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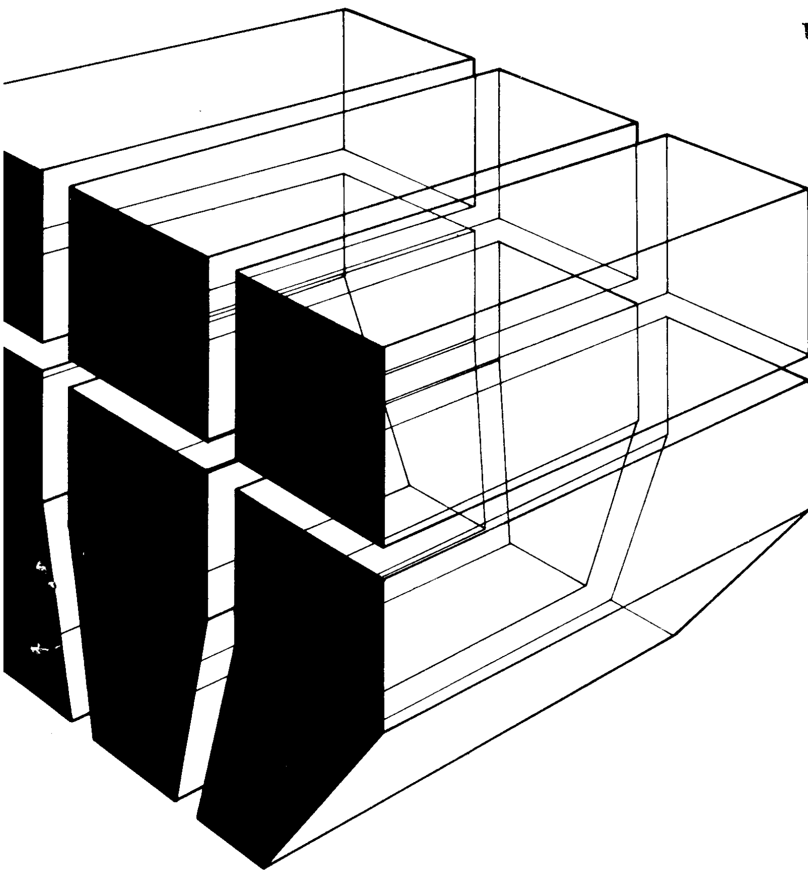
R-FACTORS FOR SOIL LOSS IMPACT PREDICTION



by
Robert E. Riggins
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A procedure has been developed for determining design R-values for use in soil-loss impact analysis. The procedure brings together a new, more simple method of calculating R-values, the concept of simple risk and readily available precipitation data. The procedure was tested using precipitation data from stations in Texas and Georgia. The R-values determined using this procedure

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follow a log-normal probability distribution and can be adjusted to be comparable with published R-values in Agricultural Handbook No. 537*.

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*Wischmeier, W. H., and Smith, D. D., "Predicting Rainfall Erosion Losses-A Guide to Conservation Planning," Agriculture Handbook No. 537, United States Department of Agriculture, 1978.

FOREWORD

This manuscript is reprinted with permission from the Vol. 107, No. 4, issue of the Journal of the Environmental Division, Proceedings of the American Society of Civil Engineers.

The work was done by the Environmental Division, U. S. Army Construction Engineering Research Laboratory (CERL) and was funded by the Office, Chief of Engineers under Project 4A762720A896, "Environmental Quality for Construction and Operation of Military Facilities"; Task Area C; Work Unit 001, "Water Quality Model System for Impact Analysis."

Dr. R. K. Jain is Chief of the Environmental Division. Dr. L. R. Shaffer is Technical Director of CERL, and COL Louis J. Circeo is Commander and Director.

R-Factors for Soil Loss Impact Prediction

By Robert E. Riggins,[1] M. ASCE and John T. Bandy[2]

Introduction

Soil loss is an important consideration in many environmental impact analysis situations. Soil loss from agricultural areas can be predicted using the universal soil loss equation (USLE) as described in Agriculture Handbook No. 537 (HB537) (5). The USLE is

$$A = RKLSCP \qquad (1)$$

in which A = the computed soil loss, in tons per acre from a given storm period; R = the rainfall erosion index for the given storm period, in units of foot-ton inch per acre-hour (described further in the following); and K, L, S, C, and P are othe factors which are described in HB537. Use of the USLE has expanded to other land uses and, although designed for prediction of long-time averages, the USLE has been applied to specific events. There are, however, several limitations to this procedure when applied to general impact analysis.

Traditionally, agricultural soil loss has been predicted on an average annual basis. As interest in other soil loss situations has grown, a need has arisen for consideration of other time intervals. In construction, e.g., soil may be exposed for only a brief period before vegetation is reestablished or erosion control techniques are applied. Evaluation of sediment impacts on aquatic biota requires knowledge of sediment concentrations from single storm events.

Risk should be incorporated into impact analysis. Since rainfall can be considered a stochastic process, frequency analysis can be performed and risk concepts can be applied. Erosion control can then be designed in relation to the cost (both from an engineering and environmental standpoint) associated with failure.

One aspect of impact analysis is data. Effective impact analysis requires a source of readily-available, inexpensive data. Because frequency analysis can require considerable data, techniques which are data-conservative are preferred.

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All these limitations relate to the R-factor of the USLE. This paper describes a procedure for determining R-values for variable time intervals while incorporating the concept of simple risk.

R-Factor

The rainfall factor, R, is the rainfall erosion index reported by Wischeier (6) and defined for a single storm as

$$R = \frac{EI_{30}}{100} \qquad (2)$$

in which E = the total kinetic energy of a given storm, in foot-tons per acre; and I_{30} = the maximum 30-min rainfall intensity for the storm, in inches per hour. The kinetic energy of rainfall has been given by Wischmeier and Smith (7) as

$$E = 916 + 331 \log_{10} I \qquad (3)$$

in which I = rainfall intensity, in inches per hour.

Total storm kinetic energy is obtained by dividing the storm into increments, computing E for each increment and summing to obtain the total for the storm. The rainfall factor, R, is computed from rainfall records of individual storms and summed over a given time interval to obtain the cumulative R-value to be used in the soil loss equation.

The average annual R-value for any location in the Continental United States has been summarized in the form of an isoerodent map presented in HB537. Tables give 5%, 20%, and 50% probability values of the annual erosion index for selected locations. In addition, the expected magnitudes of the single storm erosion index values are given for return periods of 1 yr, 2 yr, 5 yr, 10 yr, and 20 yr without specifying the storm duration periods. These tabulated data are inadequate for many soil loss situations of current interest. R-values for each storm are needed for the application of simple risk concepts.

The disadvantages of the USLE rainfall factor are the size of the data base and the computational time required to calculate single storm values for later use in frequency analysis. A newer method of calculating R-values using only rainfall depth and storm duration, has been developed by Hotes, Ateshian, & Sheikh (3). The data base for this method is smaller than one containing incremental rainfall.

The USLE rainfall factor can be expressed as a function of intensity alone (Eqs. 2 and 3). Hotes used graphical approximations from typical rainfall distribution curves to obtain incremental storm intensity. Using the method prescribed by Wischeier and Smith, individual storm rainfall factors were calculated for various values of total rainfall. The following general relationships resulted

$$R' = 15 \frac{D^{2.2}}{H^{0.6065}} \qquad (4)$$

Hawaii, Alaska, and the coastal side of the Sierra Nevada and Cascade Mountains in California, Oregon, and Washington.

$$R' = 19.25 \frac{D^{2.2}}{H^{0.4672}} \quad \text{Remaining United States, Puerto Rico and Virgin Islands.} \quad (5)$$

in which R' = the R-value computed using the new method; D = total rainfall depth, in inches; and H = storm duration, in hours.

The two methods have been compared by Bhutani, et al. (1) and neither method was judged clearly superior. If time distribution of rainfall is available, the USLE rainfall factor is preferred. The advantage of the new procedure is that it requires only total rainfall and storm duration.

These new R-factors can be used to overcome the limitations described previously. Hourly rainfall data is readily available from the National Climatic Center and can be used to provide the rainfall depth and duration values needed for this relationship. With this data source, R-values can be calculated for any time interval up to annual. Frequency analysis can be performed and risk concepts can be applied.

Risk Assessment

Practical application of simple risk in hydrologic design is described by Yen (8). Simple risk of failure is defined as the probability of occurrence of the variable X greater than a design magnitude, R. The risk of failure for a n-year period is

$$P(X > R) = 1 - \left(1 - \frac{1}{T}\right)^{N} \quad (6)$$

in which $P(X > R)$ = probability of occurence of the magnitude of an event, X, greater than the design magnitude, R; T = design return period, in years, and N = expected project life, in years.

For application to soil loss prediction, this equation can be rearranged to identify the design return period for which the risk of exceedance is a specified amount. Rearranged, the equation is

$$T = \frac{1}{1 - [1 - P(X > R)]^{1/N}} \quad (7)$$

with T, N, $P(X > R)$ defined in the foregoing.

Probability distribution can be determined using the interval R-values or the values of maximum single storm R for each year of record. Then, simple risk can be used to identify the R-value to be used to predict soil loss. The results from two test cases are described in the following.

Procedure

The procedure for determining a design R-factor is two-staged. In the first stage, the precipitation data tape is processed to produce a reference data base containing storm dates, depths, and durations. This data file is then used in the second stage.

To determine a design R-value, the user first specifies an interval of interest, that is, a start data and an end date. Storm data within the interval are used

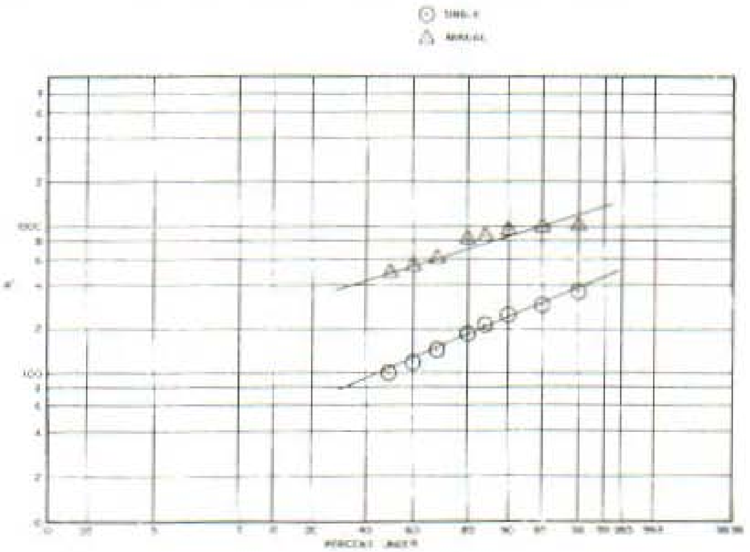

FIG. 1.—Log-Probability Plot for Single and Annual R′-Values for Ft. Benning

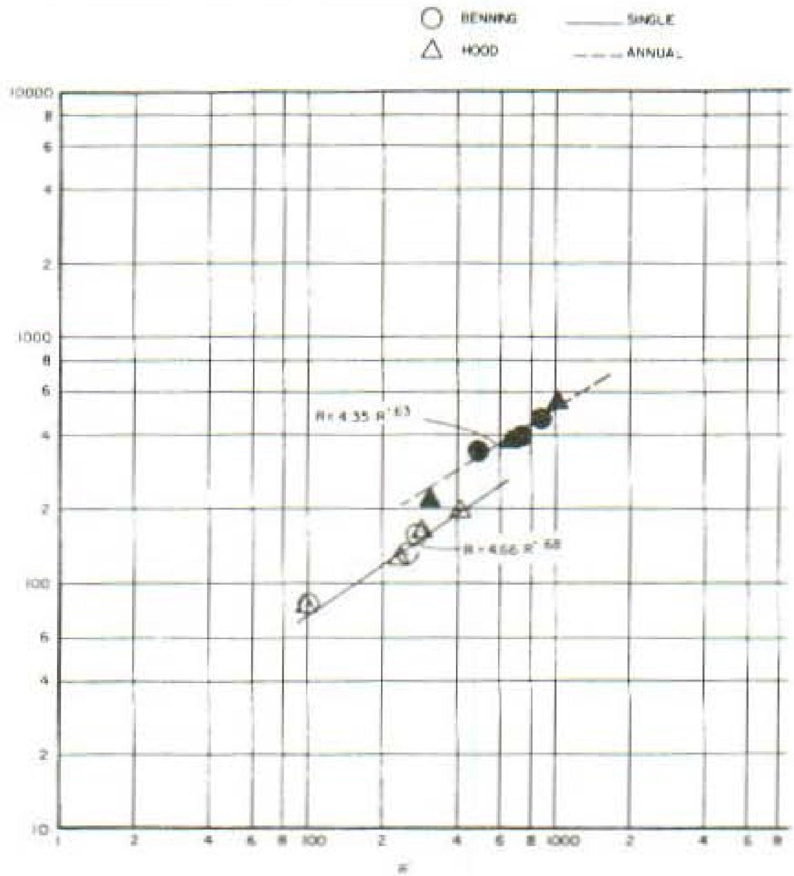

FIG. 2.—*R* Versus R′ for Single Storm and Annual Values

to calculate R-values for each storm. Interval R-values are determined by summing the single storm R-values for each year of record. In addition, the maximum single storm R-value is found for each year. These two arrays of R-values are ranked to determine return periods. The user can then specify a design return period or a risk of exceedance to obtain the appropriate R-value for the interval or single storm.

Precipitation data for two areas, Ft. Hood, Tex., and Ft. Benning, Ga., were used to calculate interval and single storm R-values. Fig. 1 shows a plot of the Ft. Benning R-values. The data fits well to a straight line on log-normal probability graph paper. A test of how well the newer procedure calculates R-values is to compare with the values published (see Ref. 5). A log-log plot of R′-values versus R-values (Fig. 2) shows a relationship and R-values computed

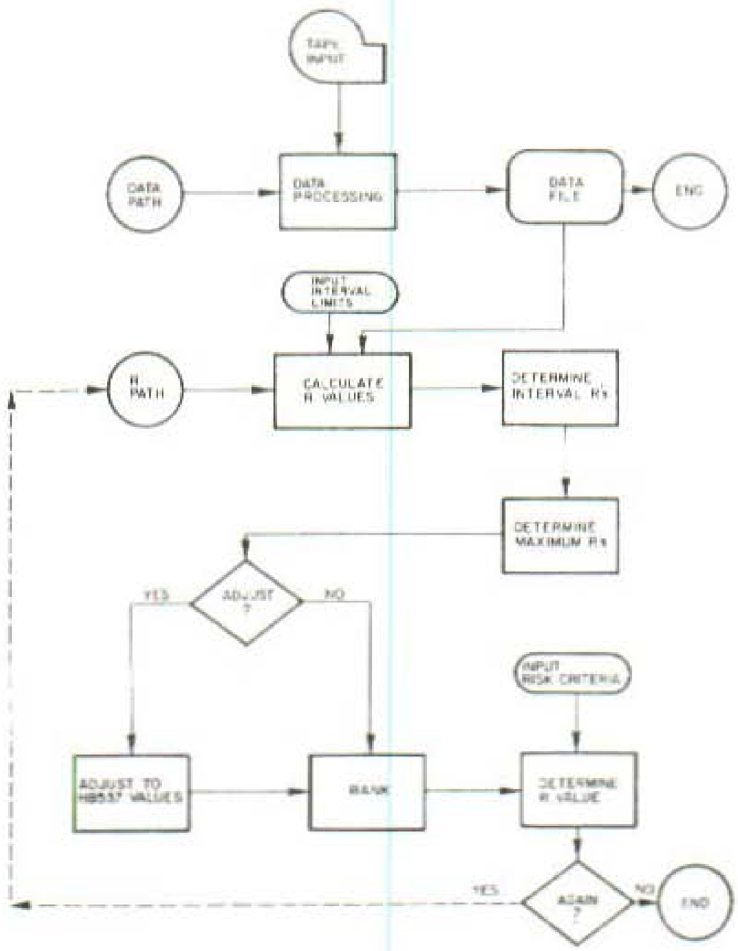

FIG. 3.—Flow Diagram of Procedure to Determine Design R-Values

using the new method can be adjusted to the values published in Ref. 5. The equations to adjust interval and single storm R-values are

$$R_s = 4.35\, R_s'^{\,0.63} \quad (8)$$

in which R_s = adjusted single storm rainfall erosion index; and R_s' = single storm rainfall erosion index calculated using the new method, and

$$R_i = 4.66\, R_i'^{\,0.68} \quad (9)$$

in which R_i = adjusted interval rainfall erosion index; and R_i' = interval rainfall erosion index calculated using the new method. A flow diagram of the complete procedure is shown in Fig. 3.

Practical Applications

The procedure described in this paper can be used to determine R-values for use in soil-loss prediction in environmental impact analysis. The procedure provides a capability to select design R-values based on return interval or simple risk. It permits the consideration of any time interval up to 1 yr. The procedure is applicable to a variety of situations, e.g., construction, lands management, military training, and should be efficient and economical for impact analysis.

Conclusions

A procedure has been developed for determining design R-values for use in soil-loss impact analysis. The procedure brings together a new, more simple method of calculating R-values, the concept of simple risk and readily available precipitation data. The procedure was tested using precipitation data from stations in Texas and Georgia. The R-values determined using this procedure follow a log-normal probability distribution and can be adjusted to be comparable with published R-values in Agricultural Handbook No. 537 (5).

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Appendix II.—Notation

The following symbols are used in this paper:

A = computed soil loss;
C = cropping management factor;

D = rainfall depth;
E = kinetic energy of rainfall;
H = storm duration;
I = rainfall intensity;
K = soil-erodability factor;
L = slope-length factor;
N = expected project life;
P = erosion-control practice factor;
$P(\ )$ = probability;
R = rainfall factor;
R' = new rainfall factor;
S = slope gradient factor;
T = return interval; and
X = magnitude of an event.

Subscripts

i = interval; and
s = single storm.