DOTs tend to make slopes as steep as practical which is usually 2H to 1V. This slope is somewhat steeper than the 3H to 1V recommended by ASTM D-6459, but the testing should be done on the steepest slope on which the product will be used.

The test site will consist of a number of test cells. Each test cell should be at least 5 ft (1.5 m) wide, but might be as wide as 10 ft (3.1 m), depending on the width of erosion control product to be tested or the size of the earth moving equipment available to service the cell. The equipment will be needed to replenish and compact the test soil between test runs and must be able to work between the boundary boards between cells.

Boundary boards are used to insure that the rainfall-runoff from one cell does not flow over the areas of adjacent cells. In this way the amount of rain falling on the area of one cell can be related to the amount of runoff and eroded soil. If wood boards are used, they can be treated with a preservative that does not pollute the environment. As an alternative, boards made of plastic or metal could be used.

The boundary boards can be any convenient size, depending on the manner in which the investigator wishes to manage the site. Boards are embedded in soil to prevent flow from one cell to adjacent cells. Wood boards could be 1'' (2.5 cm) x 6'' (15 cm) or 1'' (2.54 cm) x 8 '' (20 cm) wood planks embedded approximately 3'' (7.6 cm)+/- into the soil and, thus, stick out of the soil about  $2\frac{1}{2}$  + inches (6.3 cm). Boundary boards can be left in place once the cell has been constructed, or they can be removed to add a layer of soil, then replaced.

The length of the cell must be at least 20 ft (6.1m) long, to insure sufficient soil is eroded on the control cell to make a confident measurement. The length of the cell may be extended to 30 ft. (9.2 m) or 40 ft. (12.2 m) as conditions may allow. ASTM D-6459 recommends a cell size of 8 ft (2.4 m) x 30 ft (9.2 m).

A diagram of a single test cell is shown in Figure 4.1. Details of the collection system can be seen in Figures 4.3, F-3 and F-6. Figure 4.3 is a schematic diagram of the box containing the tipper bucket with the inlet and outlet pipes and mechanical counter. Figure F-3 is a top-side photo of the box and Figure F-6 is a front view of the box.

A test facility may comprise many of these test cells placed side by side as shown in Figure F.1. The boundary boards are on the sides and the top and bottom of the cell. The bottom of the cell has a plastic sheet as shown and the boundary boards are at about a 45 deg. angle so that the runoff and eroded material will be directed to the collector. Figure 4.2 is a side view of the cell showing the recommended slope and the set-up for testing filter berms and silt fences. Several photos of a typical multi-cell field installation are shown in Appendix F including the flow measuring tipper box and water sample collection system (Figure F-3). A schematic diagram of the tipper box is shown in Figure 4.3. A tipper unit can be purchased from any supplier of home septic system components and it is usually placed in the distribution box of a system.

There is a basic problem with using natural rainfall to examine the performance of erosion control products. There is no way of predicting the total capacity of collection system that will be required for the variety of storms that may occur. It is required that the capacity of the collection system not be exceeded, because if an overflow occurs there is no way of obtaining a representative sample. Therefore it is recommended that only a fraction of the runoff be collected, as reported by Demars et al (2000). An example of this arrangement is shown in Figure F-6. This figure shows a setup to collect approximately 1/5 or 20% of the total runoff. The primary purpose of the collected runoff is to measure its solids content. It is assumed that the collected sample is representative of the runoff. The amount of runoff is measured by the tipper bucket shown schematically in Figure 4.3. As can be seen from Figure F-6 in the appendix, the front of the box has 5 equally spaced round holes, which are the easiest holes to cut. The pipe from the middle hole conducts the runoff into the collection bucket, shown in Figure F-6 with its top covered with plastic. The purpose of the plastic cover is to exclude rain falling on the collection system from entering the bucket.

NOTE: Boards staked every 5' to prevent flow between cells and surrounding areas.



Figure 4.1 Schematic Diagram of Test Cell. Dimensions may vary.



Figure 4.2 Schematic Diagram of Test Cell Prepared for Filter Berm Test



Figure 4.3 Schematic Diagram of Tipper Box for Flow Measurement

### **4.3 Soil Selection and Preparation**

ASTM recommends erosion control product testing with three different soil types including a sand, loam and clay. The recommended sand has a fine to coarse gradation with some silt and clay which reduces infiltraton of water and promotes runoff needed for erosion. The loam is a well-graded silty sand of low plasticity with a plasticity index PI =  $4.5 \pm 2.0$  and typical of many glacial soils (tills) found in New England (Figure 4.4). The clay is of medium plasticity with a PI =  $15.0 \pm 2.0$  Gradation curves for typical sand and loam materials are provided in ASTM D6459. The cost of testing three soils, however, greatly increases the cost of testing an erosion control material. Long and Demars (2004) have suggested that results from a single, well-graded soil such as the ASTM loam can provide important information if the eroded sediment is collected and analyzed for particle size distribution. This recommended particle size analysis will define the effectiveness of erosion control products for a given soil type. This is important, since each erosion control product is unlikely to be effective against all soil types.

The test bed will normally contain the soil of interest. Erosion during the test will selectively remove soil particles of some smaller sizes. For subsequent tests, the top 3 inches (7.6 cm) of soil should be replaced with a fresh supply of the soil of interest. The soil left in place is referred to as the base material. This can be leveled with a steel hand rake and lightly compacted with a lawn roller. The base material that comprises the embankment may be significantly compacted to Proctor density and finish graded by a dozer. The base material can be graded with a steel hand rake with the surface left rough for good contact with the layer of test soil. Any depressions, voids, soft spots or uncompacted areas should repaired before testing commences. Large obstructions and protrusions should be eliminated from the surface by removing roots or stones before grading the base and surface layers.

Certain particle sizes are lost to the erosion process during each testing or storm event. Since the particles lost tend to be the smaller particles, the particle size distribution changes somewhat with each event. The particle size distribution will shift toward the larger sizes. As testing progresses it will eventually necessary to change or add soil with the original particle size distribution. This will require replacement of a layer of surface soil about 2 or 3 inches thick.

The amount of soil needed to be replaced can be found by multiplying the length of the area by its width by the thickness of the soil to be added. For a plot 5'x20' to which must be added 3" of soil, the amount of soil to be added is 25 cubic feet. The same thickness of soil to be added to a plot 5'x30' would require 37.5 cubic feet. These quantities of material are small enough that they could be placed and graded by hand if the site is not accessible to equipment such as a backhoe.



Figure 4.4 Typical Gradation Curves for New England Silty Sand

Following testing, it could also be removed by hand if necessary and discarded so the testing sequence can be repeated on a given plot free of rills and gullies. If the new soil differs significantly from the previous test soil, additional soil properties should be measured as discussed in Section 6.2.

### **4.4 Erosion Control Treatment**

Placement of an erosion control material treatment should follow the manufacturers' or industry-wide specification. While some materials such as composts and mulches are held in-place on a slope by friction, most sheet materials are stapled to a slope and the manufacturer may specify a particular staple type and an elaborate stapling pattern. The material should completely cover the test plot up to each boundary and this may require trimming with scissors or a utility knife. Some materials may have a preferred orientation to the direction of runoff or a top and bottom side. Joints may have a specified overlap and termination details at top and bottom of the test plot should be followed. All of these installation details should be given the opportunity to install their product. Once a product is installed, there should be no further foot traffic over a test plot and a photographic record of test plot details should be prepared prior to testing. The photo documentation should include material close-up, staple pattern, overlap, termination and boundary details.

### **5. Field Erosion Testing Program**

### 5.1 General

Tests can be run in many ways, depending on the objectives of the activity and agency. Those designing the tests must be aware of the problems and pitfalls of each technique. Without proper planning, testing is a candidate for unanticipated consequences. One of the most difficult questions in testing is," Will this set of measurements give me the information I need?"

Large-Scale tests can be run using natural rainfall or a rainfall simulator to apply water to the test cells. The method used depends upon the information desired, and the time in which it is required. If the interest is in comparison testing with no specific performance requirement for a storm of a given intensity, side by side tests can be done as reported by Demars et al (2000). Tests using natural rainfall may at first seem simple and may therefore be preferred by some, especially for less conventional erosionprotection covers such as wood waste or composted material. Average rainfall, however, does not occur every year, but over a period of years. Testing over a period of years may well exceed the length of time the protective cover is needed to prevent erosion for an application.

Testing using rainfall simulators are normally planned with the intensity and duration of the critical design-storm. These tests can be done quickly with conditions that can be readily reproduced, but the technique requires a device to simulate rainfall. Testing using either water source can be conducted with the cells shown in Figure 4.1 and Appendix F (Figures F.1 to F.6). The use of a number of cells (for side by side comparison) when using natural rainfall is recommended to insure that different products and replicates are subject to at least similar rainfall events.

Regardless of how the testing is carried out, collection of the eroded soil samples and analysis will be the same. The samples of runoff (water + soil) can be dried and weighed as described in most elementary text books on Soil Mechanics (Das, 1998). These texts also describe methods of measuring the particle size distribution of soil.

#### 5.2 Large-Scale Tests with Natural Rainfall

The research report by Demars et al (2000) contains many of the basic concepts for this type testing. Briefly, the testing was done at a site large enough to contain 14 cells, three of which were bare soil cells. Rainfall was measured with an electronic rainfall gauge (Figure F-4) to determine both magnitude and intensity. Amount of runoff was estimated from the number of tippings of a bucket of known volume (Figure 4.3). The discussion here will concentrate on the lessons learned and the difficulties that should be expected and planned for in this type testing.

1.) It is especially important to insure that the intensity and amount of rainfall in each storm event is accurately measured with electronic rain gages located in each cell. The intensity and amount of natural rainfall can vary measurably over small distances in each natural event. For instance in the work of Demars et al (2000), the attempts to compute the amount of runoff from the soil in the cell sometimes yielded negative results. The most likely explanation for this phenomenon is that the amount of rain falling on the cell under investigation was less than the cell containing the rain gage. Calculating the amount of rain that fell on the plastic apron using the amount of rainfall measured by the closest gage resulted in a value that was too great. This computed amount subtracted from the amount of measured total runoff for that cell resulted in a "negative" amount. Another factor in this measurement-calculation was the condition of the soil in the cell at the beginning of the storm event. When the soil in the cell is dry at the beginning of the storm event, the rain falling on the ground during the early stages of the storm event will percolate into the dry soil instead of running off. The combination of dry soil and varying intensity of rainfall over the area probably caused the "negative" result. One way of preventing this is to measure the amount of rainfall with a gage at each plastic apron.

2.) It is impossible to know exactly when natural rainfall will deliver a storm event of the intensity and duration to test the erosion product under the worst conditions that the product may experience when used in that region. A good example is the work of Demars et al (2000). During the particular summer of those tests the natural rainfall was less than average and the products would not have been subjected to a storm of 3 in/hr if there had been no event provided by the effects of a hurricane. Unless the product is subjected to the intensity and duration of a storm event that can be considered a design storm or one of greater intensity there is no way of extrapolating the data to obtain the needed information on performance. Therefore the test must continue until the product is exposed to at least one storm event representing the intensity and duration that the product will experience in service.

3.) Rainfall events tend to occur in clusters. An intense storm event usually does not last very long, often preceded and followed by storms of lesser intensity. The ability of the data to predict performance of the product under worst conditions depends on the diligence of the data collectors in retrieving samples from the site for a single storm event. This will often require collecting samples on holidays and weekends. If samples are not collected in a timely manner, average values are obtained, which may not answer the question about losses from intense storm events.

4.) A major problem with natural rainfall events is the amount of runoff to expect. It is often impossible to collect all of the runoff from an intense rainstorm, especially since the intensity and duration of the event is not known in advance. One effective method of dealing with this is the collection of a predetermined portion (1/5) of the runoff as reported by Demars et al (2000) by sampling only one of five equal exit holes in the tipper box.

5.) Diligence is also required in maintaining the test site throughout the testing of a product. The control and product cells must remain free of vegetation if the product is to be evaluated properly. The presence of roots will reduce the amount of soil that will erode from the cell. Over the course of several weeks various plants tend to seed themselves in the soil of the cells. These plants must be eliminated, if the accuracy of the results is to be maintained. The plants cannot be removed by pulling since the removal of roots from the soil in this manner will loosen and disturb the soil surface. The only way to handle this problem properly is to visit the site at least weekly and spray the plant life with a herbicide.

6.) A question of interest is, how well will vegetation grow beneath the product? The question can best be answered by a growing test, separate from the cells measuring erosion. It is relatively easy to set up some separate samples in boxes in which the soil is seeded and covered with the erosion product.

Another aspect of which one must be aware, is the influence of water content on the soil at the beginning of the storm on the amount of soil eroded. The action of the water will depend on the state of the soil. If the soil is dry the initial rainfall will percolate into the soil and run off will erode the soil only when no more can be absorbed. This will affect the amount of runoff and therefore the amount of eroded soil from the storm event. As a result the amount eroded from a given intensity and duration storm will vary inversely according to the water content at the beginning of the storm, that is the drier the soil the less runoff.

### 5.3 Repeatable / Reproducible Results

Most of the early field testing programs established test plots on a natural or manmade embankment (Musgrave, 1947; W&H Pacific, 1993; Demars and Long, 1998) and used natural rainfall to evaluate soil erosion and erosion control product performance by means of the RUSLE parameters. The use of natural rainfall creates several problems when evaluating erosion control products; the most significant being the lack of repeatable rainfall since no two storms are exactly alike in magnitude, intensity and duration. The frequency of natural storms is unpredictable with many thunder storms being localized in area. Test plots may dry-out during periods between storms in the summer. Subsequently, during a small storm the soil may absorb all of the water without eroding. In the spring the soil may be saturated and experience significant erosion from a small storm. Many natural storms are too small (less than ½ inch of rain) to generate measurable erosion, yet they will disturb a test plot enough to require cleaning and recalibration before the next rainfall event (Demars et al, 2000). Thus a substantial effort is needed to obtain useable data.

For test results to be reproducible under these conditions, it would be necessary to have multiple test plots (at least three to be statistically significant) with the same geometry and treatment and a similar number of untreated plots for comparison. The quest for reproducible results has led to the development of standardized tests (ASTM, 2000 i and ii) to evaluate the performance of erosion control materials. These tests attempt to simulate the conditions typically found on a construction site at the conclusion of earthwork operations but before the vegetation is re-established. This is achieved by subjecting a prepared test plot to simulated rainfall in a controlled and documented environment. The key elements of such a test include a) a rainfall simulator with calibration procedure, b) selection of test soil and test plot preparation, c) properties and documentation of erosion control material, d) preparation of erosion control material, e) performance of test, f) measurement of runoff and mass of eroded sediment, g) analysis of data, and h) reporting of results. Details of each element are presented in the ASTM Standards.

The use of a rainfall simulator is essential to obtaining repeatable and reproducible results. A simulator can be used to pre-condition a test plot, to initialize soil moisture and to eliminate the randomness and uncertainty of natural rainfall events, to reduce test time and to increase the efficiency of a test by providing rainfall on demand. There are many rainfall simulator designs and the Norton Ladder Rainfall Simulator (see Appendix B) was developed by the USDA National Soil Erosion Research Laboratory. These simulators are commercially available and a quote for 3 different size models is presented in Appendix C. These are presented to give the reader an estimate of the cost and should not be considered an endorsement of the product. A six-head model is needed for a test plot that is 5 feet (1.5 m) wide by 20 feet (6.1 m) long. These simulators are made of aluminum to minimize weight so they can be moved by hand.

### **5.4 Rainfall Calibration with Gauges**

Once a rainfall simulator has been calibrated (see Appendix A) and a calibration schedule is in place, there is little need for detailed rainfall data collection during each test. However, ASTM recommends that 20 visual rain gauges be used in the calibration process of the simulator to measure rainfall intensity and uniformity of rainfall application. The calibration process is to be performed annually or following equipment maintenance. At least one rainfall intensity/ uniformity check should be performed every 90 days, or after 4 products have completed a test series, which ever comes first. An electronic rain gauge should be used for each product tested to provide a rainfall-time graph as part of the test documentation. This graph can also be used to spot check the calibration of the rainfall simulator.

The size distribution of rain drops varies with storm intensity. More intense rainfall has larger drop sizes. Two examples are illustrated in a figure in Appendix B. A method for measuring the rain drop size distribution is given in ASTM D-6459 and is briefly summarized in Appendix A.

### 5.5 Measuring Runoff and Erosion

There are several methods for measuring the volume of runoff and the mass of sediment eroded from a test plot. It is important to note that the total volume of runoff can be large depending on the type of soil and initial degree of soil saturation. For every 1-inch (25.4 mm) of rainfall that runs off a 5 foot by 20 foot test plot, the total runoff volume will be a maximum of 8.33 ft<sup>3</sup> (136.5 l) or 70 gallons, if there is 100% runoff (or no percolation). Therefore one method to measure this volume would be to collect it in a calibrated 100 gallon tank placed at the bottom of the test plot. The mass of sediment could be determined by stirring the tank to suspend all of the solids and collecting several representative bottle samples. These samples could be oven-dried in the laboratory to determine mass of sediment /volume. This method would yield the runoff volume with time and could also allow determination of mass of eroded sediment with time by collecting sediment samples at a prescribed interval such as every 3 minutes. The tank could be drained after each test and the process repeated. Also, a sediment sample of eroded material could be obtained by allowing the tank to settle for a period of time and siphoning the water without disturbing the sediment. The sediment collected in this fashion could be subjected to gradation analysis to further evaluate the performance of the erosion treatment.

An alternative method would involve a flow measuring device such as a calibrated tipper bucket (Demars et al, 2000), as shown in Figure F-3, where the flow volume per tip is calibrated in the laboratory. Each tip of the bucket could be measured with a mechanical digital counter to determine the total flow volume. An electronic data logger could be added to determine the time of each tip and thus the flow volume with time. The outflow from the tipper box could be sampled in a bottle at a prescribed time or tip interval to determine the mass of sediment eroded with time (Figure F-6)

### 5.6 Short- and Long-Term Testing

An important feature of a test system is the ability to perform both short-term testing over a period of days or a few weeks and long-term testing over a period months or a year to evaluate erosion treatment performance and changing conditions such as the effects of frost, plant growth/ weed control or erosion winnowing. The use of a portable rainfall simulator will allow a prepared plot to be tested with the same rainfall dosing. Thus, a single test plot can be evaluated before treatment, after treatment, after turf establishment, during frost penetration and after frost removal to look a time effects on site modification. One test series, consisting of three repetitions of the same rainfall, should only take one or two days. Thus, the test apparatus could be moved to an adjacent test plot for testing another product or parameter of interest before returning it to the original plot to examine time effects.

### 6. Laboratory Testing

### **6.1 Erosion Control Product**

In addition to testing products in a soil erosion test cell, the products should also be subjected to a number of properties tests to either confirm manufacturer product data, if available, or provide material properties data. The tests cited below have been mentioned by various test facilities such as TTI. Some of these tests follow ASTM Standards. All of these tests may not be crucial for all applications. Several ASTM standardized tests have been developed which are relevant to erosion control products and some of the properties need to borrow test methods from other materials such as soil and clothing textiles. These tests for temporary degradable products (used to enhance the establishment of vegetation) include:

- 1. Tensile Strength -ASTM D 5035
- 2. Thickness ASTM D 5199
- 3. Creep Limited Strength- ASTM D5262
- 4. Mass per Unit Area ASTM D 5261
- 5. Water Absorption
- 6. Swell
- 7. Light Penetration- ASTM D6567
- 8. Stiffness
- 9. Smolder Resistance

For permanent non-degradable products (used to provide long-term reinforcement of vegetation) the properties include:

- 1. Tensile Strength ASTM D 5035
- 2. Thickness- ASTM- D 5199
- 3. Creep Limited Strength- ASTM D 5262
- 4. Mass per Unit Area ASTM D 5261
- 5. Specific Gravity
- 6. Porosity
- 7. Open Volume/ Unit Area
- 8. Stiffness
- 9. Light Penetration- ASTM D6567
- 10. U. V. Stability (% tensile retention) ASTM D 4355

For bulk erosion control materials such as source separated compost, wood chips, pine bark mulch or pebbles, the testing should include:

1) Organic Matter Content -ASTM D 2974

- 2) Moisture Content ASTM D 2216
- 3) Particle Size Distribution –ASTM D 422
- 4) Conductivity Measurement of Soluble Salt- ASTM D4542
- 5) Compost Stability Index by Dewar Self Heating Test
- 6) Acidity Determination of pH- ASTM D 2976

### **6.2 Testing Soil- Before and After**

Many erosion control products, such as silt fence, filter berm or geotextile mat, may only be effective retaining particles larger than a specific size -i.e. have a lower size limit of effectiveness. These soil particles, smaller than the lower size limit, would move along with the runoff water. It is these fine particles that are the most problematic, should they enter water course, stream or lake, because they can remain in suspension for a long time. This filtering action of an erosion control product is an important aspect of performance that should be determined.

The soil used on the erosion test cells should be similar to that shown in Figure 4.3 with a large range of particle sizes. Thus, the soil particles that move through an erosion control product can be collected along with the runoff water to determine the suspension density of the runoff (Demars et al, 2000) and determine turbidity level that is problematic. The sediment in runoff can be allowed to settle from suspension, decanted to remove excess water and oven-dried. This dried sediment can be analyzed for particle size distribution by hydrometer using ASTM Test Method D422 Particle-Size Analysis of Soils. This technique can be used to determine the largest particles that pass through the test cell which is the lower limit of effectiveness for a product.

#### 6.3 Small-Scale Erosion Control Testing

There is considerable interest in using small-scale or bench top testing as a replacement for large-scale field testing, because of the lower costs involved. The Erosion Control Testing Council (ECTC), a manufacturers' organization has developed the testing protocols in use today. At present there are two ECTC testing protocols: one attempts to index erosion control products based on their ability to prevent rainsplash-induced erosion and the other attempts to index erosion control products on their ability to prevent channel erosion caused by the shear stress of flowing water. Long and Demars (2004) reviewed the advantages and disadvantages of these small-scale tests and concluded that there is presently insufficient information to correlate the results from these tests with field performance. They further note that some modification to the test equipment will be needed before small-scale tests provide an effective correlation.

In the meantime, there is a Federal Highway Administration sponsored study just concluding at Colorado State University to compare large-scale to small-scale test results in hopes of finding some correlation. Yet the cost and difficulty of running large-scale tests will continue to push the need for small-scale, less expensive testing at the benchscale.

### 7. Summary, Conclusion and Recommendations 7.1 Summary

This study examines the design requirements and testing protocol for a soil erosion control testing facility in New England to evaluate erosion protection products and techniques. This study is based on a literature review of current and past erosion testing experiences. Only field erosion testing is considered. The testing facility design/ protocol is evaluated considering current soil erosion theories. A series of recommendations was prepared for the New England DOTs that is based on ASTM standard test methods and that considers the economics and quality of results of erosion testing.

### 7.2 Conclusions

1) There are well developed test standards available from ASTM for determination of erosion control product performance in protecting soil slopes from rainfall-induced erosion. These test methods can be used to evaluate other erosion control products such as composts, mulches, hay/ hay bales and crushed stone.

2) Repeatable and reproducible erosion performance data will require standardizing the test soil(s) size distribution and placement density, the simulated rainfall including drop size, velocity and energy and the test plot including area, length and slope. Quality control will require periodic calibration of the rainfall simulator and routine measurements of soil properties.

3) The primary advantage of standardized testing is that short- and long-term test results can be compared to isolate erosion control effects of interest such as plant growth, soil density and frost penetration.

### 7.3 Recommendations

The New England DOTs should develop an erosion control field testing facility that examines, in detail, the costs and advantages of a system based on simulated rainfall. The erosion test results from rainfall simulators can be compared to natural rainfall on a specific test site and can be moved to adjacent states to compare portability. Long-term and seasonal effects can be studied to assess the utility of simulators.

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### 9. Appendices Appendix A. Calibration of a Rainfall Simulator

A rainfall simulator should be calibrated a minimum of once per year or following maintenance of the equipment (ASTM, 2004). Calibration should include measuring the rainfall intensity across the test plot and determining the rain drop size distribution for each intensity.

The rainfall intensity should be measured when the wind velocity is less than 5 mph (about 8 km/h. ASTM recommends that 16 to 20 rainfall site gauges be used to measure the uniformity of rainfall intensity. Each rain gauge should be spaced to cover about the same tributary area (about 2.5 x 2.5 feet on a side). Rainfall intensity measurements should be made for 15 minutes (+/- 1 second) with the rainfall simulator repositioned until an even rainfall distribution is attained as defined by the Christianson uniformity coefficient, a statistical method.

The drop size distribution is to be measured for each rainfall intensity using three pie pans with sifted flour, struck off with a ruler to produce a smooth, uncompacted surface. The three pie pans should be placed along the centerline of the test plot and positioned about 8 inches off the ground on a horizontal support such as a paint can. Each pie pan should be covered when the rainfall starts and then removed for a few seconds at the desired rainfall intensity to form pellets in the flour. This process should be repeated for each intensity. The flour pellets should be air-dried for a minimum of 12 hours. The semi-dry pellets should be sieved with a 70 mesh sieve to remove excess flour and the remaining pellets should be dried for another 2 hours at 43 C (110 F). The hardened pellets should then be sieved through a nest of standard sieves to determine equivalent raindrop size distribution. ASTM recommends performing this procedure three times for each desired intensity. The raindrop fall height should be measured for each intensity by using a surveyor's rod held vertical in the spray and determining the wetted height.

### Appendix B. The Norton Ladder Rainfall Simulator (SPECIFICATION SHEET supplied by Advanced Design and Machine Co., Clarks Hill, Indiana)

Designed by USDA National Soil Erosion Research Laboratory-NSERL at Purdue University, West Lafayette, Indiana

### 1) Summary

Rainfall simulator is the ideal tool for soil infiltration, soil erosion, and other relative field researches, it can successfully simulate the process and characteristics of natural rainfall simulator. Those include rainfall intensity, raindrop size and distribution, terminal velocity, rainfall energy, spatial distribution of raindrop and validity rainfall area. The simulator should be light enough for transportation and suitable for field conditions. The rainfall simulation process should not be influenced strongly by wind. A curtain should be installed on the wind side to protect the rainfall, but is not included.

### 2) Reference standards

The Norton Rainfall Simulator guidelines, listed in this document, are information guidelines supplied by the National Soil Erosion Research Laboratory, United States Department of Agriculture, West Lafayette, Indiana. It is the responsibility, of the people operating the simulator to achieve results based on these guidelines.

### 3) Operating environment

Environmental temperature: 5 to 43.9 C (must be above freezing) Max. Humidity: 90% The simulator can be used normally at slopes as steep as 20% slope. If slope greater than 20%, it is recommended that the down slope side legs be supported to not exceed the 20% slope.

### 4) Technical data (supplied by NSERL)

NSERL has furnished the following technical data, which is believed to be reliable, but which seller does not warrant.

### Norton-Style Multiple-Intensity Rainfall Simulator

The Norton-style multiple-intensity rainfall simulator is based on the programmable oscillating VeeJet nozzle rainfall simulator developed by USDA soil erosion scientists at

West Lafayette, Indiana. The technical information presented here is based on the results presented in the literature on the oscillating VeeJet nozzle rainfall simulator.

The selection of the VeeJet nozzle for rainfall simulation research was based on the work of L. D. Meyer in 1958. Dr. Meyer evaluated 4 nozzles: VeeJet 80100, VeeJet 8070, FullJet 106SQ and FullJet 50SQ, for their drop size, velocity, kinetic energy and spray pattern and selected the VeeJet nozzle for rainfall simulation (Meyer, 1958).

Two types of spray nozzles are used in the Norton-style multiple-intensity rainfall simulator, the VeeJet 80100 and VeeJet 80150. The drop size distributions at 41  $N/m^2$  (6 psi, pound per square inch) are shown below (Meyer and Harmon, 1979):



The exit velocity of the VeeJet nozzle is 8.8 m/s under a nozzle pressure of 41 N/m<sup>2</sup>. With 3 m fall height, the larger drops gain speed toward their terminal velocities and the smaller drops slow toward their lower terminal velocities. The terminal velocities for raindrops as compared with drop impact velocity for VeeJet nozzles at 3 m height and 41 N/m<sup>2</sup> pressure are presented in the figure below (Meyer and Harmon, 1979):



The rainfall energy is 200 kJ/ha-mm for the VeeJet 80100 nozzle and 275 kJ/ha-mm for the 80150 nozzle. Comparing to the natural rainfall data collected from the US Midsouth area (northern Mississippi), the impact energy for spray from the 80150 nozzle is about the same as that of natural rainfalls at intensities greater that 25 mm/h and while the 80100 nozzle is the same as rain at about 10 mm/h. The comparison of natural rainfall to VeeJet nozzle energy is shown below (Meyer and Harmon, 1979):



Note: Energy Units—1 (kilo Joule/ hectare- mm) = 123.4 (kilo watt-s)/ (Acre-feet)

#1. Which nozzle?

The VeeJet 80100 Nozzles is the most common nozzle used with the Norton Ladder Rainfall Simulator.

We (the NSERL) have occasionally used the VeeJet 80150 nozzles in the past to achieve higher rainfall intensities. But we most often utilize only the VeeJet 80100.

Both nozzles are interchangeable, but they do have different flow rates and therefore different rainfall distributions. Calibrations should be done to determine rainfall intensity for both (or either) nozzles.

If you are wanting rainfall intensities over 100 mm/h then the 80150 nozzles should be used. Some customers order both the 80100 and 80150 nozzles

#2. Rainfall Intensities.

The rainfall intensities available from the Ladder Simulator utilizing the VeeJet 80100 nozzles range from:

(9.5 mm/h) with switch setting = 1-SINGLE. (99.0 mm/h) with Switch setting 5-DOUBLE.

The first thing to achieve a higher intensity, greater than 99 mm/h, would be to switch to

the VeeJet 80150 nozzles. Calibrations will have to be done to find the correct switch setting that yields the desired rainfall intensities. The 80150 nozzle has about a 50% higher flow rate than the VeeJet 80100; knowing this may help to choose which switch settings to calibrate with the 80150 nozzle.

It is recommended to leave the pressure alone (6 p.s.i.g.) because increasing the pressure too much will make the raindrops much smaller.

#3. Size of Pump Required.

When conducting field experiments using this rainfall simulator, Scott McAfee (National Soil Erosion Lab - SDA) uses a 5.0 hp gasoline engine pump and it more than delivers sufficient flow to the rainfall simulator.

You need to use a pump that has more flow capacity than needed, so that you can throttle the valves down to get your pressures up to 6.0 psig at the nozzles.

I would not go much smaller than a 5 hp pump.

#4. Total Water Consumption.

Regarding how much total volume of water at 104 mm/h. Our highest rainfall rate with the VeeJet 80100 nozzles are 99.0 mm/h with the controller's switch set to '5-DOUBLE'. This setting is such that the nozzle never comes to rest, so it is over the opening a large percentage of the time.

These are my calculations of total water consumption for this simulator with the VeeJet 80100 nozzles.

Switch Settings # sweeps/minute Calculated water consumption per hour

- 1 Single 23 67.62
- 1 Double 48 141.12
- 2 Single 47 138.18
- 2 Double 94 276.36
- 3 Single 71 208.74
- 3 Double 142 417.48
- 4 Single 95 279.3
- 4 Double 190 558.6
- 5 Single 118 346.92
- 5 Double 238 -699.72

Each nozzle has a flow rate of 14.75 liters/minute at 6 psig.

#5. The ground manifold has 1.5" fittings. We use a 1.5" flat discharge hose to go from the discharge of the pump to the simulator's ground manifold. We also use a 1.5" suction

hose to go from the tank to the suction side of the pump.

Scott McAfee NSERL-USDA

The Norton-style simulator has VeeJet nozzles spaced 1.37 m (54 in) apart. With nozzles at 2.5 m (8 ft) height:

A) 2 head unit provides rainfall to a1.5 m wide, 2 m long area

B) 4 head unit provides rainfall to a 1.5 m wide, 4.5 m long area

C) 6 head unit provides rainfall to a 1.5m wide, 7m long area.

The reported coefficient of uniformity for the rainfall distribution with VeeJet 80100 nozzles spaced at 1.40 m by 1.52 m grid showed an average of 88.7 with a range between 84.8 and 92.6 from 9 measurements (Neibling et al., 1981).

The intensity control of the Norton-style simulator is based on a timing circuit that controls the sweep frequency. The more frequent the nozzle sweeps, the higher the rainfall intensity. The nozzle sweep frequency is controlled from a stand-alone controller, which has 10 preset and 2 adjustable intensity controls. This range of control is sufficient for almost all the rainfall simulation needs.

### 5) Construction, materials

The Norton Rainfall Simulator is primarily constructed of bare Aluminum products – bare finish. Since people move the simulator manually, it is essential to be constructed as lightweight as is practical. For this reason, the simulator is somewhat fragile and must be handled cautiously. Proper handling is the responsibility of the technicians using it.

### Appendix C. Price Quote for Norton Ladder Rainfall Simulator



## a) **QUOTATION**

MAY 3, 2005

ATTN: RICHARD LONG

COMPANY: DEPT. OF CIVIL AND ENV. UNIVERSITY OF CONNECTICUT 261 GLENBROOK ROAD U-37 STORRS, CT 06269-2037

#### NORTON LADDER RAINFALL SIMULATOR - PER UNITED STATES DEPARTMENT OF

AGRICULTURE (USDA), NATIONAL SOIL EROSION RESEARCH LABORATORY (NSERL) SPECIFICATIONS -LOCATED AT PURDUE UNIVERSITY.

- 1) MATERIAL AND LABOR TO MANUFACTURE SIMULATOR
- 2) MOTOR, CLUTCH, & WIRING FOR MOTION CONTROL (120 VAC 60 HERTZ)
- 3) RAINFALL INTENSITY CONTROLLER (120VAC 60 HERTZ)
- 4) STATION MANIFOLD (SUPPLY TO TWO (2) VEEJET NOZZLES
  - a. TWO (2) HEAD RAINFALL SIMULATOR REQUIRES ONE (1) MANIFOLD
  - b. FOUR (4) HEAD RAINFALL SIMULATOR REQUIRES TWO (2) MANIFOLDS
  - c. SIX (6) HEAD RAINFALL SIMULATOR REQUIRES THREE (3) MANIFOLDS
- 5) ONE (1) SET OF VEEJET NOZZLES

#### **NOT INCLUDED IN THIS QUOTATION:**

- 1) GENERATOR, PUMP, WATER RESERVOIR (WATER TANK), OR TRANSFORMER (IF REQUIRED)
- 2) HOSE CONNECTION FROM WATER RESERVOIR TO PUMP AND FROM PUMP TO MANIFOLD(S).
- 3) TRAINING BY USDA NSERL LOCATED AT PURDUE UNIVERSITY (TO BE ARRANGED BETWEEN YOU AND NSERL AND COST CAN BE ADDED TO THIS QUOTE)

TWO (2) HEAD NORTON RAINFALL SIMULATOR	PRICE : \$11,838.00 USD
FOUR (4) HEAD NORTON RAINFALL SIMULATOR	<b>PRICE :</b> \$12,757.00 USD
SIX (6) HEAD NORTON RAINFALL SIMULATOR	<u>PRICE :</u> \$15,041.00 USD

CRATING AND SHIPPING (APPROXIMATE)

\$2,000.00 USD

TERMS:

1) 60% WITH PURCHASE ORDER.

2) 40% WHEN READY FOR DELIVERY + CRATING + SHIPPING

NO TAXES, TRADING COMPANY FEES, DISTRIBITOR COMMISSION, ETC. OF ANY KIND ARE INCLUDED WITH THIS QUOTATION.

THIS QUOTATION IS VALID FOR THIRTY DAYS.

THANK YOU FOR THE OPPORTUNITY TO SUBMIT THIS QUOTATION!

ADVANCED DESIGN AND MACHINE, INC.

2. BY:-----,-PRES.

JOE METZINGER

Appendix D. Notes on the Design of a Field Erosion Test Facility for the New England States.

Regardless of the method of applying the rainfall events the following characteristics must be available at a test site.

I. Needs for all types testing facility

A. Select a site with a proper soil and a good amount of soil to replenish the slopes.

B. Use or create a slope on 2 horizontal to 1 vertical at least 20 feet long

C. Create cells approximately 5 feet wide by placing barriers to the flow of surface water approximately 3 inches below the final soil surface and 2  $\frac{1}{2}$  or more inches above the soil surface.

D. Prepare the area at the bottom of each cell with approximately 2 to 3 feet of opaque 5 mil polyethylene sheet on the soil surface to insure that the eroded soil is carried into the collection container.

E. Create a barrier at the bottom of each test cell that channels the runoff into the collection container.

*F.* Optional – method of physically measuring the runoff by counting the number of tips of a collection bucket.

G. Construct a collection container that will collect all of the runoff for a typical storm, say 3 in/hr for 30 minutes for short-term tests or collect about 20% for long-term tests.

*H.* Develop means for removing the solids from the collection container and means for determining the amount of soil eroded.

*I.* Develop method for determining the particle size distribution for the eroded soil.

J. Choose a means for measuring the amount of rainfall at appropriate locations in the test cells (see Appendix A).

II. Limitations to using naturally occurring rainfall.

A. There is no way of predicting the number and type of storm events over an extended period of time.

B. The eroded soil and runoff must be removed from the collection system after each storm event, before the next event is due.

C. The water content of the soil will not be the same before each event unless the test area is watched very closely and the water content adjusted just before each storm event.

D. If the test is carried out long-term and under a series of storm events, care must be exercised because the nature of the soil available for erosion is constantly changing.

III. Using Rainfall Simulators

A. Advantage is that the type and amount of a storm event can be designed.

B. Testing can be completed in a shorter time.

C. Water Content of the soil can be measured just before testing.

D. Reproducibility of storm event can be assured through calibration.

E. Soil can be replaced for each new erosion control product tested so that the same erosion potential exists in each product.

### IV. Limitations with using rainfall simulators

A. Rainfall simulator must be designed, developed and calibrated for the specific site.

B. The complete design must include spacing of nozzles and units to achieve uniform rainfall over the test cells.

C. Simulator units must be maintained and calibrated on a regular schedule to insure reproducibility of storm events.

### Appendix E. Advantages and Limitations of Long- and Short-Term Tests

In this Appendix, short-term testing refers to testing "on demand" using a rainfall simulator. Long-term testing refers to the random rainfall results produced by natural rainfall.

### Long-Term Tests (Using naturally occurring rainfall)

### Advantages

- 1. No need to determine the size distribution of the raindrops.
- 2. No need to simulate the effects of frost.

### **Limitations**

- 1. Frequency and intensity of storm events cannot be predicted.
- 2. Impossible to expose different materials to the same storms unless they are tested simultaneously at the same site.
- 3. Can only collect a portion of the runoff coming from the test site.
- 4. Must take measurements when the storm event has occurred, may require site visits on weekends to gather samples and prepare cells for the next storm event.
- 5. Requires frequent applications of herbicide to keep weeds under control as the roots from plants reduce erosion. This is especially important for the control cells where the bare soil can pick up seeds transported by various means.
- 6. The beginning soil moisture content will be different for each storm event.
- 7. Particle size distribution changes for each storm event. The most erodible particles being removed during the first storm event.

### Short-Term Tests (Using a rainfall simulator)

### Advantages

- 1. One test can be accomplished in a predetermined time such as 30 minutes and three replicates in about 90 minutes.
- 2. A desired intensity and magnitude of rainfall can be applied.
- 3. Frost effects can be simulated by controlling the density of the soil and controlling the permeability of the soil layers.
- 4. Test conditions are reproducible
- 5. Various products can be subjected to the same storm conditions and the results compared.
- 6. Soil conditions, such as particle size distribution, are the same for all tests.
- 7. Beginning soil moisture content can be controlled
- 8. Portable rainfall simulators can be used at various field sites.

### **Limitations**

- Short-term testing requires rainfall simulators.
  Equipment must be calibrated periodically for both rainfall amount and rain drop size distribution.
- 3. A water supply and pump system is needed.

Appendix F. Photos of Multi-cell Field Test Facility



Figure F-1 Photo of 14 Cell Field Test Facility



Figure F-2 Photo Showing Detail of Mulch Berm, Hay Bale and Silt Fence



Figure F-3 Detail of Tipper Box and Water Sample Collection Bucket



Figure F-4 Electronic Rain Gage without Cover



Figure F-5 Test Cells at End of Growing Season with Unplanned Growth



Figure F-6 View of Test Cells Looking Up Hill

# Norton Rainfall Simulator (2-4-6 Head)

# Configuration

6-Head Unit (Leg Extensions Removed)



4 Head Unit



# Fact Sheet

- Design based on Norton Ladder Rainfall Simulator Developed by USDA-ARS.NSERL at Purdue University-West Lafayette, Indiana
- Available in 2-4-6 head configurations, each 2 head section is 8ft (2.4 meters) in length
- Rainfall rate determined by pressure and nozzle size (Standard rate 2-4 in/hr)
- Removable leg extensions improves simulator portability (Figure 1)
- Tubular construction eliminates ladder and improves strength (Figure 2)
- Ball bearing drive support increases reliability (Figure 3)
- Modular construction allows for compact shipping (Figure 4)
- Rainfall intensity incremental or continuous regulated by stand-alone controller or computer (Figure 5)

Completed 6-Head Unit in Shipping Crate





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Figure F-7 Norton Rainfall Simulator (2-4-6 Head)