CHAPTER TWO

R factor -- Rainfall/Runoff Erosivity

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Analyses of data indicated that when factors other than rainfall are held constant, soil loss is directly proportional to a rainfall factor composed of total storm kinetic energy (E) times the maximum 30-min intensity (I_{30}) (Wischmeier and Smith, 1958). The numerical value of R is the average annual sum of EI_{30} for storm events during a rainfall record of at least 22 years. Details for the calculation of R values are given in AH-703 (Renard et al., 1997; Chapter 2 and Appendix B). Individual calculations of R values were made for almost 200 stations in the Eastern United States and more than a thousand locations in the Western United States to account for climate variability due to mountains. The point values of R then were plotted on maps and contouring principles applied to construct "isoerodent" maps for all States in the conterminous United States, plus Hawaii.

Special Case: For the erosion induced by melting snow, rain on snow, and thawing soils, a procedure was developed to compute the R_{eq} (Equivalent R) as explained later in this chapter.

CITY Code Files

In RUSLE, climate data for numerous locations are stored in the CITY Database files. To select an appropriate R value for a specific location at which a soil-loss calculation is to be made, the RUSLE user must: (1) determine if a CITY Database is available for the site, or its immediate vicinity, or if not, (2) develop a database using the procedures described in AH-703. The United States Department of Agriculture (USDA), Natural Resources Conservation Service (NRCS) has many CITY Database files for each State in addition to those provided in RUSLE. Users of RUSLE should consult with local or State personnel of the NRCS concerning data available for an area of interest.

CITY (CLIMATE) Database

The CITY Database file contains numerous types of data as shown in **Figure 2-1.** Explanations follow for the Tombstone, Arizona data screen.

Identifier Information

A unique number is assigned to each location in the CITY file. For example, the first or first two digits represent the state location in the alphabetical array. Thus, "1" represents files from Alabama, 3" from Arizona, and "50" represents files from Wyoming. The three digit number following the State code represents the climate-gage number within the State. Thus, 999 gages can be identified and stored for any state. The city name and State abbreviation are for identification purpose only.

```
                    File        Exit        Help        Screen
+-------------------< Create/Edit City Database Set 1.06 >----------------------+

      city code: 3004          city: TOMBSTONE___________     state: AZ
        total P: 14.1"   EI curve #: 71      Freeze-Free days/year: 237
  elevation(ft): 4540      10 yr EI: 62                   R factor: 65
 --- Mean P(") ---------- Tav (deg. F) --------------- %EI --------- %EI -------
       1: 0.86            1: 47.1                   1: 0          13: 9.1
       2: 0.82            2: 49.8                   2: 0.7        14: 18.5
       3: 0.61            3: 54.4                   3: 1.2        15: 40.6
       4: 0.29            4: 61.7                   4: 1.6        16: 59.7
       5: 0.2             5: 69.2                   5: 2.1        17: 74
       6: 0.51            6: 78                     6: 2.8        18: 86.3
       7: 3.68            7: 79                     7: 3.3        19: 91.7
       8: 3.5             8: 76.8                   8: 3.6        20: 94.7
       9: 1.53            9: 74                     9: 4          21: 96
      10: 0.64           10: 65.4                  10: 4.5        22: 96.7
      11: 0.63           11: 54.7                  11: 5.6        23: 97.3
      12: 0.87           12: 47.3                  12: 6.5        24: 98.8


+------------------< F7 Saves, Esc Returns to CITY Main Menu >------------------+
Tab  Esc F1   F2  F7   F9   Del
FUNC esc help clr save info del
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Figure 2-1. CITY CODE Database file for station 3004, Tombstone, AZ.

Total Precipitation

As the title implies, the total precipitation is the sum of the monthly-precipitation depth (in inches) for the 12 entries shown under the column heading "Mean P". Changing any of the individual monthly values automatically changes the annual total.

EI Curve Number

The spatial variability of EI distribution zones within the contiguous United States is shown in AH-703 (**Figure 2**-7). The identifying code from **Figure 2-7** automatically identifies the percentage of the annual EI_{30} value occurring between the first and 15th day or the 16th and last day of a particular month. The 24 semi-monthly values are then automatically inserted in the appropriate position (% EI) of the CITY file. These values are used in weighting of the soil erodibility (K) value and in the weighting of soil-loss ratios (SLRs) used to calculate the seasonally-weighted K and C values as discussed in forthcoming chapters. Soil-loss ratios represent the temporal distribution of the cover-management factor used in estimating soil loss.

Freeze-Free days per year

The freeze-free days number indicates the continuous period (days) for which the minimum temperature is above freezing (32 degrees F). This information is used for determining the seasonal distribution of soil erodibility (K) in the Eastern U.S. Soil erodibility also varies seasonally in the Western U.S., but the diverse topography and climate of this region has precluded the development of satisfactory relationship upon which to base soil-erodibility adjustments. The freeze-free data were obtained from U.S. Department of Commerce, Environmental Science Service Administration, 1968.

Elevation

Although this information is not used directly in the calculations performed within RUSLE, the information often is valuable in Basin and Range physiographic provinces of the Western United States. For example, most National Weather Service (NWS) gages and the data used to calculate R are located near airports and cities in valleys that often receive less precipitation than received at higher elevations. So, where no rainfall data are available to compute the R value by standard methods, an estimate of R may be made based on the difference in elevation using the relation below:

$$R_{new} = R_{base} (P_{new}/P_{base})^{1.75} \tag{2-1}$$

where: R_{new} = the new value for R at the desired new location when an R value is not available from a map,
R_{base} = R value at a base location where R is known (hopefully in the same general vicinity),
P_{new} = the average annual precipitation at the new location, and
P_{base} = the average annual precipitation at the base location.

A value for the average annual precipitation at the new location may not be known. An estimate of this precipitation amount can be obtained based upon a comparison of vegetative conditions at the new site and at the base location. Another way to estimate the precipitation at the new location is to adjust for the difference in elevation. As a very approximate estimate, an increase of between 2 and 3 inches of precipitation can be assumed for each 1,000 feet increase in elevation.

Similar topographic coefficients might be used to adjust the monthly precipitation and temperature data based on adiabatic temperature-elevation relations. Care must be taken using all such procedures to ensure that results seem reasonable in relation to the vegetation community at the new location. When sufficient meteorological data are accumulated at the new site, after several years that include relatively "normal" climatic conditions, the R value should be calculated using the procedures described in AH-703.

10 year frequency EI data

These data represent the single-storm maximum EI having a recurrence frequency of once in 10 years, or a 10% probability of occurring in any given year (**Figures 2-9 through Figure 2-12** of AH-703). This information is used in RUSLE to estimate a storm-rainfall depth (design storm) for the calculation of the conservation support practices (P) value, discussed in Chapter 6. The equation used is:

$$V_r = 0.255\,[(EI)_{10}]^{0.662} \qquad [6\text{-}6]\ \ (2\text{-}2)$$

where:

V_r = rainfall depth in inches.

Rainfall depth is used in the NRCS runoff-curve number method to estimate a runoff volume. This methodology is described in detail in most hydrology textbooks (e.g. American Society of Civil Engineers, 1996). Runoff-curve numbers for various climatic areas and management practices in the United States are used to convert these precipitation depths to runoff volumes and peak discharges. The runoff data are then used with fundamental sediment-transport relations to simulate the effect of conservation support practices. Although the calculations are somewhat complicated, RUSLE executes the necessary computations using specified inputs.

[ ] refers to an equation from AH-703.
( ) refers to an equation in these Guidelines.

R factor

The R-factor value is used directly in the soil-loss calculation. It is the first entry in the "Soil Loss and Sediment Yield Computation Worksheet" of RUSLE. These values were computed from recording-gage precipitation records using the mathematical relation:

$$\boldsymbol{R} = \frac{1}{n} \sum_{j=i}^{n} \left[\sum_{k=1}^{m} (E)\ (I_{30})_r \right] \qquad \text{[B-1]} \quad (2\text{-}3)$$

Where:

E = total storm kinetic energy
I_{30} = maximum 30-min rainfall intensity
j = index of number of years used to produce the average
k = index of number of storms in a year
n = number of yrs used to obtain average R (22 yrs minimum preferred)
m = number of storms in each year, and
R = average annual rainfall erosivity

This equation shows that the annual R factor is calculated by summing the product of the storm kinetic energy times the maximum 30-min intensity for each storm occurring in an "n" year period as depicted in Equation 2-4. The EI interactance term is closely related to soil loss (Wischmeier and Smith, 1958).

$$EI = (E)\ (I_{30}) = \left[\sum_{k=1}^{m} e_r \, \Delta V_r \right] I_{30} \qquad \text{[B-2]} \quad (2\text{-}4)$$

Where:

e_r = rainfall energy per unit depth of rainfall per unit area
ft • tonf • $acre^{-1}$ • in^{-1}
ΔV_r = depth of rainfall (in) for the rth increment of the storm hyetograph which is divided into m parts, each with essentially constant rainfall intensity ($in \cdot h^{-1}$).

Equation 2-5 is used to compute the kinetic energy for each uniform increment of rainfall depth as recorded on the analog trace of a recording rain gage. When multiplied times the maximum depth of rain occurring in the storm time-depth record, it results in the estimate of storm energy and intensity (EI). The unit energy, e_r, is a function of rainfall intensity and is computed as:

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

[B-3] (2-5)

and

$$i_r = >V_r / >t_r$$

Where:

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

i_r = rainfall intensity ($in \cdot h^{-1}$)

Finally, the EI for a specified time period (such as the annual value) is the sum of the computed value for all rain periods within that time. Thus, for ease of computation:

$$\boldsymbol{R} = 3 \; E\, I_{\mathbf{30}} \; (10^{-2})$$

Where:

R = average annual rainfall erosivity with the units: hundreds of $ft \cdot tonf \cdot in \cdot acre^{-1} \cdot h^{-1} \cdot yr^{-1}$

The calculation of $R = 3\ E \cdot I_{30}$ is time consuming and laborious. Use of published values is encouraged. where possible (e.g. using the values provided in RUSLE, AH-703, or provided by NRCS).

Average monthly temperature

Average monthly temperatures (degrees Fahrenheit) are obtained from NWS records. These data, along with the mean monthly precipitation data, are used in the estimation of (organic) residue decomposition in the determination of cover-management

(C) values. Because residue amounts are one of the most influential parameters affecting soil loss, these data are important and soil-loss prediction is very sensitive to this value.

Special Erosion Situations

Ponded Water and Splash Erosion Reduction -- RUSLE can account for the reduction of rainfall erosivity due to ponded water. The ponded water absorbs raindrop energy. RUSLE will compute a reduced R value based on hillslope gradient and the 10-yr frequency EI. The effect of ponding is greatest on very flat hillslopes where rainfall erosivity is very large. The ponding option should not be chosen if the surface is ridged or rough so that more than half of the soil projects above the water line and is directly exposed to raindrop impact.

Erosion Resulting from Snowmelt, Rain on Snow, and Thawing Soil -- For climate and soil conditions in the northwestern part of the United States, a modified R-factor value is used for soil-loss estimation and is called R_{eq}. The pertinent geographic area includes eastern Washington, north-central Oregon, northern Idaho, southeastern Idaho, southwestern Montana, western Wyoming, northwestern Utah, and northwestern Colorado. In this region, soil erosion on cropland, mined land, construction sites, and reclaimed land frequently is dominated by Spring events. Many of the events involve rainfall and/or snowmelt on thawing soils. The thawing soil remains quite wet above the frost layer and is highly erodible until the frost layer thaws, to allow draining and soil consolidation. The frost layer near the surface limits infiltration and creates a super-saturated moisture condition causing almost all rainfall and snowmelt to become runoff. For these conditions, the R_{eq} value is used. If the land has not been disturbed within the last seven years or so, the standard R value should be appropriate. A linear interpolation is used to estimate the R value for the intervening years between soil disturbance and soil consolidation. For areas where the annual precipitation is greater than 7.5 inches, R_{eq} may be estimated as a function of precipitation (P) by means of the relation:

$$R_{eq} = -48.4 + 7.78\,P \qquad (2\text{-}7)$$

Whenever precipitation is less than 7.5 inches:

$$R_{eq} = \text{the standard } R \text{ calculated by means of Equation 2-3.} \qquad (2\text{-}8)$$

When using the R_{eq} values in Washington, Idaho, Utah, Montana, Wyoming, and Colorado, it is suggested that the user consult with appropriate personnel at the appropriate State NRCS office.

Estimating R Factors from Limited Data -- In some circumstances, only annual precipitation totals are available to make estimates of the R factor. In such cases, RUSLE users are referred to Renard and Freimund (1994).

The procedure provided by Renard and Freimund (1994) for estimating R values from annual precipitation is to be used only as a last resort when there is no other alternative.

Summary

RUSLE requires the assembly of data from a variety of sources. However, most R factor data are available in AH-703, from the NRCS, or derived from published records of the NWS. A major problem in using RUSLE for soil-loss estimation in the intermountain area of the United States involves calculations of R values that reflect the orographic effects of the mountain ranges, snow accumulation (and its melting effect on erosion), effects of windward versus leeward sides of mountain ranges, as well as the effect of aspect on both snow accumulation and melting. Users of this guide will need to consider the effect of these circumstances on soil-loss estimates. Hence, conservative assumptions are warranted for soil-loss estimation and the selection and design of erosion-control practices.