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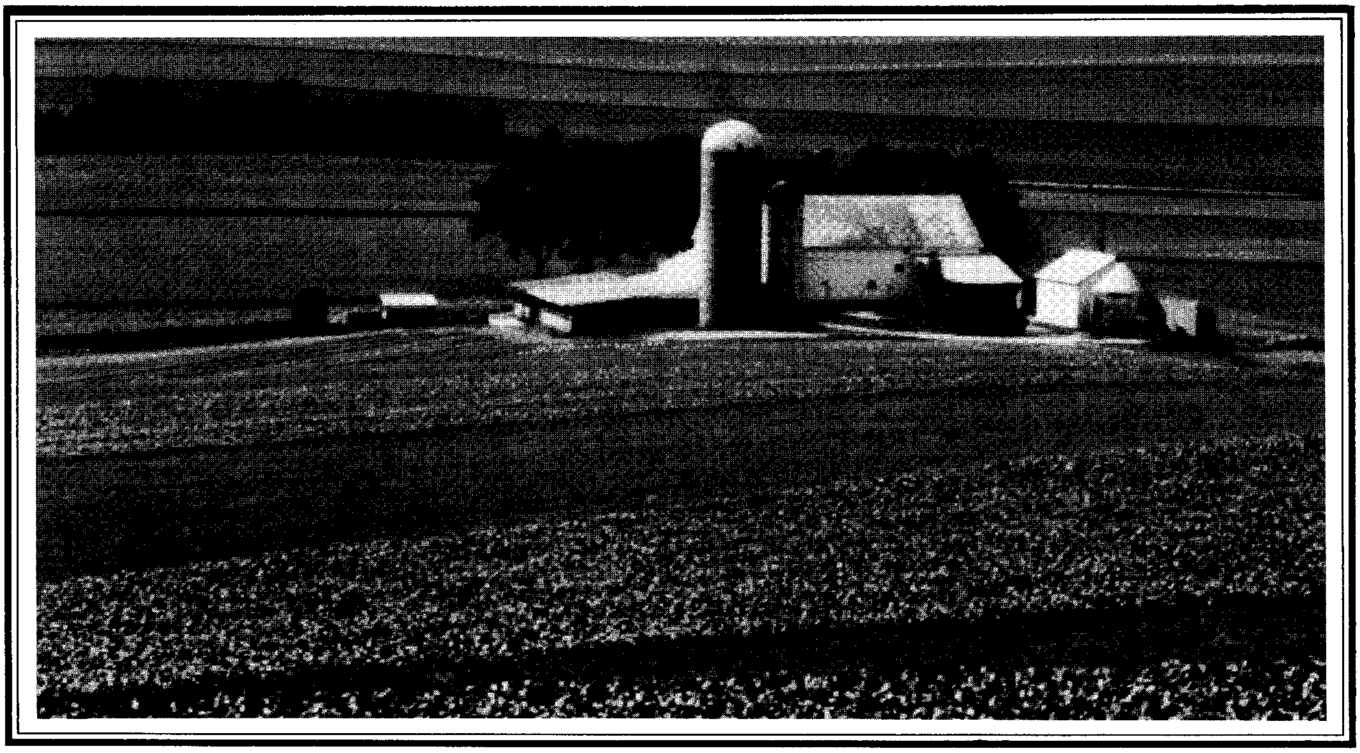
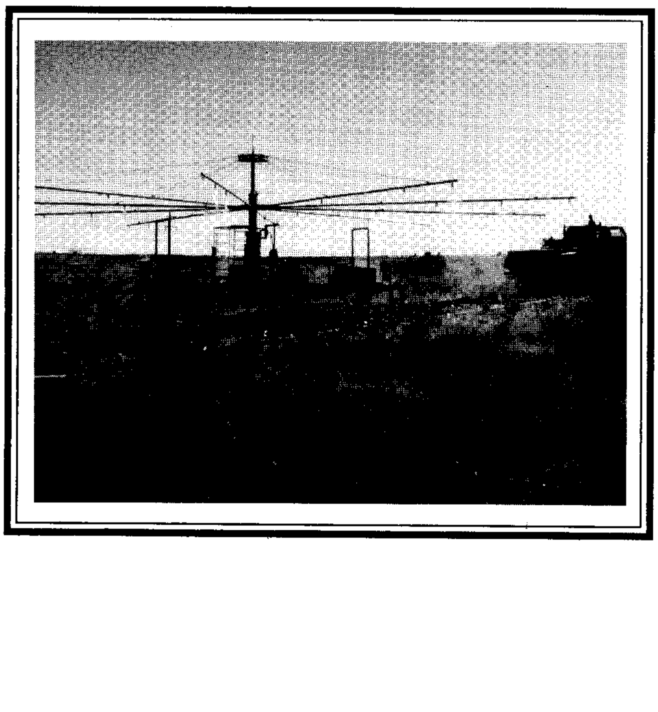
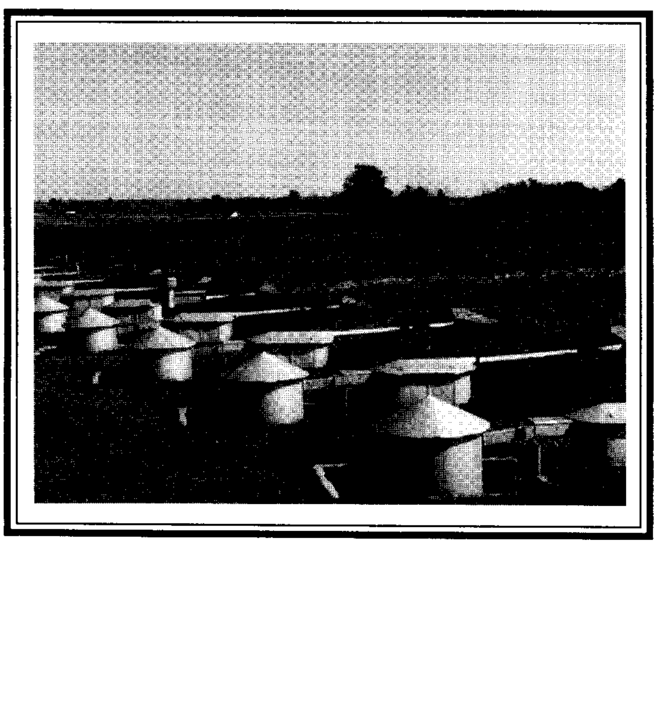
Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE)







Cover: A conservation-designed farm *(top)* in York County, PA, showing stripcropping. The farm conservation plan was developed using rainfall and runoff plot data from research plots like the ARS plots near Kingdom City, MO *(lower right)*, and from rotating-boom rainfall simulators like that on a grassland site on the ARS Walnut Gulch Experimental Watershed near Tombstone, AZ *(lower left)*.

PREDICTING SOIL EROSION BY WATER: A GUIDE TO CONSERVATION PLANNING WITH THE REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE)

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Note: See the errata at the end of the document

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ABSTRACT

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The Revised Universal Soil Loss Equation (RUSLE) is an erosion model predicting longtime average annual soil loss (A) resulting from raindrop splash and runoff from specific field slopes in specified cropping and management systems and from rangeland. Widespread use has substantiated the RUSLE's usefulness and validity. RUSLE retains the six factors of Agriculture Handbook No. 537 to calculate A from a hillslope. Technology for evaluating these factor values has been changed and new data added. The technology has been computerized to assist calculation. Thus soil-loss evaluations can be made for conditions not included in the previous handbook using fundamental information available in three data bases: CITY, which includes monthly precipitation and temperature, front-free period, annual rainfall erosivity (R) and twice monthly distributions of storm erosivity (E); CROP, including below-ground biomass, canopy cover, and canopy height at 15-day intervals as well as information on crop characteristics; and OPERATION, reflecting soil and cover disturbances that are associated with typical farming operations.

KEYWORDS: soil erosion, cropland, rangeland, rill erosion, interrill erosion, rainfall-runoff erosivity, soil erodibility, slope length, slope steepness, prior land use, surface cover, crop canopy, surface roughness, soil moisture, contouring, stripcropping, terracing, personal computer, residue decomposition

While supplies last, single copies of this publication may be obtained at no cost from USDA-ARS, Southwest Watershed Research Center, 2000 East Allen Road, Tucson, AZ 85719.

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This publication supersedes Agriculture Handbook No. 537, titled "Predicting Rainfall Erosion Losses: A Guide to Conservation Planning."

CONTENTS

SYMBOLS

A	average annual soil loss ($ton \cdot acre^{-1} \cdot yr^{-1}$)
A	coefficient used to describe the shape of the residue decomposition response to temperature (°C) (ch. 5)
A_{wr}	winter soil loss from rills alone ($ton \cdot acre^{-1} \cdot yr^{-1}$)
a	- coefficient used in unit rainfall energy relation (ch. 2) - location-dependent constant (ch. 3) - coefficient dependent on residue characteristics and climate variables (ch. 5) - coefficient dependent on contour ridge height (ch. 6)
a_1, a_2	coefficients used in determination of the discharge rate when deposition ends within a strip
B	amount of deposition considered to benefit the long-term maintenance of the soil resource ($ton \cdot acre^{-1} \cdot yr^{-1}$)
B_a	above-ground biomass ($lb \cdot acre^{-1}$)
B_b	below-ground root biomass ($lb \cdot acre^{-1}$)
B_s	weight of residue on the surface ($lb \cdot acre^{-1}$)
B_{si}	weight of a particular type of residue ($lb \cdot acre^{-1}$)
B_{ur}	mass density of live and dead roots in the upper layer of soil ($lb \cdot acre^{-1} \cdot in^{-1}$)
B_{us}	mass density of incorporated surface residue in the upper layer of soil ($lb \cdot acre^{-1} \cdot h^{-1}$)

b	- coefficient used in unit rainfall energy relation (ch. 2) - location dependent constant (ch. 3) - coefficient describing effectiveness of surface cover (dimensionless) (ch. 5) - coefficient dependent on contour ridge height (ch. 6)
C	cover-management factor (dimensionless)
CC	canopy-cover subfactor (dimensionless)
C_B	coefficient representing the relative effectiveness of the total subsurface biomass in controlling erosion (dimensionless)
C_f	surface-soil-consolidation factor (dimensionless)
c	- location-dependent constant (ch. 3) - coefficient dependent on contour ridge height (ch. 6)
c_d	consolidation factor dependent on a decay parameter and time since the soil was disturbed (dimensionless)
c_{uf}	coefficient representing the impact of soil consolidation on the effectiveness of incorporated surface residue (dimensionless)
c_{ur}	coefficient describing the effectiveness of live and dead root mass in controlling erosion ($acre \cdot in \cdot lb^{-1}$)
c_{us}	coefficient describing the effectiveness of incorporated surface residue in controlling erosion ($acre \cdot in \cdot lb^{-1}$)
D	- period length (d) (ch. 5) - if > 0, erosion rate at a point ($mass \cdot area^{-1} \cdot time^{-1}$) (ch. 6) - if < 0, deposition rate ($mass \cdot area^{-1} \cdot time^{-1}$) (ch. 6)
D_b	minimum value of detachment as it decreases over time after consolidation relative to the detachment immediately after disturbance (dimensionless)

D_e	- equivalent roughness decay coefficient (dimensionless) (ch. 5) - sediment produced on the slope by detachment ($ton \cdot acre^{-1} \cdot yr^{-1}$) (ch. 6)
D_g	mean geometric particle diameter (mm)
D_n	net erosion ($ton \cdot acre^{-1} \cdot yr^{-1}$)
D_r	roughness decay coefficient (dimensionless)
D_y	sediment transported from slope ($ton \cdot acre^{-1} \cdot yr^{-1}$)
d	coefficient dependent on contour ridge height (ch. 6)
d_t	decay parameter (d^{-1})
E	storm energy ($ft \cdot tonf \cdot acre^{-1}$)
EI	storm erosivity ($ft \cdot tonf \cdot in \cdot acre^{-1} \cdot h^{-1}$, or hundreds of $ft \cdot tonf \cdot in \cdot acre^{-1} \cdot h^{-1}$). Also a percentage of annual R
$(EI)_{10}$	storm erosivity of single storm with 10-yr return frequency (hundreds of $ft \cdot tonf \cdot in \cdot acre^{-1} \cdot h^{-1}$)
EI_{30}	storm erosivity, interchangeable with EI (hundreds of $ft \cdot tonf \cdot in \cdot acre^{-1} \cdot h^{-1}$)
EI_t	total storm erosivity since the most recent complete tillage operation; adjusted proportionately for operations disturbing less than 100% of the surface (hundreds of $ft \cdot tonf \cdot in \cdot acre^{-1} \cdot h^{-1}$)
e	rainfall kinetic energy per unit of rainfall ($ft \cdot tonf \cdot acre^{-1} \cdot in^{-1}$)
e_m	rainfall kinetic energy (metric) ($MJ \cdot ha^{-1} \cdot mm^{-1}$)
e_{max}	a maximum unit energy as intensity approaches infinity ($ft \cdot tonf \cdot acre^{-1} \cdot in^{-1}$)
F	coefficient dependent on temperature characteristics and shape of the residue decomposition response to temperature

F_c	fraction of land surface covered by canopy (dimensionless)
F_d	fraction of the soil surface disturbed by a field operation
F_u	fraction of the soil surface undisturbed by a field operation
f	function of ( )
f_i	primary particle size fraction (%)
f_r	runoff reduction factor (dimensionless)
f_{ri}	initial runoff reduction factor (dimensionless)
G	soil loss for a slope length ($ton \cdot ft^{-1} \cdot yr^{-1}$)
g	sediment load ($ton \cdot ft^{-1} \cdot yr^{-1}$)
g_{db}	sediment load at location where deposition begins within strip ($ton \cdot ft^{-1} \cdot yr^{-1}$)
g_{de}	sediment load at location where deposition ends within strip ($ton \cdot ft^{-1} \cdot yr^{-1}$)
g_p	sediment load at the end of the slope that would occur if the strips caused no deposition ($ton \cdot ft^{-1} \cdot yr^{-1}$)
g_λ	sediment load at the end of the slope ($ton \cdot ft^{-1} \cdot yr^{-1}$)
H	distance raindrops fall after striking the crop canopy (ft)
I	precipitation intensity ($in \cdot h^{-1}$)
I_{30}	maximum 30-min intensity ($in \cdot h^{-1}$)
i	- rainfall intensity ($in \cdot h^{-1}$) - subscript indicating a particular segment or strip
i_m	rainfall intensity (metric) ($mm \cdot h^{-1}$)
K	soil erodibility factor ($ton \cdot acre \cdot h \cdot$ [hundreds of $acre\text{-}ft \cdot tonf \cdot in]^{-1}$)

K_{av}	EI weighted average annual soil-erodibility value (ton· acre· h· [hundreds of acre-ft· tonf· in]$^{-1}$)
K_b	saturated hydraulic conductivity of the soil with rock fragments (in· h^{-1})
K_f	saturated hydraulic conductivity of the fine soil (< 2 mm) fraction (in· h^{-1})
K_i	soil erodibility factor at any time, t_i (in calendar days) (ton· acre· h· [hundreds of acre-ft· tonf· in]$^{-1}$)
K_{max}	maximum value of soil erodibility for a given soil (ton· acre· h· [hundreds of acre-ft· tonf· in]$^{-1}$)
K_{min}	minimum value of soil erodibility for a given soil (ton· acre· h· [hundreds of acre-ft· tonf· in]$^{-1}$)
K_{nom}	soil erodibility as determined from the nomograph (ton· acre· h· [hundreds of acre-ft· tonf· in]$^{-1}$)
K_r	ratio of average seasonal (monthly) K-factor value over the average annual K value (dimensionless)
K_{wr}	rill soil erodibility for winter period (ton· acre· h· [hundreds of acre-ft· tonf· in]$^{-1}$)
k_t	sediment transport coefficient (ton· ft^{-1}· yr^{-1})
L	slope length factor (dimensionless)
$(LS)_{wr}$	rill slope length and steepness relationship for winter period (dimensionless)
M	- product of primary particle size fractions (dimensionless) (ch. 3) - amount of deposition on a strip (ton· acre^{-1}· yr^{-1}) (ch. 6)
M_a	average residue mass during a time period (lb· acre^{-1})

M_b	residue mass at beginning of a time period ($lb \cdot acre^{-1}$)
M_e	residue mass at end of a time period ($lb \cdot acre^{-1}$)
m	slope length exponent (dimensionless) (ch. 4 and 6)
m_i	arithmetic mean of particle size limits of particular particle size (mm)
N	- number of residue types (ch. 5) - runoff index (dimensionless) (ch. 6)
n	- number of slope segments (ch. 4) - number of time periods used in summation (ch. 5) - number of strips (ch. 6)
n_i	ratio of root mass in the upper 4 in of soil to the total below-ground root biomass (dimensionless)
n_t	Manning's n
OM	organic matter (%)
P	support practice factor (dimensionless)
P	annual precipitation (in)
PLU	prior land use subfactor (dimensionless)
P_b	base value of the P factor for contouring (dimensionless)
P_{eff}	effective P-factor value for irregular slopes (dimensionless)
P_g	off-grade contouring P factor (dimensionless)
P_m	minimum P-factor value (dimensionless)
P_{mb}	minimum P-factor value for a given ridge height with base conditions (dimensionless)
P_o	on-grade contouring P factor (dimensionless)
P_s	P-factor value for stripcropping (dimensionless)

P_t	total rainfall since most recent field operation (in)
P_{wr}	winter conservation practice factor (dimensionless)
P_y	sediment delivery ratio of a slope under stripcropping or terracing (dimensionless)
P_1	calculated values of climate variable for first half-month period within a month
P_2	calculated values of climate variable for second half-month period within a month
p	- code for soil permeability (ch. 3) - coefficient dependent on residue characteristics (ch. 5)
Q	runoff amount from the 10-yr storm EI (in)
Q_k	computed runoff amount for the soil and cover-management condition indicated by subscript k (in)
q	runoff discharge rate ($ft^3 \cdot sec^{-1} \cdot ft^{-1}$)
q_{de}	runoff discharge rate for condition where sediment load equals transport capacity and deposition within strip ends ($ft^3 \cdot sec^{-1} \cdot ft^{-1}$)
R	average annual erosivity factor (hundreds of $ft \cdot tonf \cdot in \cdot acre^{-1} \cdot yr^{-1}$)
R	rainfall in the 15-d period (in)
R_a	roughness after biomass adjustment (in)
R_c	rainfall erosivity adjustment factor (hundreds of $ft \cdot tonf \cdot in \cdot acre^{-1} \cdot yr^{-1}$) (ch. 2)
R_{eq}	equivalent average annual erosivity factor (hundreds of $ft \cdot tonf \cdot in \cdot acre^{-1} \cdot yr^{-1}$)
$(R_{eq})_{wr}$	equivalent R factor of rills for winter period (hundreds of $ft \cdot tonf \cdot in \cdot acre^{-1} \cdot yr^{-1}$)

$(R_{eq})_{wt}$	total equivalent R factor for winter period (hundreds of ft· tonf· in· acre^{-1}· yr^{-1})
R_i	calculated initial roughness immediately following the previous field operation (in)
r_{max}	maximum surface random roughness; caused by protruding roots, rocks, and other effects of the long-term climate vegetative community when the soil is fully reconsolidated (in)
r_{min}	minimum surface random roughness; caused by rainfall-induced decay of tillage clods (in)
r_{nat}	for the current time period, the calculated surface random roughness caused by the factors creating r_{max} (in)
R_o	minimum average 15-day rainfall required for optimum decomposition (in)
R_n	net roughness following a field operation (in)
R_{np}	net roughness following the previous field operation (in)
R_u	roughness of surface before disturbance and roughness of the undisturbed portion of surface (in)
R_v	volume of rock fragments > 2 mm (%)
R_t	random roughness after most recent field operation (in)
R_w	weight of rock fragments > 2 mm (%)
r	excess rainfall depth (in)
r_f	roughness factor
r_i	roughness index
S	slope steepness factor (dimensionless)
SC	surface-cover subfactor (dimensionless)
SLR	soil-loss ratio (dimensionless)

$(SLR)_{wr}$	winter soil-loss ratio for rilling (dimensionless)
SM	soil-moisture subfactor (dimensionless)
S_p	land area covered by surface cover (%)
SR	surface-roughness subfactor (dimensionless)
s	- code for soil structure (ch. 3) - slope steepness (%) (ch. 4 and 6) - slope steepness (sine of slope angle) (ch. 6)
s_c	slope steepness for which a value of P_b is desired (sine of slope angle)
s_e	slope steepness above which contouring is ineffective (sine of slope angle)
s_{eb}	slope steepness for a given ridge height on base conditions at which contouring loses its effectiveness (sine of slope angle)
s_f	slope steepness along the furrows (sine of slope angle)
s_l	steepness of the land (sine of slope angle)
s_m	slope steepness at which contouring is most effective (sine of slope angle)
T	- soil-loss tolerance ($ton \cdot acre^{-1}$) - transport capacity of runoff ($ton \cdot ft^{-1} \cdot yr^{-1}$)
T_a	average temperature in 15-day decomposition period (°F)
T_{av}	average daily air temperature (°F)
T_o	optimum temperature in 15-day decomposition period (°F)
t	mean monthly temperature (°F)
t_c	time for 95% of disturbance effect to disappear by consolidation (yr)

t_{con}	amount of time required for the soil to fully reconsolidate following disturbance (yr)
t_d	time since soil was disturbed (yr)
t_i	any time (calendar days)
t_{max}	time of year when the soil erodibility factor is at a maximum (calendar days)
t_{min}	time of year when the soil erodibility factor is at a minimum (calendar days)
u_i	ratio of root mass to above-ground biomass (dimensionless)
V_f	fall velocity of sediment ($ft \cdot sec^{-1}$)
V_r	rainfall amount (in)
W	ratio of the rainfall in a 15-d period to the minimum average 15-d rainfall required for optimum residue decomposition
x	- length of each slope segment (ft) (ch. 4) - relative distance from top of the slope to the lower edge of a strip (absolute distance/slope length) (dimensionless) (ch. 6)
x_c	distance along slope length where contouring is assumed to be fully effective (ft)
x_{de}	location where deposition within strip ends (ft)
x_*	normalized distance along slope length (dimensionless)
x_1	unstable aggregate size fraction less than 0.250 mm (%)
x_2	product of modified silt fraction (0.002 to 0.1 mm) and modified sand fraction (0.1 to 2 mm)
x_3	base saturation (dimensionless)
x_4	silt fraction (0.002 to 0.050 mm) (%)
x_5	sand fraction (0.1 to 2 mm) (%)

x_6	aggregation index (dimensionless)
x_7	montmorillonite in soil (%)
x_8	bulk density of the 50- to 125-mm depth ($g \cdot cm^{-3}$)
x_9	dispersion ratio (dimensionless)
x_{10}	parameter M (product of primary particle size fractions) (dimensionless)
x_{11}	citrate-dithionite-bicarbonate extractable percentage of Al_2O_3 plus Fe_2O_3 (%)
α	ratio of the area covered by a piece of residue to the mass of that residue ($acre \cdot lb^{-1}$)
β	ratio of rill to interrill erosion (dimensionless)
Δt	length of frost-free period or growing period (calendar days)
δ	constant with value of either 0 or 1
ζ	transport capacity factor ($ton \cdot ft^{-1} \cdot yr^{-1}$)
θ	slope angle (degrees)
λ	slope length (ft)
λ_c	critical slope length (ft)
ξ	erosion factor ($ton \cdot acre^{-1} \cdot yr^{-1}$)
σ	excess rainfall rate ($length \cdot time^{-1}$)
ϕ	ratio of sediment fall velocity to excess runoff rate (dimensionless)

PREFACE

The Revised Universal Soil Loss Equation (RUSLE) is an update of Agriculture Handbook No. 537, containing a computer program to facilitate the calculations. RUSLE also includes the analysis of research data that were unavailable when Agriculture Handbook No. 537 was completed. Although the original Universal Soil Loss Equation (USLE) has been retained in RUSLE, the technology for factor evaluation has been altered and new data have been introduced with which to evaluate the terms for specified conditions.

The rainfall-runoff erosivity factor (R) database has been expanded in the western United States, and a correction has been developed for the portion of rain falling on ponded water. The soil erodibility factor (K) has been made time varying to reflect freeze-thaw conditions and consolidation caused by moisture extraction of a growing crop, an alternative regression equation was developed for volcanic tropical soils, and a correction was developed for rock fragments in the soil profile. The topographic factors, slope length and steepness (LS), have been revised and algorithms developed to reflect the ratio of rill to interrill erosion. The cover-management factor (C) has been altered from the seasonal soil-loss ratios to a continuous function that is the product of four subfactors representing prior land use (PLU), surface cover (SC), crop canopy (CC), surface roughness (SR), and (for cropland in the Northwestern Wheat and Range Region) soil moisture (SM). These subfactors include consideration of the root mass in the upper 4 in of the soil profile, as well as changes in crop cover and root mass with time, tillage, and residue decomposition. Climatic data that include monthly precipitation and temperature, the frost-free period, rainfall-runoff erosivity, and twice monthly distributions for the EI (product of kinetic energy and maximum 30-min precipitation intensity) are used for consideration of the seasonal variations in K, C, and the support practice factor (P). P has been expanded to consider conditions for rangelands, contouring, stripcropping, and terracing.

The calculations in RUSLE are more involved than those in USLE and are facilitated with a computer program.

CHAPTER 1. INTRODUCTION AND HISTORY

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CHAPTER 1. CONTENTS

PURPOSE OF HANDBOOK

Scientific planning for soil conservation and water management requires knowledge of the relations among those factors that cause loss of soil and water and those that help to reduce such losses. Controlled studies on field plots and small watersheds have supplied much valuable information on these complex interrelations of factors. But the maximum benefits from such research can be realized only when the findings are applied as sound practices on the farms, ranches, and other erosion-prone areas throughout the United States. Specific guidelines are needed for the selection of the control practices best suited to the particular needs of each site.

Such guidelines are provided by the procedure for soil-loss prediction presented in this handbook. The procedure methodically combines research information from many sources to develop design data for each conservation plan. Widespread field experience for more than four decades has proved that this technology is valuable as a conservation-planning guide.

The procedure is founded on the empirical Universal Soil Loss Equation (USLE) (described in handbooks by Wischmeier and Smith 1965, 1978) that is believed to be applicable wherever numerical values of its factors are available. Research has supplied information from which at least approximate values of the equation's factors can be obtained for specific farm or ranch fields or other small land areas throughout most of the United States. Tables and charts or the personal-computer program presented in this handbook makes information readily available for field use.

The Revised Universal Soil Loss Equation (RUSLE) includes analyses of data not available when the previous handbooks were prepared. The analyses are documented so that users can review, evaluate, and repeat them in the process of making local analyses. Debate on this revision of USLE is important. Any such debate should be focused on the data, theory, and concepts described in the chapters. Many reviewers have helped with the debate. Their reviews were essential, and they should help to establish the credibility of this revision.

Judgments were necessary during the revision because some data were limited and inconclusive, and a few were conflicting. The decisions were made by the use of the collective knowledge of a number of erosion scientists. Furthermore, the technology was revised to permit the addressing of problems not included or inadequately addressed in earlier versions of USLE. The current revision is intended to provide the most accurate estimates of soil loss without regard to how the new values compare with the old values.

This revision updates the content of the earlier handbooks (Wischmeier and Smith 1965, 1978) and incorporates new material that has been available informally or in scattered research reports and professional journals. Some of the original charts and tables have been revised to conform with additional research findings, and new charts and tables have been developed to extend the usefulness of RUSLE. In some instances, expanding a table, chart, or computer program sufficiently to meet the needs for widespread field application required the projection of empirical factor relationships appreciably beyond the physical limits of the data from which the relationships were derived. Estimates obtained in this manner are the best information available for the conditions they represent. These instances are identified in the chapter discussions of the specific erosion factors, tables, charts, and computer program.

The background material for each RUSLE factor value is presented in the text that helps the user select correct values of individual factor parameters. This revision, with its background chapters, user's guide, and associated computer program, will provide erosion technology for use in addressing problems being proposed in the last decade of the 20th century or until new technology becomes available, such as that from USDA's Water Erosion Prediction Project (WEPP) (Foster and Lane 1987, Lane and Nearing 1989).

HISTORY OF EROSION-PREDICTION EQUATIONS

Efforts to mathematically predict soil erosion by water started only about a half century ago. The development of erosion-prediction technology began with analyses such as those by Cook (1936) to identify the major variables that affect soil erosion by water. Cook listed three major factors: susceptibility of soil to erosion, potential erosivity of rainfall and runoff, and soil protection afforded by plant cover. A few years later, Zingg (1940) published the first equation for calculating field soil loss. That equation described mathematically the effects of slope steepness and slope length on erosion. Smith (1941) added factors for a cropping system and support practices to the equation. He also added the concept of a specific annual soil-loss limit, and he used the resulting equation to develop a graphic method for selecting conservation practices for certain soil conditions in the midwestern United States.

Progress continued on methods to predict erosion during World War II, but publication of the research was delayed until after the war. Browning and associates (1947) added soil erodibility and management factors to the Smith (1941) equation and prepared more extensive tables of relative factor values for different soils, crop rotations, and slope lengths. This approach emphasized the evaluation of slope-length limits for different cropping systems on specific soils and slope steepness with and without contouring, terracing, or stripcropping. Smith and Whitt (1947) presented a method for estimating soil losses from fields of claypan soils. Soil-loss ratios at different slopes were given for contour farming, stripcropping, and terracing. Recommended limits for slope length were presented for contour farming. Relative erosion rates for a wide range of crop rotations were also given. Then Smith and Whitt (1948) presented a "rational" erosion-estimating equation, $A = C \cdot S \cdot L \cdot K \cdot P$, which broadened the application to principal soils of Missouri. The C factor was the average annual soil loss from claypan soils for a specific rotation, slope length, slope steepness, and row direction. The other factors for slope steepness (S), slope length (L), soil erodibility (K), and support practice (P) were dimensionless multipliers used to adjust the value of C to other conditions. P-factor values were discussed in detail. Smith and Whitt acknowledged the need for a rainfall factor to make this equation applicable over several states.

The Milwaukee, Wisconsin, regional office of USDA's Soil Conservation Service (SCS) recognized the value of a soil-loss equation for farm planning and teamed with researchers in that region to develop a system for regional application. The result was the slope-practice method of estimating soil loss for use in the Corn Belt. To adapt the Corn Belt equation for use in other regions, a workshop for erosion specialists from throughout the United States was held in Ohio in 1946. Workshop participants reviewed soil-loss data from all over the United States, reappraised the factors previously used, and added a rainfall factor. The resulting so-called Musgrave equation included factors for rainfall, flow characteristics of surface runoff as affected by slope steepness and slope length, soil characteristics, and vegetal cover effects (Musgrave 1947).

Graphs to solve the Musgrave equation were prepared by Lloyd and Eley (1952). They tabulated values for many major conditions in the northeastern states. Van Doren and Bartelli (1956) proposed an erosion equation for Illinois soils and cropping conditions that estimated annual soil loss as a function of nine factors. One of the factors was soil loss as measured on research plots; soil loss was adjusted to site conditions by several factors used by previous researchers and also factors for prior erosion and management levels.

The state and regional erosion-prediction equations were so useful that soil conservation leaders recommended that an effort be initiated to develop a national equation. As a result, the Agricultural Research Service (ARS) established the National Runoff and Soil Loss Data Center at Purdue University (West Lafayette, Indiana) in 1954. The Data Center was given the responsibility of locating, assembling, and consolidating all available data from runoff and erosion studies throughout the United States for further analyses (Wischmeier 1955). During subsequent years, Federal-state cooperative research projects at 49 U.S. locations contributed more than 10,000 plot-years of basic runoff and soil-loss data to this Center for summarizing and overall statistical analyses.

To hasten the development of a national equation, joint conferences of key researchers and users were held at Purdue University in February and July of 1956. The participants concentrated their efforts on reconciling the differences among existing soil-loss equations and on extending the technology to regions where no measurements of erosion by rainstorms had been made. The equation that resulted had seven factors; they were for crop rotation, management, slope steepness, slope length, conservation practice, soil erodibility, and previous erosion. The group established the maximum permissible loss for any soil as 5 $\text{ton} \cdot \text{acre}^{-1} \cdot \text{yr}^{-1}$ but set lower limits for many soils. Workshop participants concluded that insufficient data were available to justify adding a rainfall factor; subsequent analyses at the Data Center led to a rainfall factor for the states east of the Rocky Mountains. Subsequent study also showed that the equation's crop rotation and management factors could be combined into one factor (Wischmeier et al. 1958).

Using the data assembled at the Data Center along with conclusions from deliberations at the 1956 conferences and subsequent analyses, Wischmeier, Smith, and others developed USLE as described in earlier handbooks (Wischmeier and Smith 1965, 1978). USLE quantifies soil erosion as the product of six factors representing rainfall and runoff erosiveness, soil erodibility, slope length, slope steepness, cover-management practices, and support conservation practices.

USLE was designed to provide a convenient working tool for conservationists. A relatively simple technique was needed for predicting the most likely average annual soil loss in specific situations. A goal for the equation was that each factor (1) could be represented by a single number; (2) could be predicted from meteorological, soil, or erosion research data for each location; and (3) must be free from any geographically oriented base. The term "Universal" in USLE distinguishes this prediction model from the regionally based models that preceded it. However, the use of USLE should be limited to situations in which its factors can be accurately evaluated and to conditions for which it can be reliably applied (Wischmeier 1976).

USLE overcame many of the deficiencies of its predecessors. The form of USLE is similar to that of previous equations, but the concepts, relationships, and procedures underlying the definitions and evaluations of the erosion factors are distinctly different. Major changes include (1) more complete separation of factor effects so that results of a change in the level of one or several factors can be more accurately predicted; (2) an erosion index that provides a more accurate, localized estimate of the erosive potential of rainfall and associated runoff; (3) a quantitative soil-erodibility factor that is evaluated directly from research data without reference to any common benchmark; (4) an equation and nomograph that are capable of computing the erodibility factor for numerous soils from soil survey data; (5) a method of including the effects of interactions between cropping and management parameters; and (6) a method of incorporating the effects of local rainfall patterns throughout the year and specific cropping conditions in the cover and management factor (Wischmeier 1972).

Regression analysis of the assembled data determined the mathematical relationship between each USLE factor and soil loss. Effects of slope length and steepness, crop sequence, and soil- and crop-management practices were most accurately described as percentage increases or decreases in soil loss. A multiplicative model was selected for the equation. It uses four dimensionless factors to modify soil loss as described by dimensioned rainfall and soil factors.

USLE was introduced at a series of regional workshops on soil-loss prediction in 1959-62 and by a U.S. Department of Agriculture special report (USDA 1961). Several years of trial use by SCS and others plus extensive interaction between the developers and users resulted in improved factor values and the evaluation of additional conditions. Finally, USLE was presented in Agriculture Handbook No. 282 (Wischmeier and Smith 1965).

Widespread acceptance of USLE took time but came progressively as more regions and groups began to use this equation. During the same period, important improvements in USLE expanded its usefulness by providing techniques for estimating site values of its factors for additional land uses, climatic conditions, and management practices. These include a soil-erodibility nomograph for farmland and construction areas, topographic factors for irregular slopes, cover factors for range and woodland, effects of tillage practices on cover and management, prediction of erosion in construction areas, estimated erosion index values for the western states and Hawaii, soil erodibility factors for benchmark Hawaiian soils, and improved design and evaluation of erosion-control-support practices. These improvements were incorporated in an updated version of USLE, published as Agriculture Handbook No. 537 (Wischmeier and Smith 1978).

The erosion-research history that led to the development of USLE (Smith and Wischmeier 1962, Meyer 1984, Meyer and Moldenhauer 1985) shows that USLE was the logical culmination of several decades of innovative effort by scientists having unusual expertise and dedication. Since its introduction, USLE has had a tremendous impact and has become the major soil conservation planning tool in the United States and abroad.

Since the publication of Agriculture Handbook No. 537, additional research and experience have resulted in improvements in USLE. These include new and (in some instances) revised isoerodent maps; a time-varying approach to reflect freeze-thaw conditions and consolidation caused by extraction of moisture by a growing crop for the soil erodibility factor (K); a subfactor approach for evaluating the cover-management factor (C) for cropland, rangeland, and disturbed areas; a new equation to reflect slope length and steepness (LS) (the new terms also reflect the ratio of rill to interrill erosion); and new conservation-practice values (P) for both cropland and rangeland practices. Finally, the computations are now implemented using a personal computer. These changes are detailed in this revision in the chapters for each RUSLE factor.

The revision of USLE described in this handbook incorporates the latest information available for using this erosion-prediction approach. Research on the principles and processes of erosion and sedimentation by water is continuing in order to improve the methods of predicting and controlling erosion. Knowledge from such research has been used in developing physically based models such as the erosion and sedimentation components of CREAMS (Knisel 1980, Foster et al. 1981a). Development of a new generation of technology for predicting water erosion is under way by a USDA team in WEPP working with other agencies and academic institutions (Foster and Lane 1987). The goal of this WEPP effort is a process-oriented model or family of models that are conceptually superior to the lumped-model RUSLE and are more versatile as to the conditions that can be evaluated. The WEPP technology is expected to replace RUSLE sometime in the future.

SOIL-LOSS TOLERANCE

A major purpose of the soil-loss equation is to guide the making of methodical decisions in conservation planning. The equation enables the planner to predict the average rate of soil erosion for each of various alternative combinations of cropping systems, management techniques, and erosion-control practices on any particular site. The term "soil-loss tolerance" (T) denotes the maximum rate of soil erosion that can occur and still permit crop productivity to be sustained economically. The term considers the loss of productivity due to erosion but also considers rate of soil formation from parent material, role of topsoil formation, loss of nutrients and the cost to replace them, erosion rate at which gully erosion might be expected to begin, and erosion-control practices that farmers might reasonably be able to implement. When predicted soil losses are compared with the value for soil-loss tolerance at that site, RUSLE provides specific guidelines for bringing about erosion control within the specified limits. Any combination of cropping, ranching, and management for which the predicted erosion rate is less than the rate for soil-loss tolerance may be expected to provide satisfactory control of erosion. Of the satisfactory alternatives offered by this procedure, the alternative(s) best suited to a particular farm or other enterprise may then be selected.

Values of soil-loss tolerance ranging from 1 to 5 $\text{ton}\cdot\text{acre}^{-1}\cdot\text{yr}^{-1}$ for the soils of the United States were derived by soil scientists/conservationists, agronomists, engineers, geologists, and Federal and state researchers at six regional workshops between 1959 and 1962. Factors considered in defining these limits include soil depth, physical properties and other characteristics affecting root development, gully prevention, on-field sediment problems, seeding losses, reduction of soil organic matter, and loss of plant nutrients. Since the early discussions, several reports have been produced in which soil-loss tolerance is discussed (Schmidt et al. 1982, Johnson 1987). The passage of Public Law 95-192 and the 1977 Soil and Water Resources Conservation Act (RCA) prompted considerable interest in the effect of soil erosion on crop productivity. New experimental research and computer simulation models have furthered the interest in soil-loss tolerances. Two symposia proceedings of note that resulted from this activity are "Erosion and Soil Productivity" (ASAE 1985) and "Soil Erosion and Crop Productivity" (Follett and Stewart 1985). Needless to say, many issues about soil-loss tolerance remain unresolved.

A deep, medium-textured, moderately permeable soil that has subsoil characteristics favorable for plant growth has a greater tolerable soil-loss rate than do soils with shallow root zones or high percentages of shale at the surface. Widespread experience has shown that the concept of soil-loss tolerance may be feasible and generally adequate for indefinitely sustaining productivity levels.

Soil-loss limits are sometimes established to prevent or reduce damage to offsite water quality. The criteria for defining the tolerance limits of field soil-loss tolerance limits for this purpose are ***not*** the same as those for tolerances designed to preserve cropland productivity. Soil depth is not relevant for offsite sediment control, and uniform limits on erosion rates still allow a range in the amount of sediment per unit area that is delivered to a stream. Soil material eroded from a field slope may be deposited along field boundaries, in terrace channels, in depressional areas, or on flat or vegetated areas traversed by overland flow before it reaches a watercourse. Erosion damages the cropland on which it occurs, but sediment deposited near its place of origin does not directly affect water quality.

If the soil-loss tolerance established for sustained cropland productivity fails to attain the desired water-quality standard, other limits that consider other factors should be established rather than altering the value for soil-loss tolerance. Other factors may include distance of the field from a major waterway, sediment-transport characteristics of the intervening area, sediment composition, needs of the particular body of water being protected, and the probable magnitude of fluctuations in sediment loads (Stewart et al. 1975). Placing limits on sediment yield might provide more uniform water-quality control than would lowering the limits on soil movement from field slopes. The sediment-yield criteria would also require fewer restrictions on the selection of crop system for fields in which only small percentages of eroded soil become off-farm sediment.

As currently used in conservation-planning activities, T values are often an issue of policy. We recommend that T values remain as originally defined and intended: namely, the erosion rate that can occur and yet permit crop productivity to be sustained economically. If issues of water quality, economics, and policy are to be addressed for erosion control, we recommend that they be designated T_{WQ} (soil loss for water-quality concerns), T_{EP} (soil loss for economic planning), and T_{POL} (soil loss for policy concerns).

SOIL-LOSS EQUATION

The erosion rate for a given site results from the combination of many physical and management variables. Actual measurements of soil loss would not be feasible for each level of these factors that occurs under field conditions. Soil-loss equations were developed to enable conservation planners, environmental scientists, and others concerned with soil erosion to extrapolate limited erosion data to the many localities and conditions that have not been directly represented in the research.

Erosion and sedimentation by water involve the processes of detachment, transport, and deposition of soil particles (Foster 1982). The major forces are from the impact of raindrops and from water flowing over the land surface. Erosion may be unnoticed on exposed soil surfaces even though raindrops are eroding large quantities of sediment, but erosion can be dramatic where concentrated flow creates extensive rill and gully systems. Factors affecting erosion can be expressed in an equation of the form (Renard and Foster 1983)

$$E = f\,(C,\ S,\ T,\ SS,\ M) \qquad [1\text{-}1]$$

where

E = erosion,
f = function of ( ),
C = climate,
S = soil properties,
T = topography,
SS = soil surface conditions, and
M = human activities.

Sediment yield should not be confused with erosion; the terms are not interchangeable. Sediment yield is the amount of eroded soil that is delivered to a point in the watershed that is remote from the origin of the detached soil particles. In a watershed, sediment yield includes the erosion from slopes, channels, and mass wasting, minus the sediment that is deposited after it is eroded but before it reaches the point of interest (fig. 1-1). USLE and RUSLE do not estimate sediment yield.

USLE is essentially an expression of the functional relationship shown in equation [1-1] (Wischmeier and Smith 1965, 1978). Both USLE and RUSLE compute the average annual erosion expected on field slopes as

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \qquad [1\text{-}2]$$

where

A = computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that A is expressed in $ton \cdot acre^{-1} \cdot yr^{-1}$, but other units can be selected (that is, $t \cdot ha^{-1} \cdot yr^{-1}$).

R = rainfall-runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff from snowmelt.

K = soil erodibility factor—the soil-loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow.

L = slope length factor—the ratio of soil loss from the field slope length to soil loss from a 72.6-ft length under identical conditions.

S = slope steepness factor—the ratio of soil loss from the field slope gradient to soil loss from a 9% slope under otherwise identical conditions.

C = cover-management factor—the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.

P = support practice factor—the ratio of soil loss with a support practice like contouring, stripcropping, or terracing to soil loss with straight-row farming up and down the slope.

RUSLE is an erosion model designed to predict the longtime average annual soil loss (A) carried by runoff from specific field slopes in specified cropping and management systems as well as from rangeland. Widespread use has substantiated the usefulness and validity of RUSLE for this purpose. It is also applicable to nonagricultural conditions such as construction sites.

RUSLE users need to be aware that A (in addition to being a longtime average annual soil loss) is the average loss over a field slope and that the losses at various points on the slope may differ greatly from one another. On a long uniform slope, the loss from the top part of the slope is much lower than the slope average, and the loss near the bottom of the slope is considerably higher. For instance, a 360-ft uniform slope that averages 20 ton· acre^{-1} will have an average of less than 7 ton· acre^{-1} loss on the first 40 ft but over 29 ton· acre^{-1} loss on the last 40 ft. If the slope steepness changes within that length, the variation can be even greater. This suggests that even if a field soil loss is held to "T," soil loss on some portion of the slope may reach or exceed 2T, even when the ephemeral gully and other types of erosion that are not estimated by RUSLE are ignored. These higher-than-average rates generally occur at the same locations year after year, so excessive erosion on any part of the field may be damaging the soil resource.

With appropriate selection of its factor values, RUSLE will compute the average soil loss for a multicrop system, for a particular crop year in a rotation, or for a particular crop stage period within a crop year. Erosion variables change considerably from storm to storm about their means. But the effects of the random fluctuations such as those associated with annual or storm variability in R and the seasonal variability of the C tend to average out over extended periods. Because of the unpredictable short-time fluctuations in the levels of influential variables, however, present soil-loss equations are substantially less accurate for the prediction of specific events than for the prediction of longtime averages.

USLE has also been used for estimating soil loss from disturbed forested conditions. RUSLE does not address this particular application. Users of such technology are referred to Dissmeyer and Foster (1980, 1981).

Some recent research addresses the application of USLE technology to mine spoils and reconstructed topsoil (Barfield et al. 1988). The effects of compaction on erosion are significant in such instances and are treated as an integral part of the subfactor for calculating C (see ch. 5). Furthermore, slope steepness effects on soil loss from disturbed lands (McIsaac et al. 1987a) are treated specifically in chapter 4 with the application of an LS table (see table 4-3). Other RUSLE terms remain unchanged by massive land disturbance such as that associated with construction. It is important to realize that the amount of research on effects of land disturbance on RUSLE technology is not as extensive as that associated with most other applications.

The soil-loss equation was initially developed in U.S. customary units. The factor definitions are interdependent, and the direct conversion of acres, tons, inches, and feet to metric units produces integers that are best suited for expressing equations in that system. Only U.S. customary units are used in the equation and factor-evaluation materials, but the metric equivalents are given in appendix A.

Numerical values for each of the six factors were derived from analyses of research data and from National Weather Service precipitation records. For most conditions in the United States, the approximate values of the factors for any particular site may be obtained from charts and tables in this handbook or by use of the computer program developed to assist with the RUSLE evaluation. Users in localities or countries where the rainfall characteristics, soil types, topographic features, or farm practices are substantially beyond the range of present U.S. data will find these charts, tables, and computer program incomplete and perhaps inaccurate for their conditions. However, RUSLE provides guidelines that can reduce the amount of local research needed to develop appropriate technology for their conditions.

The RUSLE User Guide (ch. 7) illustrates how to select factor values either with the computer program or by use of data from the tables and charts. Users who have no experience with the soil-loss equation may wish to read chapter 7 next. After users have referred to the computer program and have located the values used therein, they may readily move to the intervening chapters (ch. 2-6), which define the technical details associated with the factors. The soil-loss-prediction procedure is more valuable as a guide for the selection of practices if the user has general knowledge of the principles on which the equation is based. Therefore, the significance of each factor is discussed before the introduction of the computer program and before the reference table or chart from which local values may be obtained. Limitations of the data available for evaluation of some of the factors are also discussed.

Chapters 2-6 are written as background for the development of the technology to permit evaluation of the individual RUSLE factors. Although liberal use is made of material from previous versions of USLE (Agriculture Handbooks No. 282 in 1965 and No. 537 in 1978), direct quotes from that material are not always noted. The computer program, intended to assist the user of this technology, is a new development that was not a part of earlier versions.

The authors acknowledge the efforts of Laura J. Yohnka for processing the many drafts prior to completion and E. Sue Anderson for finishing work on the final copy.

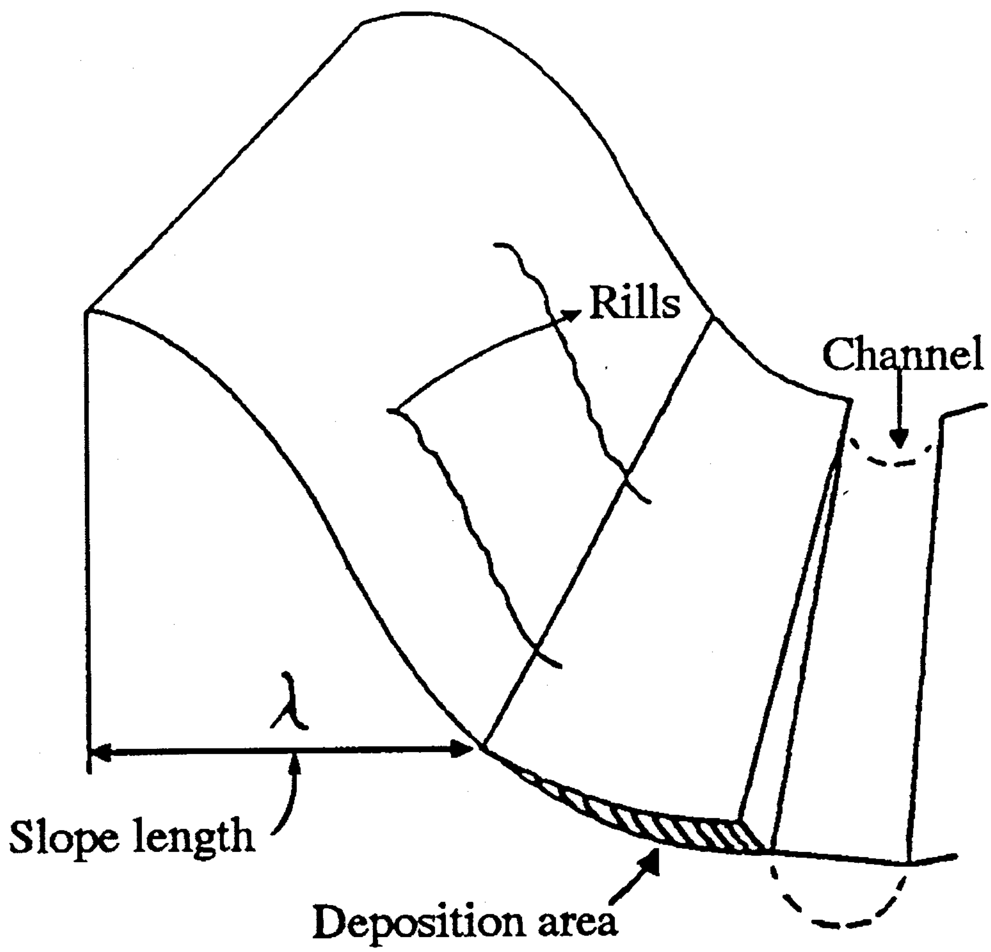

Figure 1-1. Schematic slope profile for RUSLE applications for interrill and rill erosion. λ is the RUSLE slope length (to the point where deposition occurs). Sediment yield is the sediment transported out of the channel section summed for time periods such as a storm event, month, crop stage, or year.

CHAPTER 2. RAINFALL-RUNOFF EROSIVITY FACTOR (R)

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CHAPTER 2. CONTENTS

The rainfall and runoff factor (R) of the Universal Soil Loss Equation (USLE) was derived (Wischmeier 1959, Wischmeier and Smith 1958) from research data from many sources. The data indicate that when factors other than rainfall are held constant, soil losses from cultivated fields are directly proportional to a rainstorm parameter: the total storm energy (E) times the maximum 30-min intensity (I_{30}).

Rills and sediment deposits observed after an unusually intense storm have sometimes led to the conclusion that significant erosion is associated with only a few severe storms--that significant erosion is solely a function of peak intensities. However, more than 30 yr of measurements in many states have shown that this is not the case (Wischmeier 1962). The data show that a rainfall factor used to estimate average annual soil loss must include the cumulative effects of the many moderate-sized storms as well as the effects of the occasional severe ones.

The numerical value used for R in USLE and in RUSLE must quantify the effect of raindrop impact and must also reflect the amount and rate of runoff likely to be associated with the rain. The erosion index (R) derived by Wischmeier appears to meet these requirements better than any of the many other rainfall parameters and groups of parameters tested against the plot data. The local value of this index may be obtained directly from maps. However, the index does not include the erosive forces of runoff from snowmelt, rain on frozen soil, or irrigation. A procedure for evaluating R for locations where this type of runoff is significant is given in this chapter under "R Equivalent (R_{eq}) for Cropland in the Northwestern Wheat and Range Region."

In RUSLE, the computational scheme is identical to that used in USLE, with a few exceptions (as noted later).

EI PARAMETER

The value of EI for a given rainstorm equals the product of total storm energy (E) times the maximum 30-min intensity (I_{30}), where E is in hundreds · ft· tonf · acre^{-1}, and I_{30} is in in · h^{-1}. EI is an abbreviation for energy times intensity, and the term should *not* be considered simply an energy parameter. Data show that rainfall energy itself is not a good indicator of erosive potential. The storm energy indicates the volume of rainfall and runoff, but a long, slow rain may have the same E value as a shorter rain at much higher intensity. Raindrop erosion increases with intensity. The I_{30} component reflects the prolonged peak rates of detachment and runoff. The product term EI is a statistical interaction term that reflects how total energy and peak intensity are combined in each particular storm. Technically, the term indicates how particle detachment is combined with transport capacity. Appendix B illustrates how the calculations are made from recording-raingage data.

The relation of soil loss to the EI parameter is assumed to be linear, and the parameter's individual storm values are directly additive. The sum of the storm EI values for a given period is a numerical measure of the erosive potential of the rainfall within that period. The average annual total of the storm EI values in a particular locality is the rainfall erosion index (R) for that locality. Because of apparent cyclical patterns in rainfall data, early published values for rainfall erosion indices (for example, in Agriculture Handbook No. 537) were based on 22-yr station rainfall records. Longer records are advisable, especially when the coefficient of variation of annual precipitation is large.

Rain showers of less than 0.5 in were omitted from the erosion index computations, unless at least 0.25 in of rain fell in 15 min. Furthermore, a storm period with less than 0.05 in over 6 h was used to divide a longer storm period into two storms. Exploratory analyses showed that erosion from these light rains is usually too small for practical significance and that, collectively, they have little effect on the distribution of the annual EI or erosion. The cost of abstracting and analyzing 4,000 location-years of rainfall-intensity data used to develop the initial R-factor map was greatly reduced by adopting the threshold value of 0.5 in.

The energy of a rainstorm is a function of the amount of rain and of all the storm's component intensities. The median raindrop size generally increases with greater rain intensity (Wischmeier and Smith 1958), and the terminal velocities of free-falling waterdrops increase with larger drop size (Gunn and Kinzer 1949). Since the energy of a given mass in motion is proportional to velocity squared, rainfall energy is directly related to rain intensity. The relationship, based on the data of Laws and Parsons (1943), is expressed by the equation

$$e = 916 + 331 \log_{10} i, \qquad i \leq 3 \text{ in} \cdot \text{h}^{-1} \qquad [2\text{-}1]$$

$$e = 1074 \qquad i > 3 \text{ in} \cdot \text{h}^{-1} \qquad [2\text{-}2]$$

where e is kinetic energy in ft · tonf · acre^{-1} · in^{-1}, and i is intensity in in · h^{-1} (Wischmeier and Smith 1958). A limit of 3 in · h^{-1} is imposed on i because median drop size does not continue to increase when intensities exceed 3 in · h^{-1} (Carter et al. 1974).

The corresponding SI metric-unit version of the equations are (Foster et al. 1981b, app. A)

$$e_m = 0.119 + 0.0873 \log_{10}(i_m) \qquad i_m \leq 76 \text{ mm} \cdot \text{h}^{-1} \qquad [2\text{-}3]$$

$$e_m = 0.283 \qquad i_m > 76 \text{ mm} \cdot \text{h}^{-1} \qquad [2\text{-}4]$$

where e_m has units of megajoule per hectare per millimeter of rainfall (MJ · ha^{-1} · mm^{-1}).

Other investigators have also presented algorithms for computing the kinetic energy for drop distributions in other geographic areas of the continental United States [for example, McGregor and Mutchler (1977) in Mississippi, Carter et al. (1974) in the South Central United States, Tracy et al. (1984) in southeastern Arizona, and Rosewell (1983, 1986) in Australia].

Brown and Foster (1987) used a unit energy relationship of the form

$$e = e_{max} \left[1 - a \exp(-b \cdot i)\right] \qquad [2\text{-}5]$$

where

e_{max} = a maximum unit energy as intensity approaches infinity, and

a and b = coefficients.

Kinnell (1981, 1987) showed that this distribution described unit energy-intensity relationships in Zimbabwe and Florida. Additional work by Rosewell (1983, 1986) showed that the relationship also fit data in Australia, the McGregor and Mutchler (1977) data, and the Laws and Parsons (1943) data. Unfortunately, these applications showed some variability in the a and b coefficients. Brown and Foster stated in their analysis that they recommended

$$e_m = 0.29 \left[1 - 0.72 \exp(-0.05 i_m)\right] \qquad [2\text{-}6]$$

for calculating unit energy, where e_m has units of $MJ \cdot ha^{-1} \cdot mm^{-1}$ of rain and i_m has units of $mm \cdot h^{-1}$. Brown and Foster also stated that this equation is a superior analytical form by having a finite positive value at zero intensity as data show and approaching an asymptote at high intensities as a continuous function. The U.S. customary units equivalent of equation [2-6] is

$$e = 1099\left[1 - 0.72 \exp(-1.27\, i)\right] \qquad [2\text{-}7]$$

where i has units of $in \cdot h^{-1}$ and e has units of $ft \cdot tonf \cdot acre^{-1} \cdot in^{-1}$.

Then

$$R = \frac{\sum_{i=1}^{j} (EI_{30})_i}{N} \qquad [2\text{-}8]$$

where $(EI_{30})_i = EI_{30}$ for storm i, j = number of storms in an N year period.

These equations were used for developing the isoerodent maps of figures 2-1 to 2-4.

The isoerodent maps of figures 2-1 and 2-9 were developed from equations [2-1] and [2-2]. We recommend that all future calculations be made using equation [2-6] or equation [2-7], especially in other countries where RUSLE technology is being developed.

Sample calculations of EI_{30} are given in appendix B.

ISOERODENT MAPS

Local values of the rainfall erosion index may be taken directly from isoerodent maps or from the CITY database in the computer program as explained in chapter 7. The plotted lines on the maps are called isoerodents because they connect points of equal rainfall erosivity. Erosion index values for locations between the lines can be obtained by linear interpolation.

The original isoerodent map (Wischmeier and Smith 1965) was developed from 22-yr station rainfall records by computing the EI value for each storm that met the previously defined threshold criteria. Isoerodents were then located between these point values with the help of published rainfall intensity-frequency data (U.S. Weather Bureau 1958) and topographic maps. The 11 western states were omitted from the initial map because sufficient long-term recording-raingage records were not available for establishing lines of equal erosion index values.

The isoerodent map was extended with an estimation procedure to the Pacific Coast in 1976 and was printed in Agriculture Handbook No. 537. Results of investigations at the USDA-ARS National Soil Erosion Research Laboratory at Purdue University showed that the known erosion index values in the Western Plains States and the North Central States are approximated with reasonable accuracy by the equation $R = 27.38P^{2.17}$ where P is the 2-yr frequency, 6-h rainfall amount (Wischmeier 1974). Although the isoerodents developed were compatible with the few point values that had been established in the western United States, the isoerodents were not sufficiently accurate to reflect the known spatial variability of the mountain and valley topography of the region.

In an agreement between Oregon State University, U.S. Department of Agriculture's Soil Conservation Service (SCS) and Agricultural Research Service (ARS), and the National Weather Service, 713 stations were used to determine relationships between values of EI calculated on a 15-min measurement interval basis and on values of EI calculated for the same storm on a 60-min measurement interval basis. In contrast to the calculations in the eastern United States, all storms were included to calculate EI. Of these stations, 225 had record periods of 12 yr or longer and precipitation measurement resolutions of 0.01 in. Values of coefficient of determination (r^2) in excess of 0.8 were obtained by use of the model $(EI)_{15} = b[\,(EI)_{60}\,]$.

Values of the regression parameter b ranged from 1.08 to 3.16, varying widely from one climatic zone to the next.

To supplement this work, 1,082 stations were used to calculate $(EI)_{60}$. Of these stations, 790 had 20-yr record lengths or longer. These data values were adjusted to a 15-min measurement interval using the correction cited above. Computed values of $(EI)_{60}$ for each 60-min station were multiplied by the average regression parameter b (computed for all 15-min stations in the climatic zone containing the 60-min station) to obtain equivalent 15-min values, $(EI)_{15}$. These values were then adjusted to an equivalent breakpoint basis by use of $R = 1.0667\ (R)_{15}$ (Weiss 1964). The resulting isoerodent map (R) was prepared by hand contouring the adjusted R values for stations with record periods of at least 20 yr. The resulting isoerodent maps for the West is a significant improvement over that available in Agriculture Handbook No. 537 (Wischmeier and Smith 1978). Seasonal EI distributions were developed for 84 climate zones in the western States. The maximum storm 10-yr-frequency EI values were calculated as part of the project. In this analysis, for areas where winter precipitation is predominantly snowfall, the snowfall months were excluded from the EI development. Thus, in the CITY database, the winter months show zero percent EI.

In Hawaii, isoerodent maps of figure 2-5 were computed by the use of class-A weather stations to compute R and by relating these values to National Weather Service intensity-frequency data for Hawaii. EI distribution data were also calculated for select Hawaiian stations to use in the calculation of seasonally weighted K values (ch. 3) and C values (ch. 5).

If the soil and topography were exactly the same everywhere, average annual soil losses from plots maintained in continuous fallow would be in direct proportion to these erosion index values.

R Values for Flat Slopes

Although the R factor is assumed to be independent of slope in the structure of RUSLE, splash erosion is less on low slopes. On flat surfaces, raindrops tend to be more buffered by water ponded on the soil surface than on steep slopes. Higher rainfall intensities that are correlated with higher R factors also tend to increase the depth of ponded surface water, which in turn protects the soil from rainfall impact (Mutchler 1970). To account for this soil protection by a ponded water layer on low slopes under high rainfall rates, the R factor should be adjusted using a relationship having the form (modified from Mutchler and Murphree 1985)

$$R_c = f\ (I,\ S) = f\ (R,\ S) \qquad [2\text{-}9]$$

where

R_c	=	rainfall erosivity adjustment factor,
f	=	function of ( ),
I	=	precipitation intensity,
S	=	slope steepness, and
R	=	RUSLE rainfall erosivity term.

To compute R_c assume that the 10-yr-frequency storm EI value provides an indication of storm intensity and therefore the amount of water ponded on the land surface. In this procedure, the 10-yr EI value of a CITY database is used with a runoff index (a constant CN = 78 was used) and Manning's equation to compute a flow depth ratio, y. This flow depth ratio is then used in the equation $R_c = \exp(-0.49 \cdot [y-1])$. Figure 2-6 is the result of such calculations for a variety of land slopes. For further discussion, refer to chapter 6.

EI DISTRIBUTION USED IN CALCULATION OF K FACTOR AND C FACTOR

To calculate the seasonal or average annual soil erodibility factor (K) and the seasonal or average annual cover-management factor (C), the distribution of EI is needed. In RUSLE, the EI distribution (as a percentage of the annual value) is used for twenty-four 15-d periods, corresponding with the 1st and 16th days of the month.

Figure 2-7 shows the 120 homogeneous climatic zones in the contiguous United States used in RUSLE. The EI distribution values for each of these zones have been determined and are available in the computer code. Table 2-1 shows the EI distributions for the 120 zones and 19 Hawaiian zones, as well as the equivalent EI distribution for the frozen soil area of the Northwestern Wheat and Range Region.

Most of the climatic zones in figure 2-7 also have a single station containing information on precipitation and temperature (by month), the frost-free period, and the annual R. For example, about 140 climate stations (including 19 in Hawaii) are in the computer files. A user of the computer files may want to enter additional climate data for a zone. In other instances, a user may have to enter a climate station into the program before making soil-loss estimates in that region. The climate zones of figure 2-7 represent uniform EI distributions rather than uniform precipitation data or temperature data or both. Thus, in the western United States, orographic trends may pose problems within many of the zones and the user may need to input the additional data to reflect the orographic differences.

Although 19 stations are included in the Hawaiian climatic data files, the tremendous variability in precipitation, R, and temperature are only partially included. Therefore, caution must be used when making soil-loss estimates with RUSLE in Hawaii.

EI DATA FOR 10-YR-FREQUENCY STORMS

In the P-factor calculation for contour farming (ch. 6), the 10-yr-frequency storm EI value is required. These 10-yr EI data are used to credit the effect of contour practices on the support practice value. The values were obtained from the data originally calculated for Agriculture Handbook No. 537 (Wischmeier and Smith 1978) involving 181 stations in the eastern United States and from about 1,000 stations used to develop the isoerodent values in the western United States. The maps of these isoerodent values are given in figures 2-9 to 2-12 for the eastern and western United States.

Site-specific data can be obtained by interpolation from these figures. In the RUSLE computer program (see ch. 7 for the subroutine CITY), these values are given for most stations or they can be obtained by interpolation using the figures.

R EQUIVALENT (R_{eq}) FOR CROPLAND IN THE NORTHWESTERN WHEAT AND RANGE REGION

In the dryfarmed cropland areas of the Northwestern Wheat and Range Region (Austin 1981) shown in figure 2-8, the effect of melting snow, rain on snow, and/or rain on thawing soil poses unique problems. Generally, measured soil-loss values in the regions devoted to winter wheat, spring wheat, spring barley, peas, and lentils are much greater than the value that might be expected from R values calculated with the conventional kinetic energy times maximum 30-min intensity (EI). Observations indicate that much of the soil loss occurs by rilling phenomena when the surface part of the soil profile thaws and snowmelt or rain occurs on the still partially frozen soil. To more accurately predict soil losses for this condition, an R_{eq} value has been calculated using the following procedures:

$$(R_{eq})_{wr} = \frac{A_{wr}}{K_{wr}\ (LS)_{wr}\ (SLR)_{wr}\ P_{wr}} \qquad [2\text{-}10]$$

where

$(R_{eq})_{wr}$ = equivalent R factor for winter rilling,
A_{wr} = soil loss over winter in rills alone (measured),
K_{wr} = rill soil erodibility for winter period (estimated),
$(LS)_{wr}$ = LS relationship,
$(SLR)_{wr}$ = soil loss ratio for rilling in winter period (estimated for field condition), and
P_{wr} = supporting practices factor.

The soil loss from rills (A_{wr}) was measured after the winter erosion season from strips on selected fields along a 45- to 50-mi transect across eastern Washington and northern Idaho for a period of 10 yr. This area was subsequently divided into four zones for presentation and interpretation. Similar soil-loss measurements were made in five counties in north-central Oregon for 5 yr (although data were not collected for each county every year). Soil-loss measurements in southeastern Idaho were made for 4 yr. Thus, the rill soil-loss measurements represent a potential of 10 data points.

The winter erodibility value might be obtained by use of the variable K procedure (ch. 3) and by use of the average value of K for the winter period.

However, in RUSLE, K_{av} (EI-weighted average annual K value) is used throughout the entire year; there is no provision for use of an average K value for a particular portion of the year. Therefore, for consistency, K_{av} was used to calculate $(R_{eq})_{wr}$.

The Northwestern Wheat and Range Region LS relationships in RUSLE (ch. 4) were developed from only the Palouse transect data (eastern Washington and northern Idaho). The following LS relationships were used for $(R_{eq})_{wr}$ calculation:

$$(LS)_{wr} = \left[\frac{\lambda}{72.6}\right]^{0.5} (10.8 \sin\theta + 0.03) \qquad s < 9\% \qquad [2\text{-}11]$$

$$(LS)_{wr} = \left[\frac{\lambda}{72.6}\right]^{0.5} \left[\frac{\sin\theta}{0.0896}\right]^{0.6} \qquad s \geq 9\% \qquad [2\text{-}12]$$

Values of $(LS)_{wr}$ were calculated for each segment of the measured slope based on the contributing area above the segment and the segment steepness.

The soil-loss ratio $(SLR)_{wr}$ was calculated from the following factors:

(1) The rotation was assigned a soil-moisture factor using (see ch. 5) ww/p = 0.88, ww/sf = 1.0, wr = 0.5, and ww/sb = 0.72.

(2) Surface residue effect was calculated from a residue effectiveness curve [exp (-0.05 · % cover)].

(3) Growing cover effect was obtained from [1 - fraction of land surface covered by canopy]. Growing cover was generally less than 10% and often less than 5%.

(4) Surface roughness effect was assigned values from 0.7 to 1.2 based on field observations. Most values used were about 1.1.

(5) Incorporated residue effect was obtained from [exp (-0.00045 · lb $acre^{-1}$ residue incorporated at a shallow depth)]. Shallow incorporated residue was assumed to be half of the residue incorporated less decomposition.

The soil-loss ratio $(SLR)_{wr}$ was then computed as the product of these five factors.

The winter support practices factor (P_{wr}) was assumed to be unity. Thus, $(R_{eq})_{wr}$ was calculated for each year for each zone or county by averaging all segment values.

The individual zone $(R_{eq})_{wr}$ was averaged over the years of record to obtain a zonal average value. The data points were reduced from 10 to 7 based on the number of segments and strips in a zone or county in a given year and on the number of years of data in a zone or county. The three points deleted were all from north-central Oregon. These average values were subsequently correlated against published annual precipitation for corresponding zones to obtain

$$\left(R_{eq}\right)_{wr} = -110.3 + 10.78\ P \qquad [2\text{-}13]$$

$$r^2 = 0.98$$

where P = annual precipitation (in).

Adjustment for Interrill and Non-Winter Soil Loss

Measurements of the rill to interrill ratio soil loss in the Northwestern Wheat and Range Region vary greatly. For example, rill-erosion measurements near the Columbia Plateau Conservation Research Center near Pendleton, Oregon, indicate about a 95% rill soil loss. A rule of thumb based on the old Pullman Conservation Field Station (PCFS) plots near Pullman, Washington, was that 75% of the soil loss came from rill erosion. Recent measurements over a 4-yr period from continuous fallow plots at the PCFS indicate that 85-90% of the soil loss came from rill erosion. In other instances (and varying with treatments), the attempts to separate interrill losses from total soil loss have been essentially unsuccessful. Thus, a somewhat arbitrary ratio of 90% rill loss and 10% interrill soil loss was assumed to adjust the $(R_{eq})_{wr}$ to estimate the total winter equivalent R, $(R_{eq})_{wt}$.

Then

$$\left(R_{eq}\right)_{wt} = \left(R_{eq}\right)_{wr} \cdot \frac{100}{90} \qquad [2\text{-}14]$$

The nonwinter component of soil loss was estimated in two ways, each of which gives a ratio of roughly 5% of the annual R_{eq} occurring during the nonwinter periods. Thus, we estimate total annual soil loss as

$$R_{eq} = \left(R_{eq}\right)_{wr} \cdot \frac{100}{90} \cdot \frac{100}{95} \qquad [2\text{-}15]$$

and finally

$$R_{eq} = -129.0 + 12.61P \qquad [2\text{-}16]$$

For lower precipitation areas of the Northwest Wheat and Range Region with a frozen soil erosion problem, the following relationship will provide a smooth transition from the R_{eq} to the non-R_{eq} zone:

$$R_{eq} = 1.602 \exp(0.2418\ P) \qquad 7.5 < P < 15.0 \qquad [2\text{-}17]$$

Equation 2-17 should be used for $P \leq 15.0$.

The P and R_{eq} maps for the cultivated areas farmed with winter wheat, spring wheat, spring barley, peas, or lentils in the Northwestern Wheat and Range Region are shown in figures 2-13 to 2-16. The small-grain areas include higher elevation forest and grazing land as well as the cultivated valleys and lower slopes. In general, winter wheat is not grown where P is greater than about 35 in. Thus, no R_{eq} values greater than 320 (P = 35.6 in) are plotted in figures 2-15 and 2-16.

It was necessary to distribute the R_{eq} throughout the year. The nonwinter component (5% of the total) was distributed uniformly from April 1 through September 30. The winter component (95% of the total) was distributed from October 1 through March 31. Based on historical soil-loss data from PCFS, the period of major erosivity was assigned to late January and early February. Erosivity then tapered gradually to October 1 and more steeply to March 31 (see Pullman, WA, CITY database for the R_{eq} distribution data).

RAINFALL EROSIVITY IN A COLD MOUNTAINOUS CLIMATE

Data analysis from the precipitation network in southwestern Idaho indicate major problems in assessing the erosivity index. The problems are not uniquely different from those in the Northwestern Wheat and Range Region (area of winter wheat, spring barley, peas, and lentils). RUSLE (and also its predecessor USLE) was designed to account for the effects of raindrop impact and subsequent overland flow on soil erosion (Cooley et al. 1988). In much of the western United States, precipitation occurring as snow should also be accounted for if representative EI estimates are to be produced.

Cooley et al. (1988) found that snowfall accounted for only a minor portion (4%) of EI based on annual precipitation values at low-elevation valley sites. However, at high elevation sites, snowfall accounted for most (up to 71%) of the annual precipitation. Therefore, it is important to use only the rainfall portion of annual precipitation when determining EI in areas where snowfall is significant, rather than using total annual precipitation.

Elevation was observed to have a relatively minor influence on summer (rain) EI values. Summer storms are mainly produced by air-mass thunderstorms and tend to be more random in location and smaller in areal extent than are frontal storms.

The consideration of all storms in estimating EI, rather than only storms that result in more than 0.5 in rainfall [per Wischmeier and Smith (1978) procedure], increased EI by 28-59% on the Reynolds Creek watershed. However, runoff and erosion data for evaluating the significance of these increases were not available.

Cooley et al. (1988) also tested several methods of computing average annual R involving 2-yr-frequency, 6-h-duration precipitation for comparison with long-term breakpoint-data R values (table 2-2). In mountain and range topography like that of southwestern Idaho, caution must be exercised in selecting storm values because snow events can affect the value. Cooley et al. (1988) observed that the storm value decreased by 5-34% when snowfall was eliminated from the annual data set. R decreased by 4-42% when snowfall was removed; that is, summer values were used instead of annual values.

SOUTHWESTERN AIR-MASS THUNDERSTORM

Precipitation gages operated by ARS in Arizona and New Mexico were used to compute EI data for areas dominated by air-mass thunderstorms. Of particular interest is the fact that EI during the summer period amounted to 85-93% of the annual total, which was 50-81 hundreds · ft· tonf · (acre · in · yr)$^{-1}$ (Renard and Simanton 1975).

In still other efforts, Simanton and Renard (1982) calculated the EI for a storm on the 57.7-sq-mi Walnut Gulch Experimental watershed in southeastern Arizona. Figure 2-17 shows the isohyetal values of precipitation determined for the 100 recording raingages for the event of July 22, 1964, and the corresponding isoerodent map. It should be noted that the isoerodent lines have little correlation with the isohyetal lines. An intense air-mass thunderstorm near the upper end of the area caused nearly 100 units of EI whereas only a short distance away (about 5 mi), the EI was less than 50% of the storm maximum.

Figure 2-18 illustrates the annual isohyetal map and the annual isoerodent (R) map, including the data of figure 2-17 plus the other storms occurring during the year. The highly variable rainfall illustrated in figures 2-17 and 2-18 is very typical of air-mass-thunderstorm country as shown on the isoerodent map. The 1.9 ratio of maximum to minimum annual precipitation and the 4.0 ratio of maximum to minimum R are normal occurrences.

The significance of these illustrations is that a single raingage and the EI calculations from it may be inadequate indicators of the soil loss at any specific point unless the precipitation record is collected at that site.

LIMITATIONS IN WINTER R FACTORS

Agriculture Handbook No. 537 suggests that the rainfall erosivity value (R) might be adjusted by multiplying the precipitation falling in the form of snow by 1.5 and then adding the product to EI, the kinetic energy times maximum 30-min intensity. This calculation has been used in the past at some locations, but we currently do not support this approach in RUSLE. The redistribution of snow by drifting, sublimation, and reduced sediment concentrations in snowmelt confuses the problem tremendously. But data are not presently available to support this approximation. Therefore, the developers of RUSLE recognized the weakness of ignoring the problem (except in the cropland areas of the Northwestern Wheat and Range Region where the R_{eq} data are being used).

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Table 2-1.
EI as percentage of average annual value computed for geographic areas shown in figure 2-7[1,2]

EI number	Periods 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
1	0.0	4.3	8.3	12.8	17.3	21.6	25.1	28.0	30.9	34.9	39.1	42.6	45.4	48.2	50.8	53.0	56.0	60.8	66.8	71.0	75.7	82.0	89.1	95.2
2	0.0	4.3	8.3	12.8	17.3	21.6	25.1	28.0	30.9	34.9	39.1	42.6	45.4	48.2	50.8	53.0	56.0	60.8	66.8	71.0	75.7	82.0	89.1	95.2
3	0.0	7.4	13.8	20.9	26.5	31.8	35.3	38.5	40.2	41.6	42.5	43.6	44.5	45.1	45.7	46.4	47.7	49.4	52.8	57.0	64.5	73.1	83.3	92.3
4	0.0	3.9	7.9	12.6	17.4	21.6	25.2	28.7	31.9	35.1	38.2	42.0	44.9	46.7	48.2	50.1	53.1	56.6	62.2	67.9	75.2	83.5	90.5	96.0
5	0.0	2.3	3.6	4.7	6.0	7.7	10.7	13.9	17.8	21.2	24.5	28.1	31.1	33.1	35.3	38.2	43.2	48.7	57.3	67.8	77.9	86.0	91.3	96.9
6	0.0	0.0	0.0	0.5	2.0	4.1	8.1	12.6	17.6	21.6	25.5	29.6	34.5	40.0	45.7	50.7	55.6	60.2	66.5	75.5	85.6	95.9	99.5	99.9
7	0.0	0.0	0.0	0.0	0.0	1.2	4.9	8.5	13.9	19.0	26.1	35.4	43.9	48.8	53.9	64.5	73.4	77.5	80.4	84.8	89.9	96.6	99.2	99.7
8	0.0	0.0	0.0	0.0	0.0	0.9	3.6	7.8	15.0	20.2	27.4	38.1	49.8	57.9	65.0	75.6	82.7	86.8	89.4	93.4	96.3	99.1	100.0	100.0
9	0.0	0.8	3.1	4.7	7.4	11.7	17.8	22.5	27.0	31.4	36.0	41.6	46.4	50.1	53.4	57.4	61.7	64.9	69.7	79.0	89.6	97.4	100.0	100.0
10	0.0	0.3	0.5	0.9	2.0	4.3	9.2	13.1	18.0	22.7	29.2	39.5	46.3	48.8	51.1	57.2	64.4	67.7	71.1	77.2	85.1	92.5	96.5	99.0
11	0.0	5.4	11.3	18.8	26.3	33.2	37.4	40.7	42.5	44.3	45.4	46.5	47.1	47.4	47.8	48.3	49.4	50.7	53.6	57.5	65.5	76.2	87.4	94.8
12	0.0	3.5	7.8	14.0	21.1	27.4	31.5	35.0	37.3	39.8	41.9	44.3	45.6	46.3	46.8	47.9	50.0	52.9	57.9	62.3	69.3	81.3	91.5	96.7
13	0.0	0.0	0.0	1.8	7.2	11.9	16.7	19.7	24.0	31.2	42.4	55.0	60.0	60.8	61.2	62.6	65.3	67.6	71.6	76.1	83.1	93.3	98.2	99.6
14	0.0	0.7	1.8	3.3	6.9	16.5	26.6	29.9	32.0	35.4	40.2	45.1	51.9	61.1	67.5	70.7	72.8	75.4	78.6	81.9	86.4	93.6	97.7	99.3
15	0.0	0.0	0.0	0.5	2.0	4.4	8.7	12.0	16.6	21.4	29.7	44.5	56.0	60.8	63.9	69.1	74.5	79.1	83.1	87.0	90.9	96.6	99.1	99.8
16	0.0	0.0	0.0	0.5	2.0	5.5	12.3	16.2	20.9	26.4	35.2	48.1	58.1	63.1	66.5	71.9	77.0	81.6	85.1	88.4	91.5	96.3	98.7	99.6
17	0.0	0.0	0.0	0.7	2.8	6.1	10.7	12.9	16.1	21.9	32.8	45.9	55.5	60.3	64.0	71.2	77.2	80.3	83.1	87.7	92.6	97.2	99.1	99.8
18	0.0	0.0	0.0	0.6	2.5	6.2	12.4	16.4	20.2	23.9	29.3	37.7	45.6	49.8	53.3	58.4	64.3	69.0	75.0	86.6	93.9	96.6	98.0	100.0
19	0.0	1.0	2.6	7.4	16.4	23.5	28.0	31.0	33.5	37.0	41.7	48.1	51.1	52.0	52.5	53.6	55.7	57.6	61.1	65.8	74.7	88.0	95.8	98.7
20	0.0	9.8	18.5	25.4	30.2	35.6	38.9	41.5	42.9	44.0	45.2	48.2	50.8	51.7	52.5	54.6	57.4	58.5	60.1	63.2	69.6	76.7	85.4	92.4
21	0.0	7.5	13.6	18.1	21.1	24.4	27.0	29.4	31.7	34.6	37.3	39.6	41.6	43.4	45.4	48.1	51.3	53.3	56.6	62.4	72.4	81.3	88.9	94.7
22	0.0	1.2	1.6	1.6	1.6	1.6	1.6	2.2	3.9	4.6	6.4	14.2	32.8	47.2	58.8	69.1	76.0	82.0	87.1	96.7	99.9	99.9	99.9	99.9
23	0.0	7.9	15.0	20.9	25.7	31.1	35.7	40.2	43.2	46.2	47.7	48.8	49.4	49.9	50.7	51.8	54.1	57.7	62.8	65.9	70.1	77.3	86.8	93.5
24	0.0	12.2	23.6	33.0	39.7	47.1	51.7	55.9	57.7	58.6	58.9	59.1	59.1	59.2	59.2	59.3	59.5	60.0	61.4	63.0	66.5	71.8	81.3	89.6
25	0.0	9.8	20.8	30.2	37.6	45.8	50.6	54.4	56.0	56.8	57.1	57.1	57.2	57.6	58.5	59.8	62.2	65.3	67.5	68.2	69.4	74.8	86.6	93.0

Table 2-1—Continued

EI number	Periods 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
26	0.0	2.0	5.4	9.8	15.6	21.5	24.7	26.6	27.4	28.0	28.7	29.8	32.5	36.6	44.9	55.4	65.7	72.6	77.8	84.4	89.5	93.9	96.5	98.4
27	0.0	0.0	0.0	1.0	4.0	5.9	8.0	11.1	13.0	14.0	14.6	15.3	17.0	23.2	39.1	60.0	76.3	86.1	89.7	90.4	90.9	93.1	96.6	99.1
28	0.0	0.0	0.0	0.0	0.2	0.5	1.5	3.3	7.2	11.9	17.7	21.4	27.0	37.1	51.4	62.3	70.6	78.8	84.6	90.6	94.4	97.9	99.3	100.0
29	0.0	0.6	0.7	0.7	0.7	1.5	3.9	6.0	10.5	17.9	28.8	36.6	43.8	51.5	59.3	68.0	74.8	80.3	84.3	88.8	92.7	98.0	99.8	99.9
30	0.0	0.0	0.0	0.0	0.0	0.2	0.8	2.8	7.9	14.2	24.7	35.6	45.4	52.2	58.7	68.5	77.6	84.5	88.9	93.7	96.2	97.6	98.3	99.6
31	0.0	0.0	0.0	0.0	0.0	0.2	1.0	3.5	9.9	15.7	26.4	47.2	61.4	65.9	69.0	77.2	86.0	91.6	94.8	98.7	100.0	100.0	100.0	100.0
32	0.0	0.1	0.1	0.1	0.1	0.6	2.2	4.3	9.0	14.2	23.3	34.6	46.3	54.2	61.7	72.9	82.5	89.6	93.7	98.2	99.7	99.9	99.9	99.9
33	0.0	0.0	0.0	0.0	0.0	0.6	2.3	4.2	8.8	16.1	30.0	46.9	57.9	62.8	66.2	72.1	79.1	85.9	91.1	97.0	98.9	98.9	98.9	98.9
34	0.0	0.0	0.0	0.0	0.0	1.8	7.3	10.7	15.5	22.0	29.9	35.9	42.0	48.5	56.9	67.0	76.9	85.8	91.2	95.7	97.8	99.6	100.0	100.0
35	0.0	0.0	0.0	0.0	0.0	2.5	10.2	15.9	22.2	27.9	34.7	43.9	51.9	56.9	61.3	67.3	73.9	80.1	85.1	89.6	93.2	98.2	99.8	99.8
36	0.0	0.0	0.0	0.0	0.0	0.9	3.4	6.7	12.7	18.5	26.6	36.3	46.0	53.5	60.2	68.3	75.8	82.6	88.3	96.3	99.3	99.9	100.0	100.0
37	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	3.9	9.1	19.1	26.7	36.3	47.9	61.4	75.1	84.5	92.3	96.0	99.1	100.0	100.0	100.0	100.0
38	0.0	0.0	0.0	1.1	4.3	7.2	11.0	13.9	17.9	22.3	30.3	43.1	55.1	61.3	65.7	72.1	77.9	82.6	86.3	90.3	93.8	98.4	100.0	100.0
39	0.0	0.0	0.0	0.0	0.0	1.6	6.5	11.0	17.8	24.7	33.1	42.8	50.3	54.9	59.7	68.9	78.1	83.6	87.5	93.0	96.5	99.2	100.0	100.0
40	0.0	0.0	0.0	0.0	0.0	1.5	6.2	10.1	16.3	23.3	32.5	42.2	50.1	55.6	60.5	67.5	74.3	79.4	84.1	91.1	95.8	99.1	100.0	100.0
41	0.0	0.1	0.2	0.2	0.2	0.2	0.2	0.4	1.1	6.8	22.9	40.1	54.9	63.8	70.7	81.5	89.8	96.3	98.7	99.2	99.3	99.4	99.4	99.7
42	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.9	5.2	17.3	33.8	53.2	66.5	75.9	87.6	93.7	97.5	99.0	99.7	100.0	100.0	100.0	100.0
43	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.4	2.7	9.5	21.9	42.7	58.6	71.1	84.6	91.9	97.1	99.0	99.8	100.0	100.0	100.0	100.0
44	0.0	1.7	2.3	2.4	2.4	2.4	2.4	2.7	3.5	7.6	18.5	34.3	52.5	64.0	72.3	83.3	90.0	95.1	97.3	98.5	98.9	98.9	98.9	99.2
45	0.0	0.2	0.2	0.3	0.3	0.4	0.6	0.8	1.4	3.7	10.2	22.6	41.8	54.0	64.5	78.7	88.4	96.0	98.7	99.4	99.7	99.7	99.8	99.9
46	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	2.6	7.5	19.6	32.9	48.9	63.0	73.5	83.3	89.5	95.6	98.3	99.6	100.0	100.0	100.0	100.0
47	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.6	5.8	17.0	33.0	52.5	66.4	75.7	85.5	91.3	96.5	98.8	100.0	100.0	100.0	100.0	100.0
48	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	8.1	15.4	27.8	40.7	52.6	61.1	69.3	82.6	92.0	98.0	100.0	100.0	100.0	100.0
49	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	2.7	8.3	20.0	27.5	35.6	44.6	46.0	70.2	81.3	89.2	93.6	98.5	100.0	100.0	100.0	100.0
50	0.0	0.0	0.0	0.0	0.0	0.1	0.4	2.4	8.2	13.7	23.8	38.8	55.1	66.1	73.6	81.8	87.7	93.8	97.0	99.4	100.0	100.0	100.0	100.0

Table 2-1—Continued

EI number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
	Periods																							
51	0.0	0.0	0.0	0.0	0.0	0.3	1.0	3.1	8.7	18.8	35.8	49.6	60.4	70.2	77.0	84.0	88.8	93.8	96.6	99.1	100.0	100.0	100.0	100.0
52	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	2.5	6.8	17.5	29.8	46.1	60.5	72.7	86.0	92.8	96.8	98.4	99.7	100.0	100.0	100.0	100.0
53	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	3.0	9.5	24.2	35.3	48.0	63.1	76.1	87.7	93.5	97.2	98.6	99.5	99.8	99.9	100.0	100.0
54	0.0	0.0	0.0	0.0	0.0	0.2	0.7	2.4	7.2	14.7	27.2	37.2	47.3	58.8	67.6	74.0	79.2	86.7	92.6	97.9	99.8	99.9	100.0	100.0
55	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	5.4	13.3	25.5	31.6	38.8	52.5	66.8	75.5	81.2	87.9	92.8	98.3	100.0	100.0	100.0	100.0
56	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	5.1	11.4	22.3	29.5	38.5	51.1	65.2	77.8	85.6	91.7	95.0	98.7	100.0	100.0	100.0	100.0
57	0.0	0.0	0.0	0.0	0.0	0.0	0.1	1.0	3.5	9.2	21.5	31.0	43.5	60.4	75.1	86.1	91.6	96.2	98.1	99.4	99.9	99.9	100.0	100.0
58	0.0	0.0	0.0	0.0	0.0	0.2	0.9	2.9	8.0	13.2	21.0	29.1	38.0	45.9	54.5	65.4	74.8	82.1	87.5	95.4	98.8	99.7	100.0	100.0
59	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.2	8.9	15.6	24.2	31.1	38.3	46.0	54.9	64.2	73.2	81.9	88.5	95.7	98.6	99.4	99.7	99.7
60	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	1.5	4.0	9.5	13.3	20.5	33.6	52.8	66.5	76.7	88.1	94.2	98.6	100.0	100.0	100.0	100.0
61	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3	5.0	8.5	15.5	29.8	41.8	46.0	49.2	56.0	65.1	71.6	78.6	91.1	97.3	99.3	100.0	100.0
62	0.0	0.0	0.0	0.1	0.3	0.8	2.1	3.6	6.5	9.7	13.7	16.5	20.8	27.3	40.1	56.9	72.6	83.4	89.4	95.5	98.1	99.6	100.0	100.0
63	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.9	3.7	7.8	13.3	15.8	19.9	29.0	46.8	64.7	78.3	88.8	93.9	98.5	100.0	100.0	100.0	100.0
64	0.0	0.0	0.0	0.7	2.8	7.4	12.4	14.4	15.6	17.3	19.4	21.0	24.4	32.3	48.0	61.4	72.1	81.9	87.0	90.1	92.4	98.1	100.0	100.0
65	0.0	3.6	7.0	9.6	11.4	13.0	14.4	16.3	17.7	18.4	19.3	20.5	23.6	32.0	50.0	66.2	77.2	85.4	88.8	90.4	91.3	92.7	94.8	97.0
66	0.0	0.0	0.0	0.0	0.0	0.1	0.5	1.1	2.2	3.6	6.0	7.6	11.1	19.8	38.9	59.7	74.4	83.2	88.1	94.6	97.7	99.4	100.0	100.0
67	0.0	0.0	0.0	0.0	0.0	0.1	0.4	0.9	1.6	1.9	2.4	5.0	12.1	24.8	48.3	73.6	86.5	92.0	94.3	96.6	97.9	99.5	100.0	100.0
68	0.0	2.3	4.5	7.8	10.4	12.0	13.3	16.3	17.7	18.1	18.2	18.3	18.4	19.9	24.5	35.0	54.4	69.4	78.6	85.7	89.2	91.9	93.9	97.0
69	0.0	2.0	3.7	5.7	7.8	10.5	12.4	13.7	14.3	14.7	15.1	15.7	17.1	22.7	36.7	50.4	63.6	75.0	81.8	87.8	90.8	93.2	94.9	97.5
70	0.0	0.5	0.7	1.0	1.3	1.7	2.2	2.8	3.4	3.9	4.7	5.4	7.4	15.7	36.5	55.8	70.3	80.9	86.4	90.9	93.4	96.4	98.1	99.4
71	0.0	0.7	1.2	1.6	2.1	2.8	3.3	3.6	4.0	4.5	5.6	6.5	9.1	18.5	40.6	59.7	74.0	86.3	91.7	94.7	96.0	96.7	97.3	98.8
72	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.7	0.8	1.3	3.5	9.9	24.7	51.4	71.5	83.6	93.8	97.7	99.2	99.8	99.9	99.9	100.0
73	0.0	0.0	0.1	0.1	0.2	0.2	0.3	0.6	1.3	4.1	11.5	18.1	28.3	40.2	54.1	67.0	77.2	87.7	93.3	97.5	99.1	99.6	99.8	100.0
74	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.5	1.2	2.7	6.4	10.2	18.4	31.0	50.7	68.7	81.2	91.6	96.1	98.4	99.2	99.8	100.0	100.0
75	0.0	0.1	0.1	0.1	0.2	0.5	1.3	1.9	3.0	4.1	6.6	10.0	17.6	28.3	44.7	59.4	71.6	83.9	90.3	94.7	96.7	98.8	99.6	99.9

Table 2-1—Continued

EI number	Periods 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
76	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.6	1.3	2.0	3.5	4.9	8.4	17.4	37.3	57.5	72.9	83.7	89.5	95.8	98.4	99.6	100.0	100.0
77	0.0	0.2	0.3	0.3	0.4	0.8	1.5	2.0	2.8	3.9	5.9	7.2	10.3	21.5	46.5	66.3	78.3	86.5	90.8	96.0	98.2	99.1	99.5	99.8
78	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.5	1.6	3.8	8.9	13.2	21.8	35.8	56.6	75.4	86.0	92.9	95.9	98.2	99.2	99.8	100.0	100.0
79	0.0	0.0	0.0	0.0	0.0	0.2	0.7	1.3	2.7	5.8	12.7	18.8	28.8	41.6	58.4	75.7	86.5	94.2	97.3	98.9	99.5	99.9	100.0	100.0
80	0.0	0.6	1.2	1.6	2.1	2.5	3.3	4.5	6.9	10.1	15.5	19.7	26.6	36.4	51.7	67.5	79.4	88.8	93.2	96.1	97.3	98.2	98.7	99.3
81	0.0	0.1	0.1	0.2	0.4	0.5	0.8	0.9	1.5	3.9	9.9	12.8	18.2	30.7	54.1	77.1	89.0	94.9	97.2	98.7	99.3	99.6	99.7	99.9
82	0.0	0.0	0.1	0.1	0.2	0.2	0.5	1.2	3.1	6.7	14.4	20.1	29.8	44.5	64.2	83.1	92.2	96.4	98.1	99.3	99.7	99.8	99.8	99.9
83	0.0	0.0	0.1	0.1	0.1	0.3	0.9	1.6	3.5	8.3	19.4	30.0	44.0	59.2	72.4	84.6	91.2	96.5	98.6	99.5	99.8	99.9	100.0	100.0
84	0.0	0.0	0.1	0.1	0.2	0.3	0.6	1.7	4.9	9.9	19.5	27.2	38.3	52.8	68.8	83.9	91.6	96.4	98.2	99.2	99.6	99.8	99.8	99.9
85	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	6.0	11.0	23.0	36.0	49.0	63.0	77.0	90.0	95.0	98.0	99.0	100.0	100.0	100.0	100.0
86	0.0	0.0	0.0	0.0	0.0	0.0	1.0	2.0	3.0	6.0	11.0	23.0	36.0	49.0	63.0	77.0	90.0	95.0	98.0	99.0	100.0	100.0	100.0	100.0
87	0.0	0.0	0.0	0.0	1.0	1.0	2.0	3.0	6.0	10.0	17.0	29.0	43.0	55.0	67.0	77.0	85.0	91.0	96.0	98.0	99.0	100.0	100.0	100.0
88	0.0	0.0	0.0	0.0	1.0	1.0	2.0	3.0	6.0	13.0	23.0	37.0	51.0	61.0	69.0	78.0	85.0	91.0	94.0	96.0	98.0	99.0	99.0	100.0
89	0.0	0.0	1.0	1.0	2.0	3.0	4.0	7.0	12.0	18.0	27.0	38.0	48.0	55.0	62.0	69.0	76.0	83.0	90.0	94.0	97.0	98.0	99.0	100.0
90	0.0	1.0	2.0	3.0	4.0	6.0	8.0	13.0	21.0	29.0	37.0	46.0	54.0	60.0	65.0	69.0	74.0	81.0	87.0	92.0	95.0	97.0	98.0	99.0
91	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	6.0	16.0	29.0	39.0	46.0	53.0	60.0	67.0	74.0	81.0	88.0	95.0	99.0	99.0	100.0	100.0
92	0.0	0.0	0.0	0.0	1.0	1.0	1.0	2.0	6.0	16.0	29.0	39.0	46.0	53.0	60.0	67.0	74.0	81.0	88.0	95.0	99.0	99.0	100.0	100.0
93	0.0	1.0	1.0	2.0	3.0	4.0	6.0	8.0	13.0	25.0	40.0	49.0	56.0	62.0	67.0	72.0	76.0	80.0	85.0	91.0	97.0	98.0	99.0	99.0
94	0.0	1.0	2.0	4.0	6.0	8.0	10.0	15.0	21.0	29.0	38.0	47.0	53.0	57.0	61.0	65.0	70.0	76.0	83.0	88.0	91.0	94.0	96.0	98.0
95	0.0	1.0	3.0	5.0	7.0	9.0	11.0	14.0	18.0	27.0	35.0	41.0	46.0	51.0	57.0	62.0	68.0	73.0	79.0	84.0	89.0	93.0	96.0	98.0
96	0.0	2.0	4.0	6.0	9.0	12.0	17.0	23.0	30.0	37.0	43.0	49.0	54.0	58.0	62.0	66.0	70.0	74.0	78.0	82.0	86.0	90.0	94.0	97.0
97	0.0	1.0	3.0	5.0	7.0	10.0	14.0	20.0	28.0	37.0	48.0	56.0	61.0	64.0	68.0	72.0	77.0	81.0	86.0	89.0	92.0	95.0	98.0	99.0
98	0.0	1.0	2.0	4.0	6.0	8.0	10.0	13.0	19.0	26.0	34.0	42.0	50.0	58.0	63.0	68.0	74.0	79.0	84.0	89.0	93.0	95.0	97.0	99.0
99	0.0	0.0	0.0	1.0	1.0	2.0	3.0	5.0	7.0	12.0	19.0	33.0	48.0	57.0	65.0	72.0	82.0	88.0	93.0	96.0	98.0	99.0	100.0	100.0
100	0.0	0.0	0.0	0.0	1.0	1.0	2.0	3.0	5.0	9.0	15.0	27.0	38.0	50.0	62.0	74.0	84.0	91.0	95.0	97.0	98.0	99.0	99.0	100.0

Table 2-1—Continued

EI number	Periods 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
101	0.0	0.0	0.0	1.0	2.0	3.0	4.0	6.0	9.0	14.0	20.0	28.0	39.0	52.0	63.0	72.0	80.0	87.0	91.0	94.0	97.0	98.0	99.0	100.0
102	0.0	0.0	1.0	2.0	3.0	4.0	6.0	8.0	11.0	15.0	22.0	31.0	40.0	49.0	59.0	69.0	78.0	85.0	91.0	94.0	96.0	98.0	99.0	100.0
103	0.0	1.0	2.0	3.0	4.0	6.0	8.0	10.0	14.0	18.0	25.0	34.0	45.0	56.0	64.0	72.0	79.0	84.0	89.0	92.0	95.0	97.0	98.0	99.0
104	0.0	2.0	3.0	5.0	7.0	10.0	13.0	16.0	19.0	23.0	27.0	34.0	44.0	54.0	63.0	72.0	80.0	85.0	89.0	91.0	93.0	95.0	96.0	98.0
105	0.0	1.0	3.0	6.0	9.0	12.0	16.0	21.0	26.0	31.0	37.0	43.0	50.0	57.0	64.0	71.0	77.0	81.0	85.0	88.0	91.0	93.0	95.0	97.0
106	0.0	3.0	6.0	9.0	13.0	17.0	21.0	27.0	33.0	38.0	44.0	49.0	55.0	61.0	67.0	71.0	75.0	78.0	81.0	84.0	86.0	90.0	94.0	97.0
107	0.0	3.0	5.0	7.0	10.0	14.0	18.0	23.0	27.0	31.0	35.0	39.0	45.0	53.0	60.0	67.0	74.0	80.0	84.0	86.0	88.0	90.0	93.0	95.0
108	0.0	3.0	6.0	9.0	12.0	16.0	20.0	24.0	28.0	33.0	38.0	43.0	50.0	59.0	69.0	75.0	80.0	84.0	87.0	90.0	92.0	94.0	96.0	98.0
109	0.0	3.0	6.0	10.0	13.0	16.0	19.0	23.0	26.0	29.0	33.0	39.0	47.0	58.0	68.0	75.0	80.0	83.0	86.0	88.0	90.0	92.0	95.0	97.0
110	0.0	1.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	21.0	25.0	29.0	36.0	45.0	56.0	68.0	77.0	83.0	88.0	91.0	93.0	95.0	97.0	99.0
111	0.0	1.0	2.0	3.0	4.0	5.0	6.0	8.0	11.0	15.0	20.0	28.0	41.0	54.0	65.0	74.0	82.0	87.0	92.0	94.0	96.0	97.0	98.0	99.0
112	0.0	0.0	0.0	1.0	2.0	3.0	4.0	5.0	7.0	12.0	17.0	24.0	33.0	42.0	55.0	67.0	76.0	83.0	89.0	92.0	94.0	96.0	98.0	99.0
113	0.0	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	13.0	17.0	22.0	31.0	42.0	52.0	60.0	68.0	75.0	80.0	85.0	89.0	92.0	96.0	98.0
114	0.0	1.0	2.0	4.0	6.0	8.0	11.0	13.0	15.0	18.0	21.0	26.0	32.0	38.0	46.0	55.0	64.0	71.0	77.0	81.0	85.0	89.0	93.0	97.0
115	0.0	1.0	2.0	3.0	4.0	5.0	6.0	8.0	10.0	14.0	19.0	26.0	34.0	45.0	56.0	66.0	76.0	82.0	86.0	90.0	93.0	95.0	97.0	99.0
116	0.0	1.0	3.0	5.0	7.0	9.0	12.0	15.0	18.0	21.0	25.0	29.0	36.0	45.0	56.0	68.0	77.0	83.0	88.0	91.0	93.0	95.0	97.0	99.0
117	0.0	1.0	2.0	3.0	4.0	5.0	7.0	9.0	11.0	14.0	17.0	22.0	31.0	42.0	54.0	65.0	74.0	83.0	89.0	92.0	95.0	97.0	98.0	99.0
118	0.0	1.0	2.0	3.0	5.0	7.0	10.0	14.0	18.0	22.0	27.0	32.0	37.0	46.0	58.0	69.0	80.0	89.0	93.0	94.0	95.0	96.0	97.0	97.0
119	0.0	2.0	4.0	6.0	8.0	12.0	16.0	20.0	25.0	30.0	35.0	41.0	47.0	56.0	67.0	75.0	81.0	85.0	87.0	89.0	91.0	93.0	95.0	97.0
120	0.0	1.0	2.0	4.0	6.0	7.0	9.0	12.0	15.0	18.0	23.0	31.0	40.0	48.0	57.0	63.0	72.0	78.0	88.0	92.0	96.0	97.0	98.0	99.0
[2]121	0.0	8.0	16.0	25.0	33.0	41.0	46.0	50.0	53.0	54.0	55.0	56.0	56.5	57.0	57.8	58.0	58.8	60.0	61.0	63.0	66.5	72.0	80.0	90.0
122	0.0	7.0	14.0	20.0	25.5	33.5	38.0	43.0	46.0	50.0	52.5	54.5	56.0	58.0	59.0	60.0	61.5	63.0	65.0	68.0	72.0	79.0	86.0	93.0
123	0.0	4.0	8.0	12.0	17.0	23.0	29.0	34.0	38.0	44.0	49.0	53.0	56.0	59.0	62.0	65.0	69.0	72.0	75.0	79.0	83.0	88.0	93.0	96.0
124	0.0	4.0	9.0	15.0	23.0	29.0	34.0	40.0	44.0	48.0	50.0	51.0	52.0	53.0	55.0	57.0	60.0	62.0	64.0	67.0	72.0	80.0	88.0	95.0
125	0.0	7.0	12.0	17.0	24.0	30.0	39.0	45.0	50.0	53.0	55.0	56.0	57.0	58.0	59.0	61.0	62.0	63.0	64.0	66.0	70.0	77.0	84.0	92.0

Table 2-1—Continued

EI number	Periods 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
126	0.0	9.0	16.0	23.0	30.0	37.0	43.0	47.0	50.0	52.0	54.0	55.0	56.0	57.0	58.0	59.0	60.0	62.0	64.0	67.0	71.0	77.0	86.0	93.0
127	0.0	8.0	15.0	22.0	28.0	33.0	38.0	42.0	46.0	50.0	52.0	53.0	53.0	53.0	53.0	54.0	55.0	57.0	59.0	63.0	68.0	75.0	83.0	92.0
128	0.0	8.0	15.0	22.0	29.0	34.0	40.0	45.0	48.0	51.0	54.0	57.0	59.0	62.0	63.0	64.0	65.0	66.0	67.0	69.0	72.0	76.0	83.0	91.0
129	0.0	9.0	16.0	22.0	27.0	32.0	37.0	41.0	45.0	48.0	51.0	53.0	55.0	56.0	57.0	57.0	58.0	59.0	61.0	64.0	68.0	73.0	79.0	89.0
130	0.0	10.0	20.0	28.0	35.0	41.0	46.0	49.0	51.0	53.0	55.0	56.0	56.0	57.0	58.0	59.0	60.0	61.0	62.0	65.0	69.0	74.0	81.0	90.0
131	0.0	8.0	15.0	22.0	28.0	33.0	38.0	41.0	44.0	47.0	49.0	51.0	53.0	55.0	56.0	58.0	59.0	60.0	63.0	65.0	69.0	75.0	84.0	92.0
132	0.0	10.0	18.0	25.0	29.0	33.0	36.0	39.0	41.0	42.0	44.0	45.0	46.0	47.0	48.0	49.0	51.0	53.0	56.0	59.0	64.0	70.0	80.0	90.0
133	0.0	8.0	16.0	24.0	32.0	40.0	46.0	51.0	54.0	56.0	57.0	58.0	58.0	59.0	59.0	60.0	60.0	61.0	62.0	64.0	68.0	74.0	83.0	91.0
134	0.0	12.0	22.0	31.0	39.0	45.0	49.0	52.0	54.0	55.0	56.0	56.0	56.0	56.0	57.0	57.0	57.0	57.0	58.0	59.0	62.0	68.0	77.0	88.0
135	0.0	7.0	15.0	22.0	30.0	37.0	43.0	49.0	53.0	55.0	57.0	58.0	59.0	60.0	61.0	62.0	63.0	65.0	67.0	70.0	74.0	79.0	85.0	92.0
136	0.0	11.0	21.0	29.0	37.0	44.0	50.0	55.0	57.0	59.0	60.0	60.0	60.0	60.0	61.0	61.0	61.0	62.0	63.0	64.0	67.0	71.0	78.0	89.0
137	0.0	10.0	18.0	25.0	30.0	39.0	46.0	51.0	54.0	57.0	58.0	59.0	59.0	60.0	60.0	60.0	61.0	62.0	63.0	64.0	67.0	72.0	80.0	90.0
138	0.0	11.0	22.0	31.0	39.0	46.0	52.0	56.0	58.0	59.0	60.0	61.0	61.0	61.0	61.0	62.0	62.0	62.0	63.0	64.0	66.0	71.0	78.0	89.0
139	0.0	8.0	14.0	20.0	25.0	32.0	37.0	42.0	47.0	50.0	53.0	55.0	56.0	58.0	59.0	61.0	63.0	64.0	66.0	68.0	71.0	76.0	85.0	93.0
[3]140	0.0	13.0	28.0	43.0	56.0	65.0	69.0	69.4	69.7	70.1	70.4	70.8	71.1	71.5	71.9	72.2	72.6	73.0	73.3	73.6	74.0	76.0	81.0	89.0

[1] Periods are 15-d beginning January 1.
[2] Zones 121-139 are for stations in Hawaii.
[3] Zone 140 is the R_{eq} distribution for Pullman, WA.

Table 2-2.
Average annual and summer EI and 2-yr-frequency 6-h-duration precipitation computed from actual data in southwestern Idaho. Data for EI are compared with data in methods of Wischmeier (1974), Simanton and Renard (1982), Cooley (1980), and Cooley et al. (1988).

					R (hundreds ft · tonf · $acre^{-1}$ · yr^{-1})							
	Precipitation 2-yr 6-h storm[2] (inches)		Observed EI		Wischmeier (1974)[3] $27.38P^{2.17}$		Simanton and Renard (1982) $27.38P^{1.62}$		Cooley (1980)[4] $13.00P^{2.15}$		Cooley et al. (1988) $22.17P^{2.56}$	
Site[1]	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual	Summer	Annual
057	0.71	0.75	10.5	10.9	12.6	14.3	15.6	17.0	6.2	6.9	9.2	10.6
127	.75	.83	9.5	11.3	14.3	17.7	17	20	6.9	8.6	10.6	13.8
116	.79	.91	10	14.6	16	21.7	18.5	23.2	7.8	10.5	12.1	17.4
155	.83	1.06	16	31	17.7	30.9	20	30.1	8.6	14.8	13.8	36.9
176	.83	1.22	14.2	45.3	17.7	41.8	20	37.7	8.6	19.9	13.8	36.9
163	.91	1.38	17.3	59.3	21.7	54.6	23.2	45.8	10.5	25.9	17.4	50.6

[1] Site elevation: 057 is 3,885; 127 is 5,410; 116 is 4,770; 155 is 5,410; 176 is 6,802, and 163 is 7,100 ft above m.s.l.
[2] Determined from actual gage data. NOAA Atlas 2 (Miller et al. 1973) would not permit defining the orographic results shown.
[3] Wischmeier (1974) and Ateshian (1974) agree within about 2%.
[4] Includes precipitation during winter periods in the form of snow, a questionable computation according to Cooley et al. (1988).

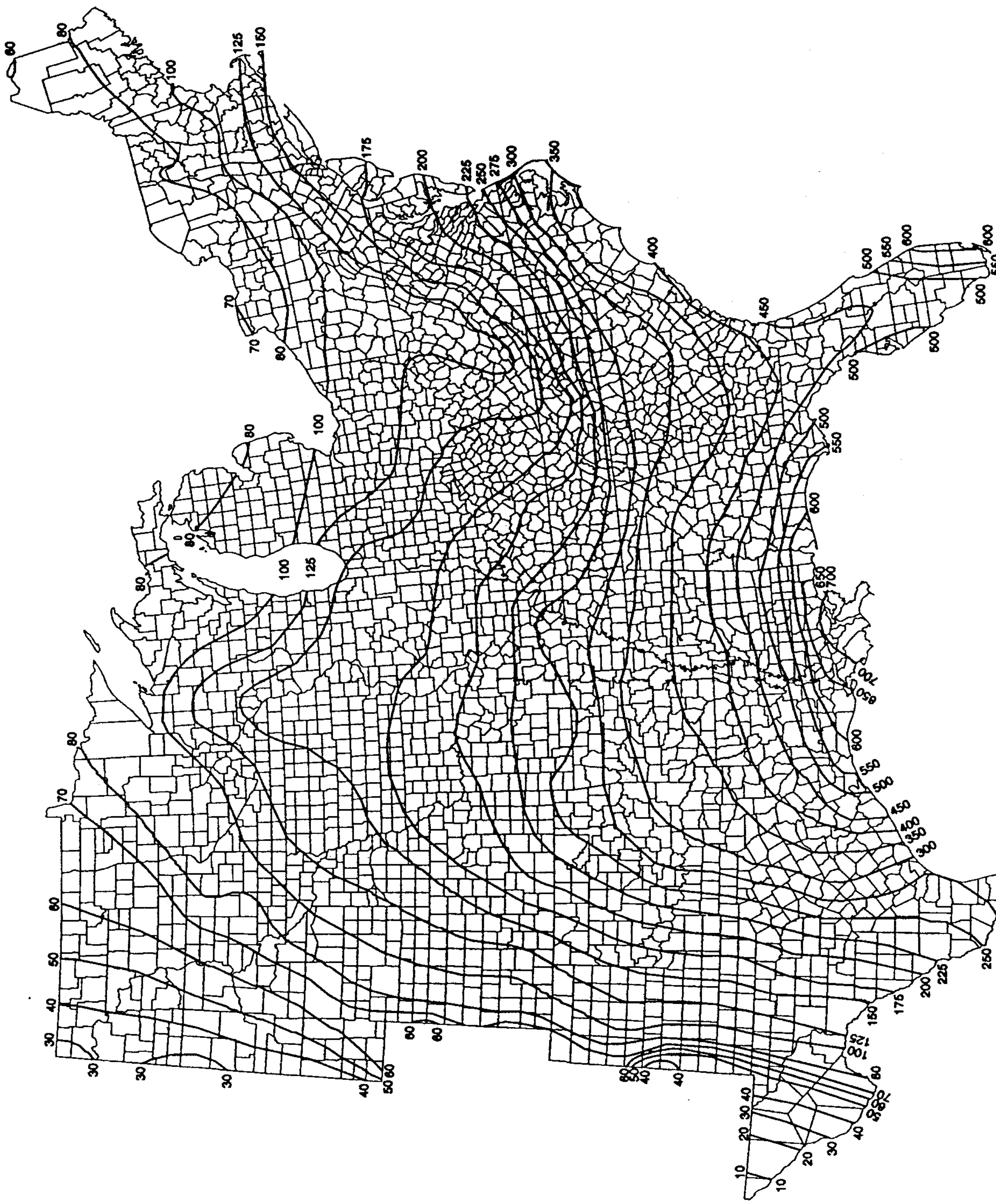

Figure 2-1. Isoerodent map of eastern United States. Units are hundreds ft·tonf·in(ac·h·yr)$^{-1}$.

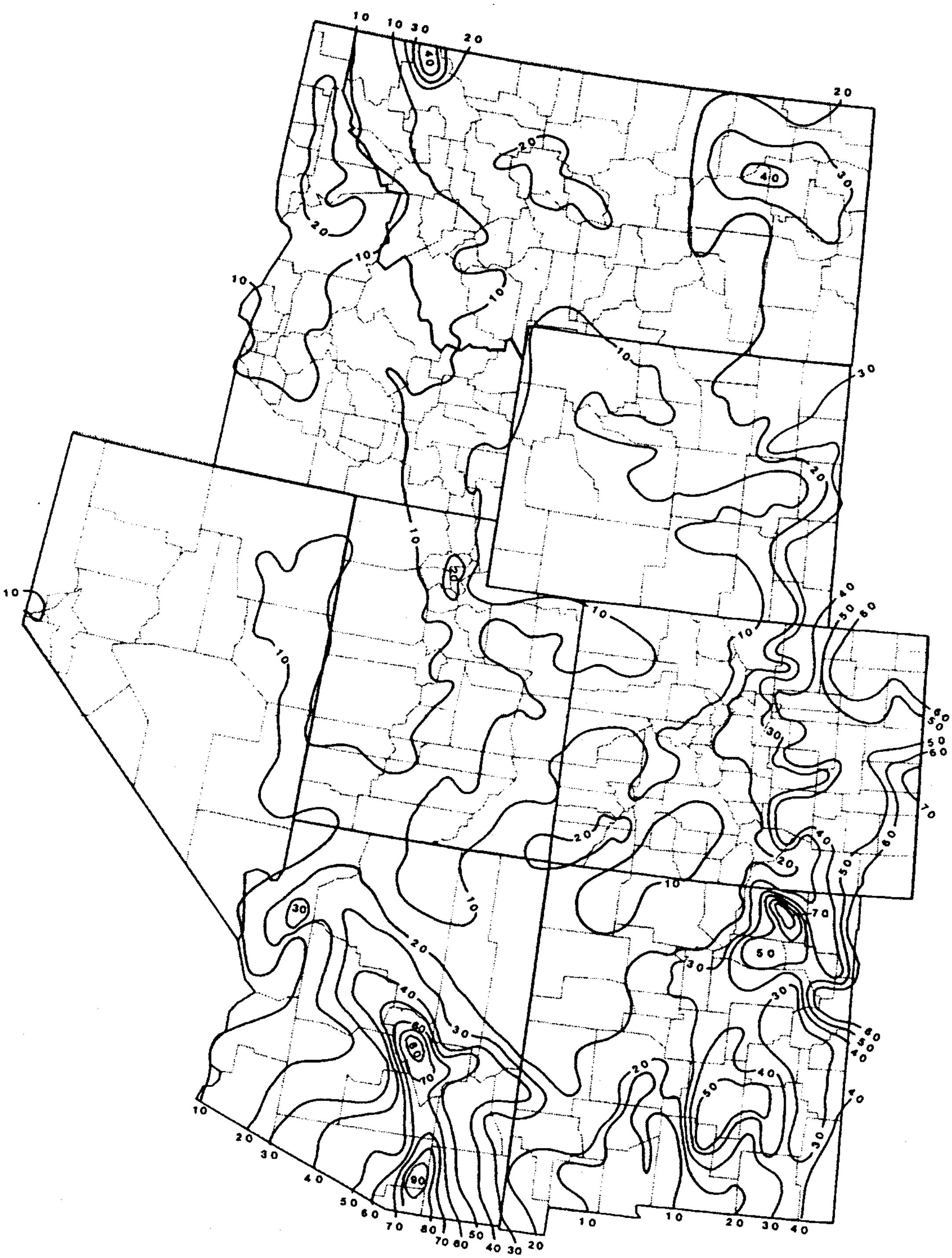

Figure 2-2. Isoerodent map of western United States. Units are hundreds ft·tonf·in(ac·h·yr)$^{-1}$.

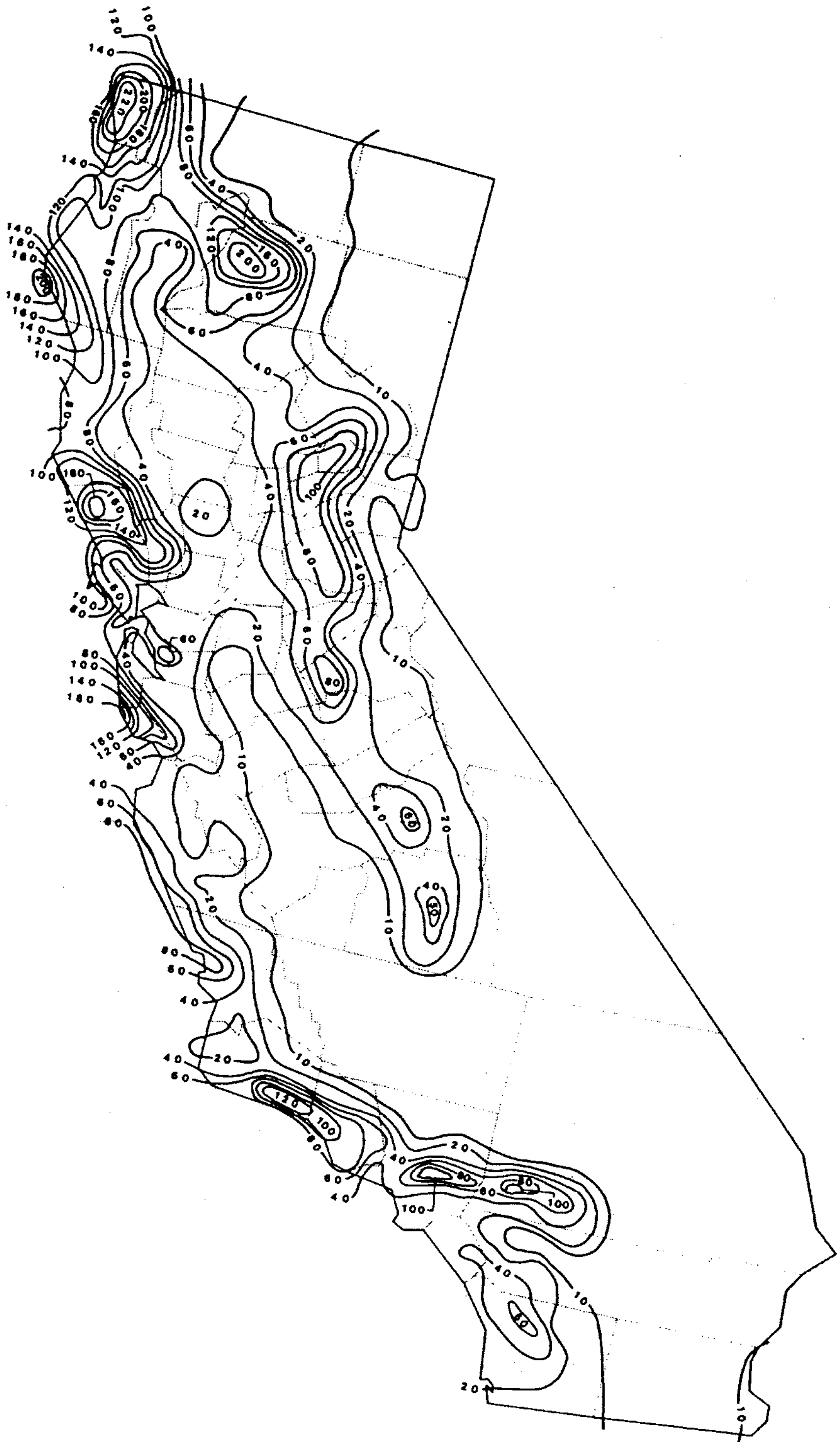

Figure 2-3. Isoerodent map of California. Units are hundreds ft·tonf·in(ac·h·yr)$^{-1}$.

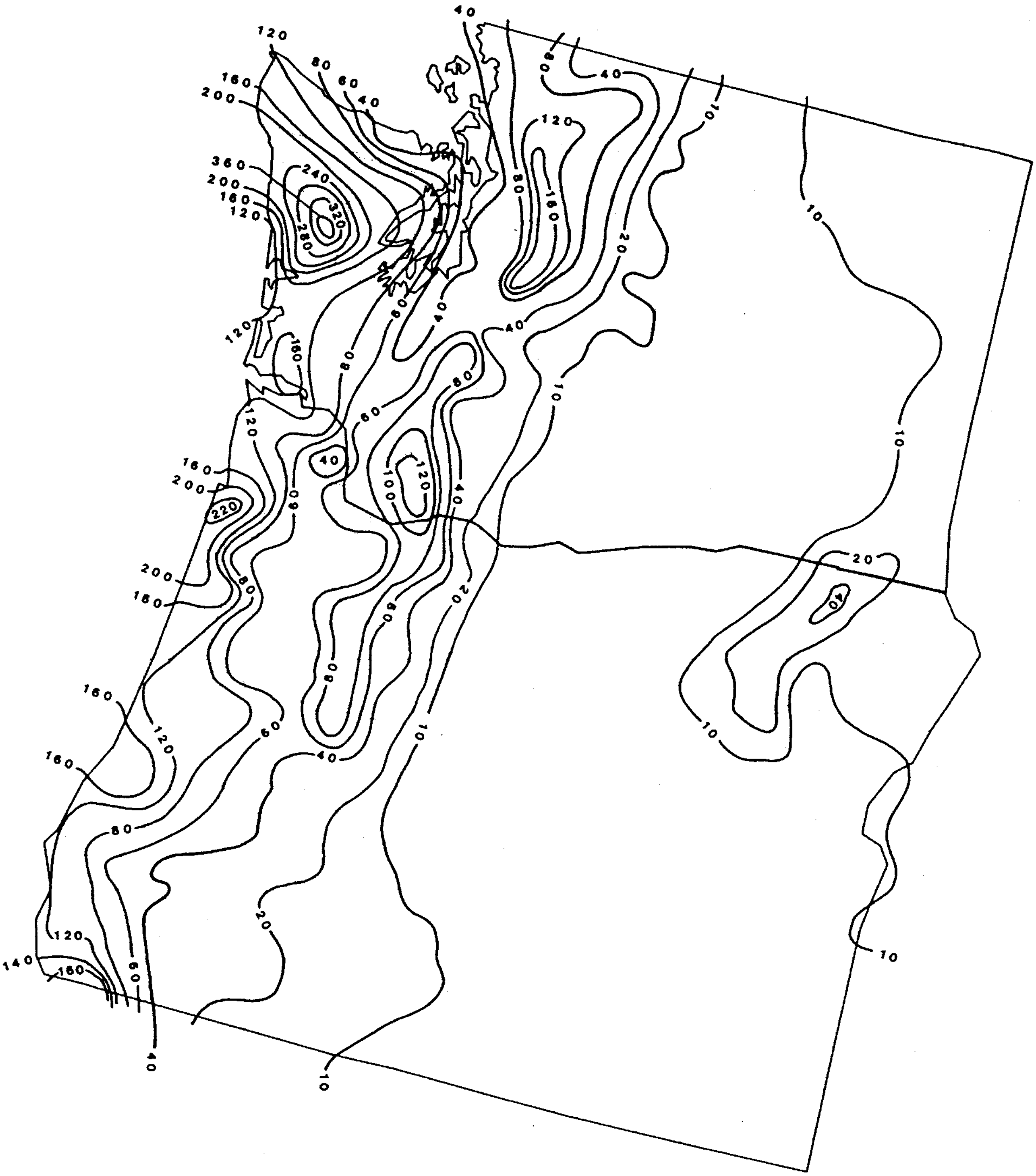

Figure 2-4. Isoerodent map of Oregon and Washington. Units are hundreds $ft\cdot tonf\cdot in(ac\cdot h\cdot yr)^{-1}$.

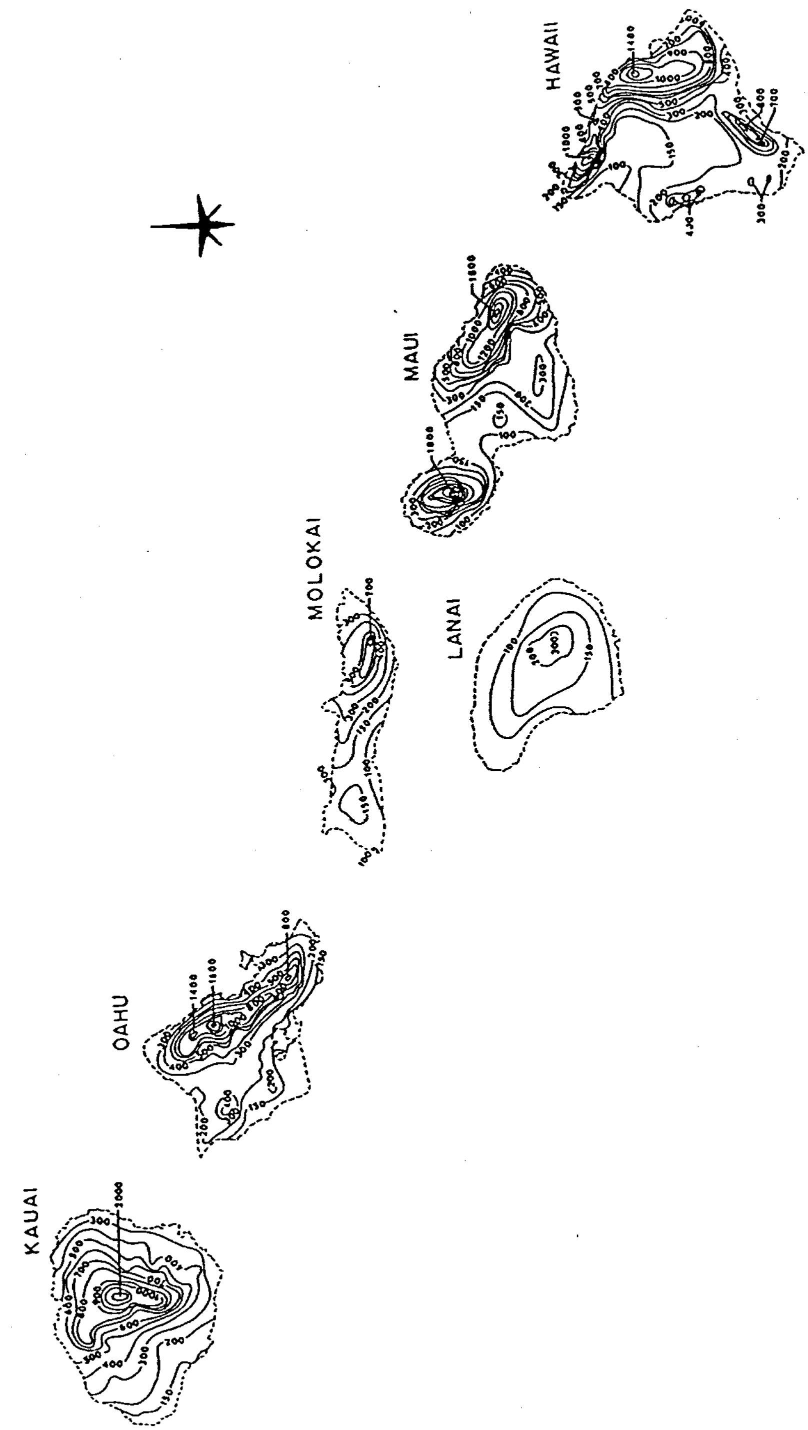

Figure 2-5. Isoerodent map of Hawaii. Units are hundreds ft·tonf·in(ac·h·yr)$^{-1}$.

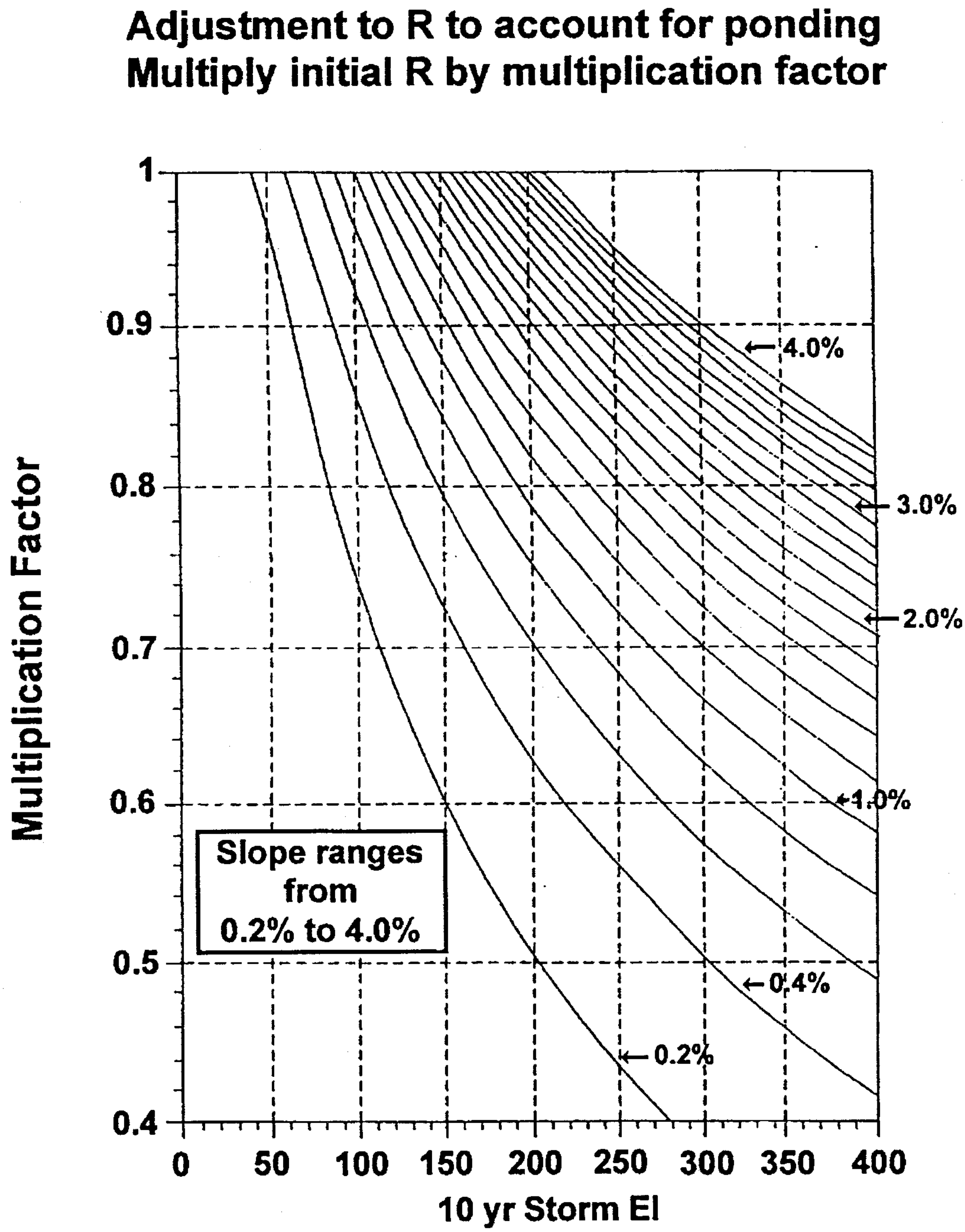

Figure 2-6. Corrections for R factor for flat slopes and large R values to reflect amount of rainfall on ponded water

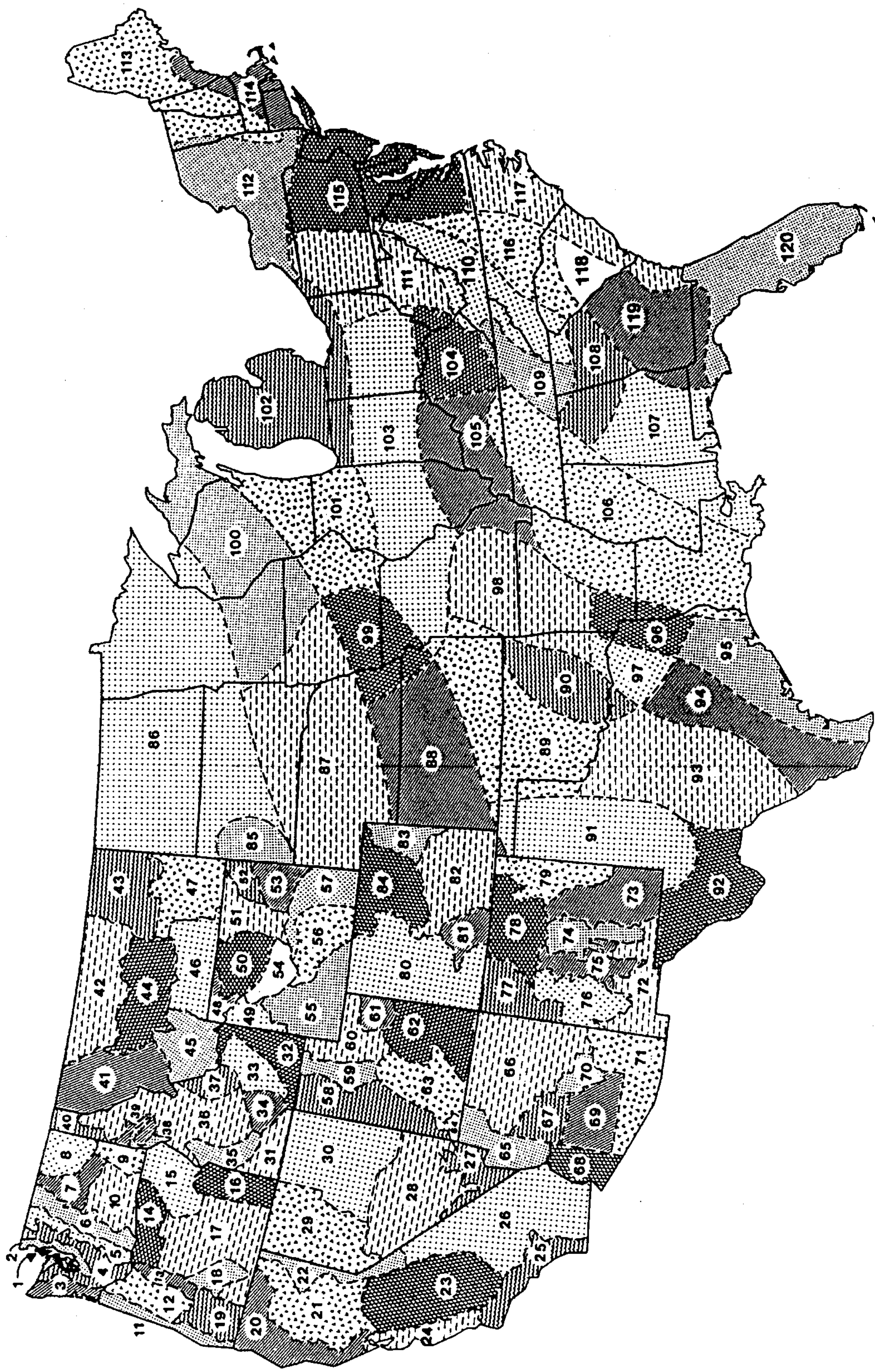

Figure 2-7. EI distribution zones for contiguous United States

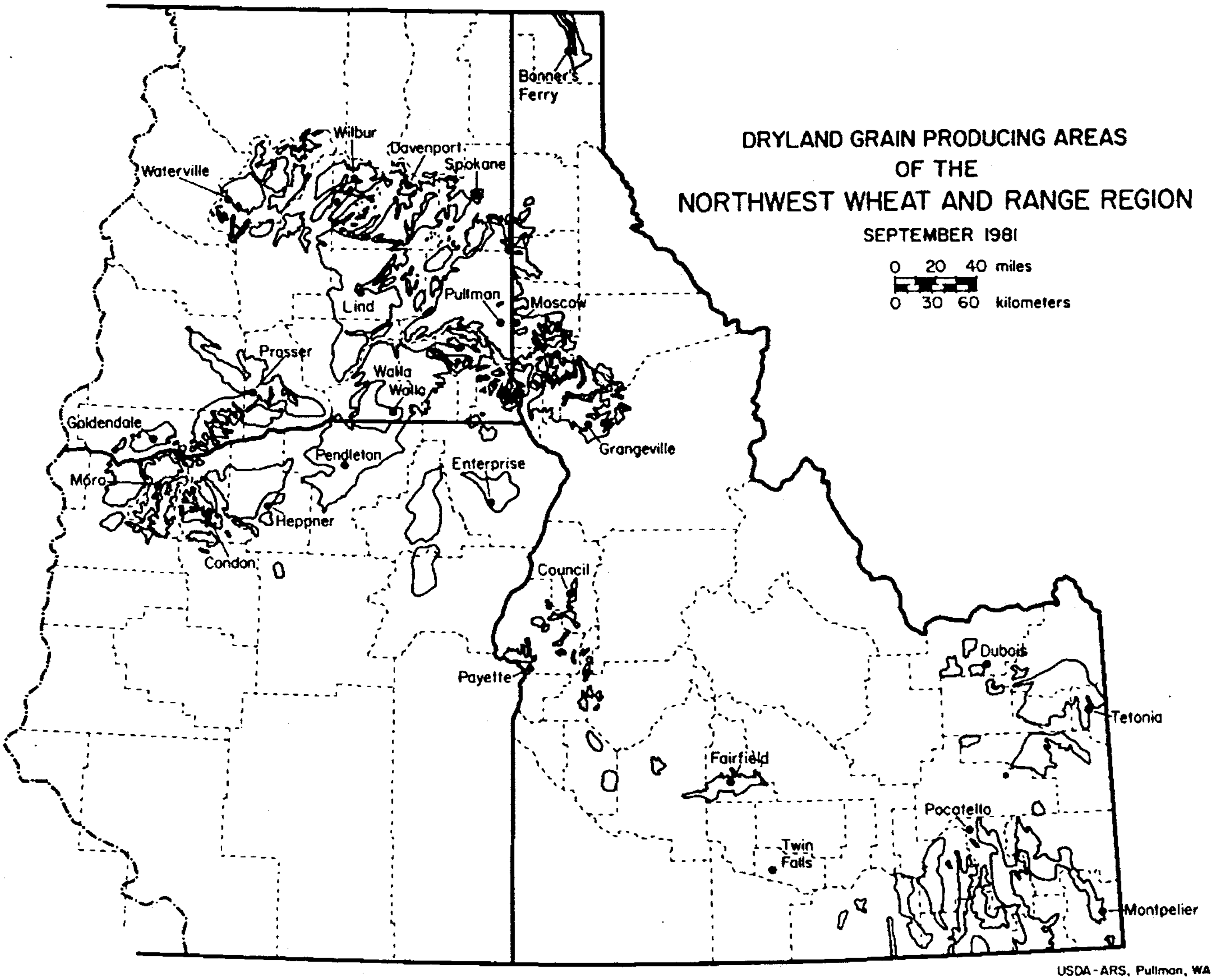

Figure 2-8. Location map of the cropland area of Northwestern Wheat and Range Region (adapted from Austin 1981)

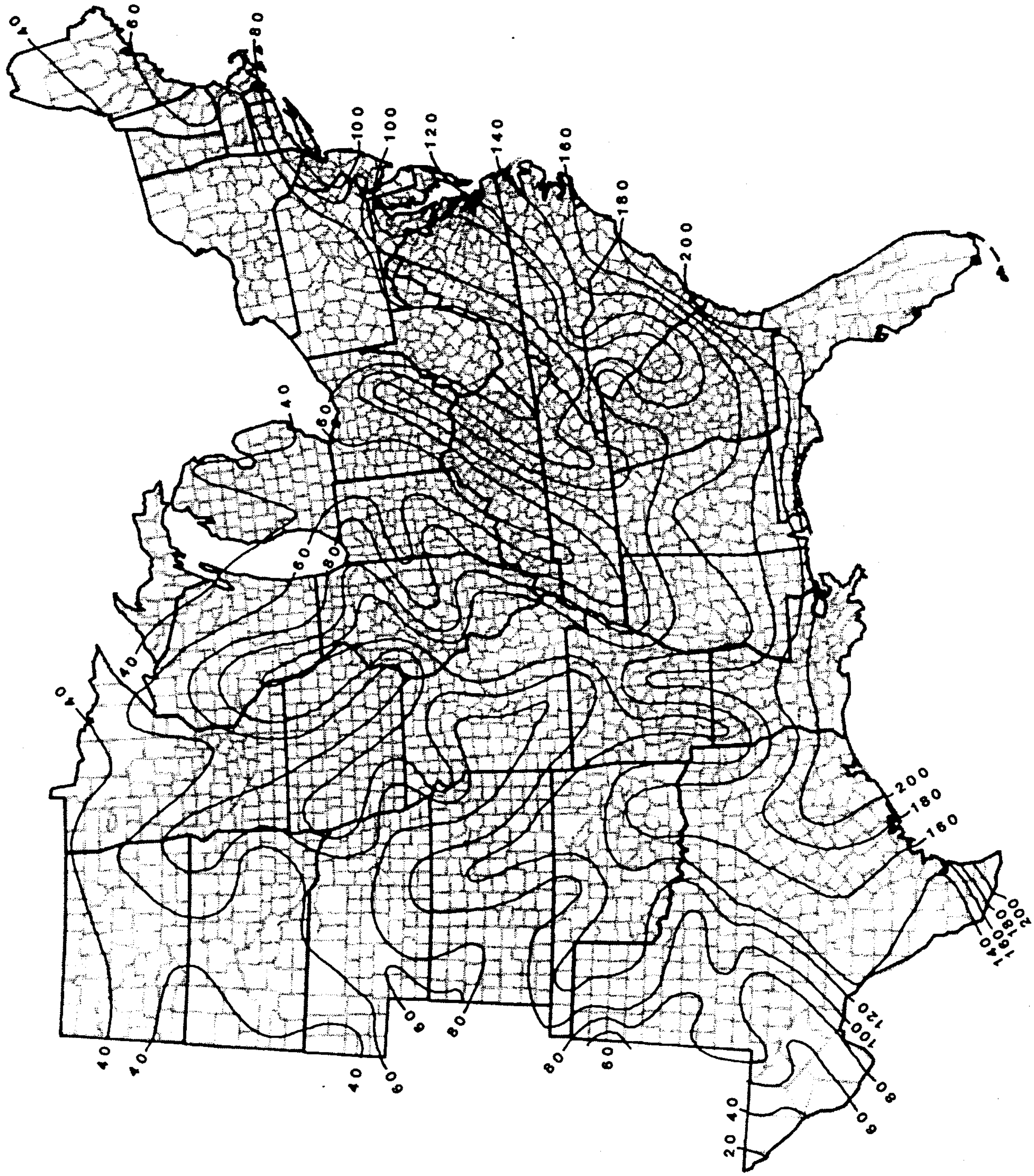

Figure 2-9. Ten-yr-frequency single-storm erosion index for eastern United States. Units are hundreds ft·tonf·in(ac·h)$^{-1}$.

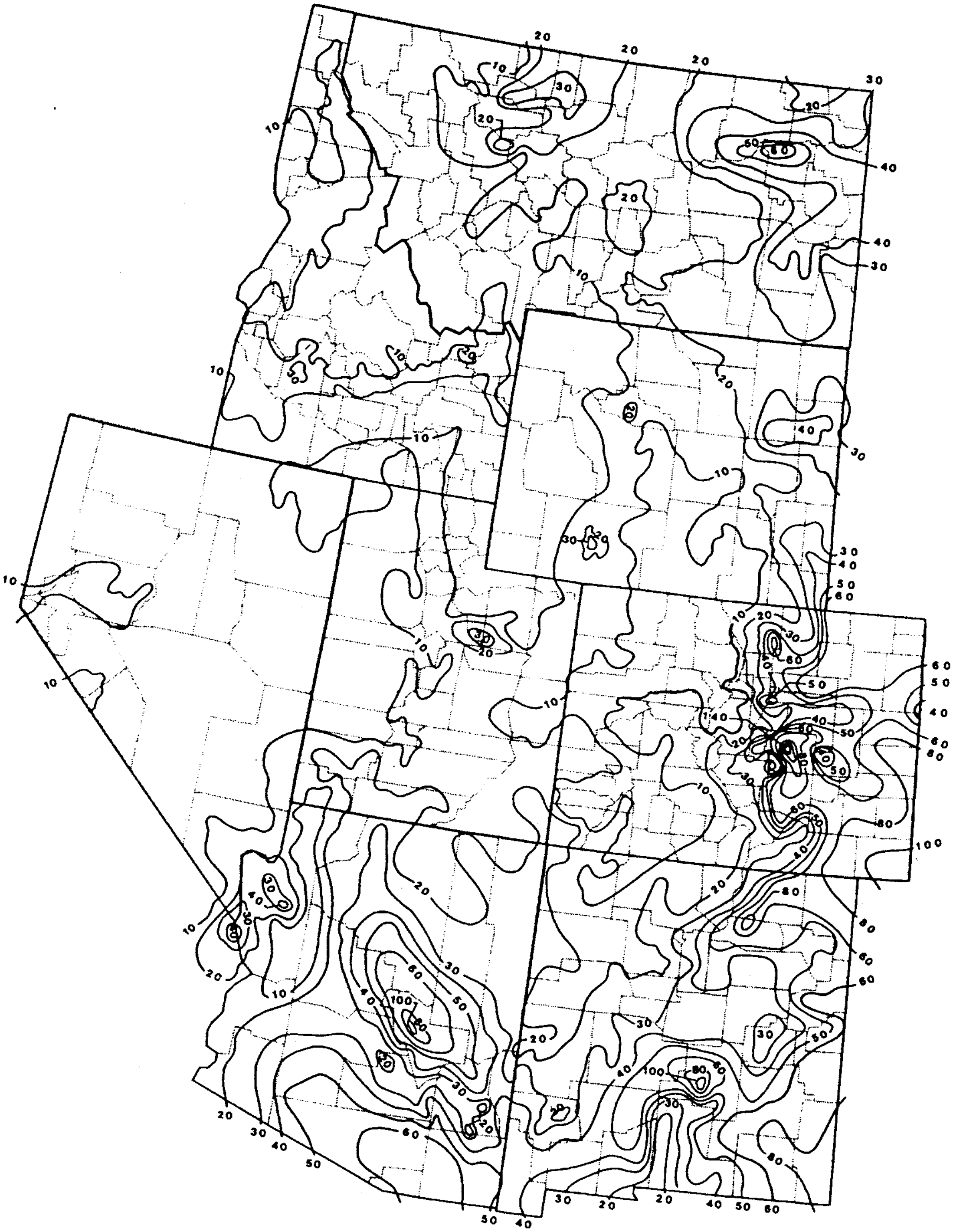

Figure 2-10. Ten-yr-frequency single-storm erosion index for western United States. Units are hundreds ft·tonf·in(ac·h)$^{-1}$.

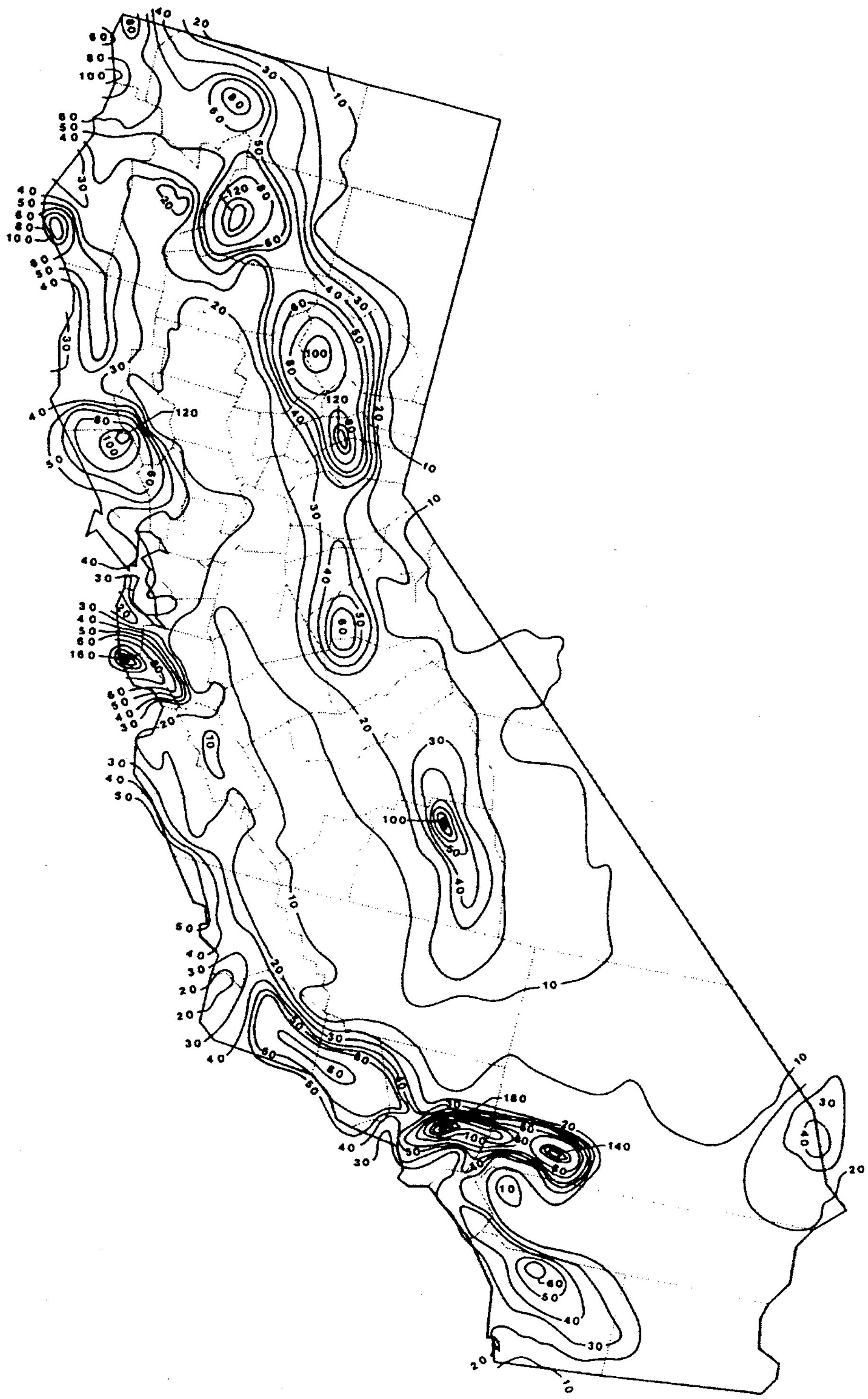

Figure 2-11. Ten-yr-frequency single-storm erosion index for California. Units are hundreds ft·tonf·in$(ac \cdot h)^{-1}$.

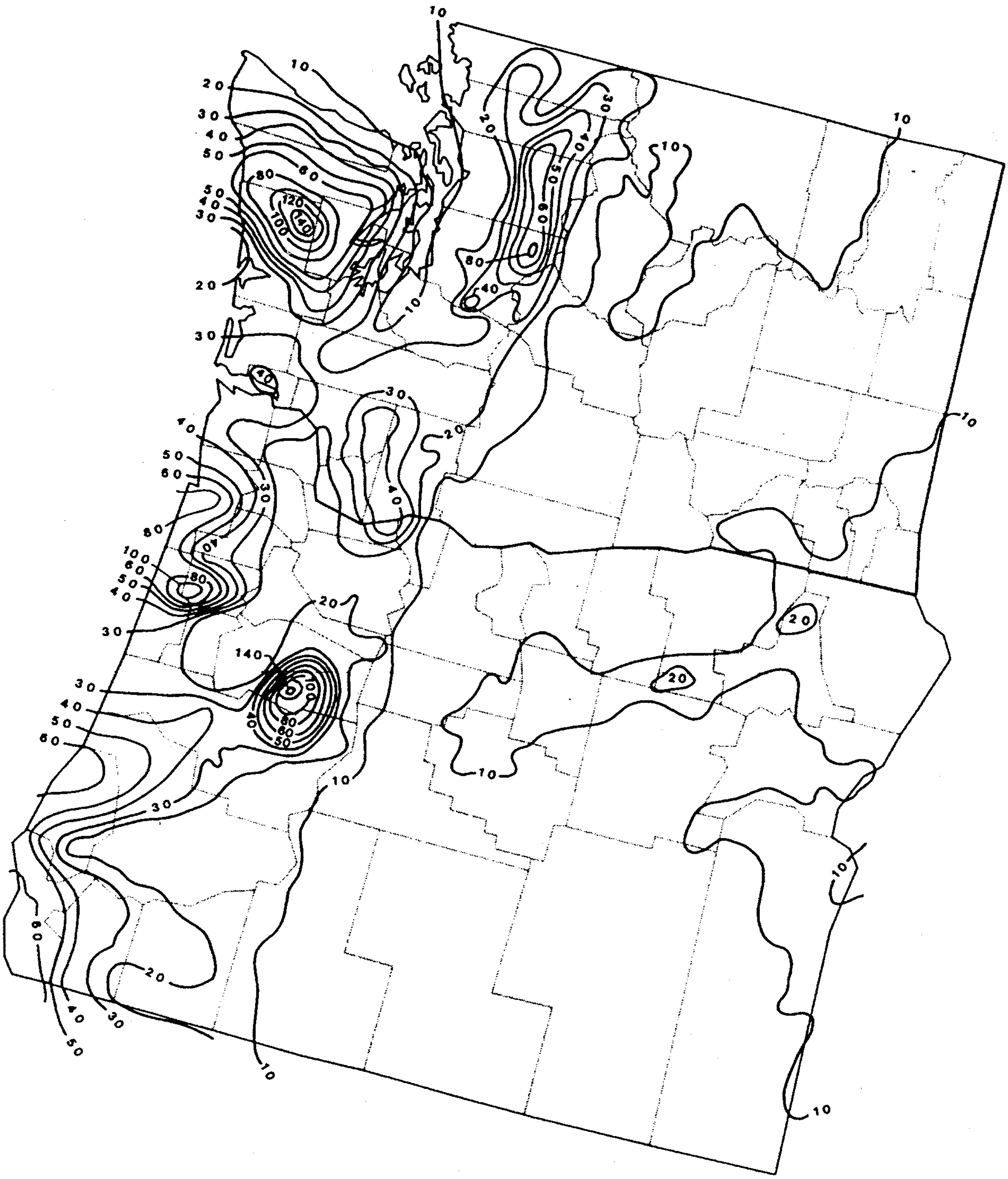

Figure 2-12. Ten-yr-frequency single-storm erosion index for Oregon and Washington. Units are hundreds ft·tonf·in(ac·h)$^{-1}$.

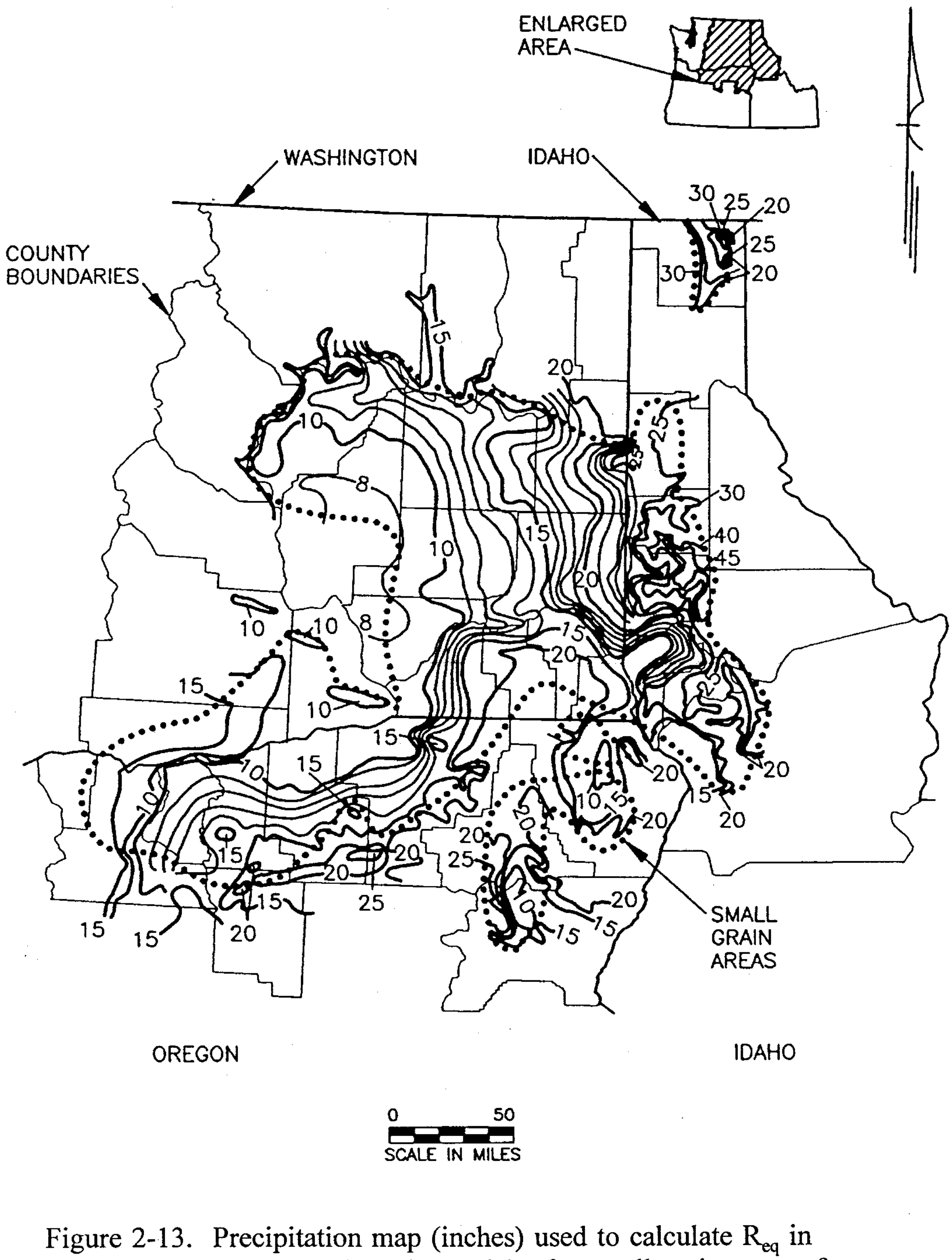

Figure 2-13. Precipitation map (inches) used to calculate R_{eq} in Washington, Oregon, and northern Idaho for small-grain areas of Northwestern Wheat and Range Region. Precipitation units are inches.

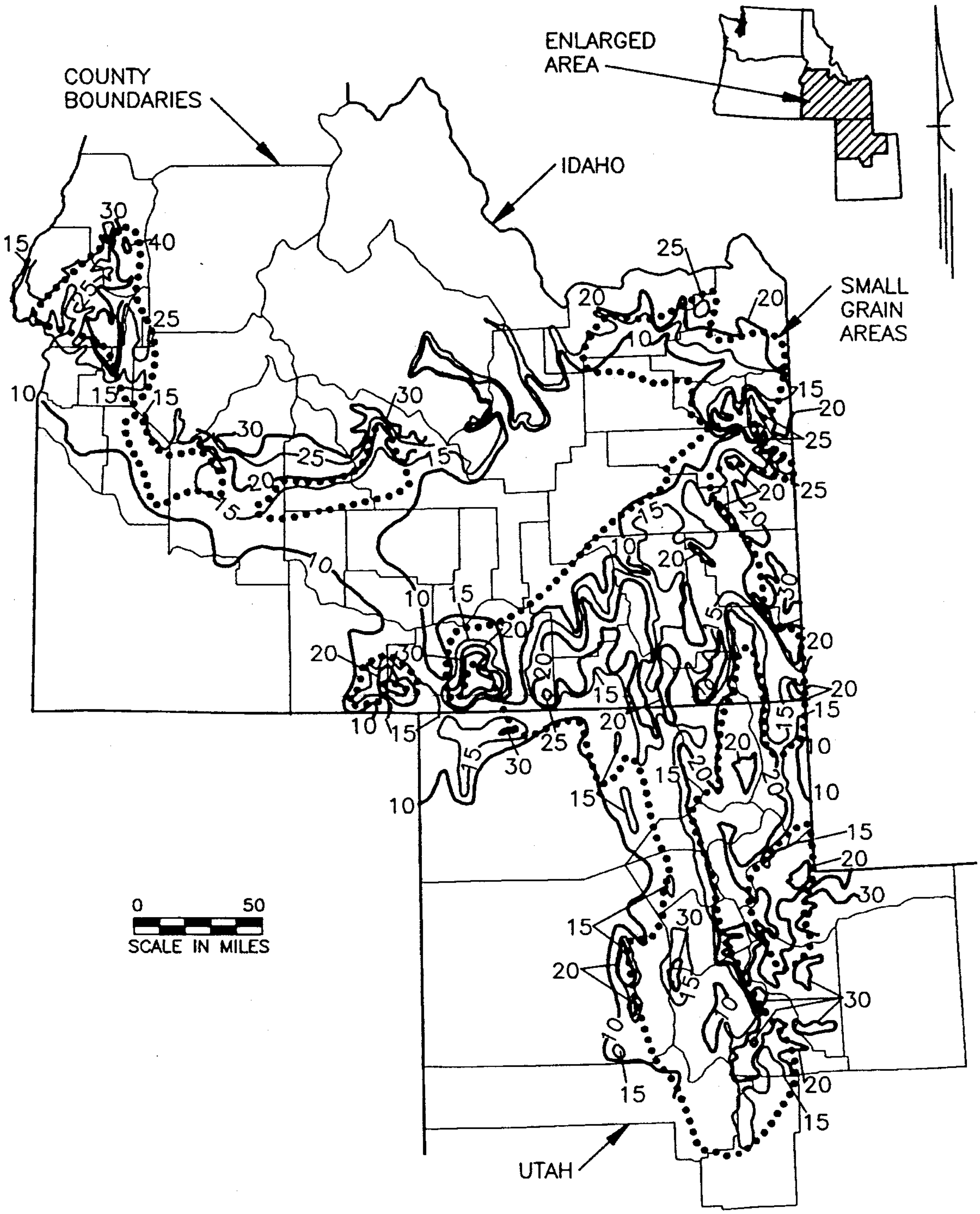

Figure 2-14. Precipitation map (inches) used to calculate R_{eq} in southern Idaho and Utah for small-grain areas of Northwestern Wheat and Range Region. Precipitation units are inches.

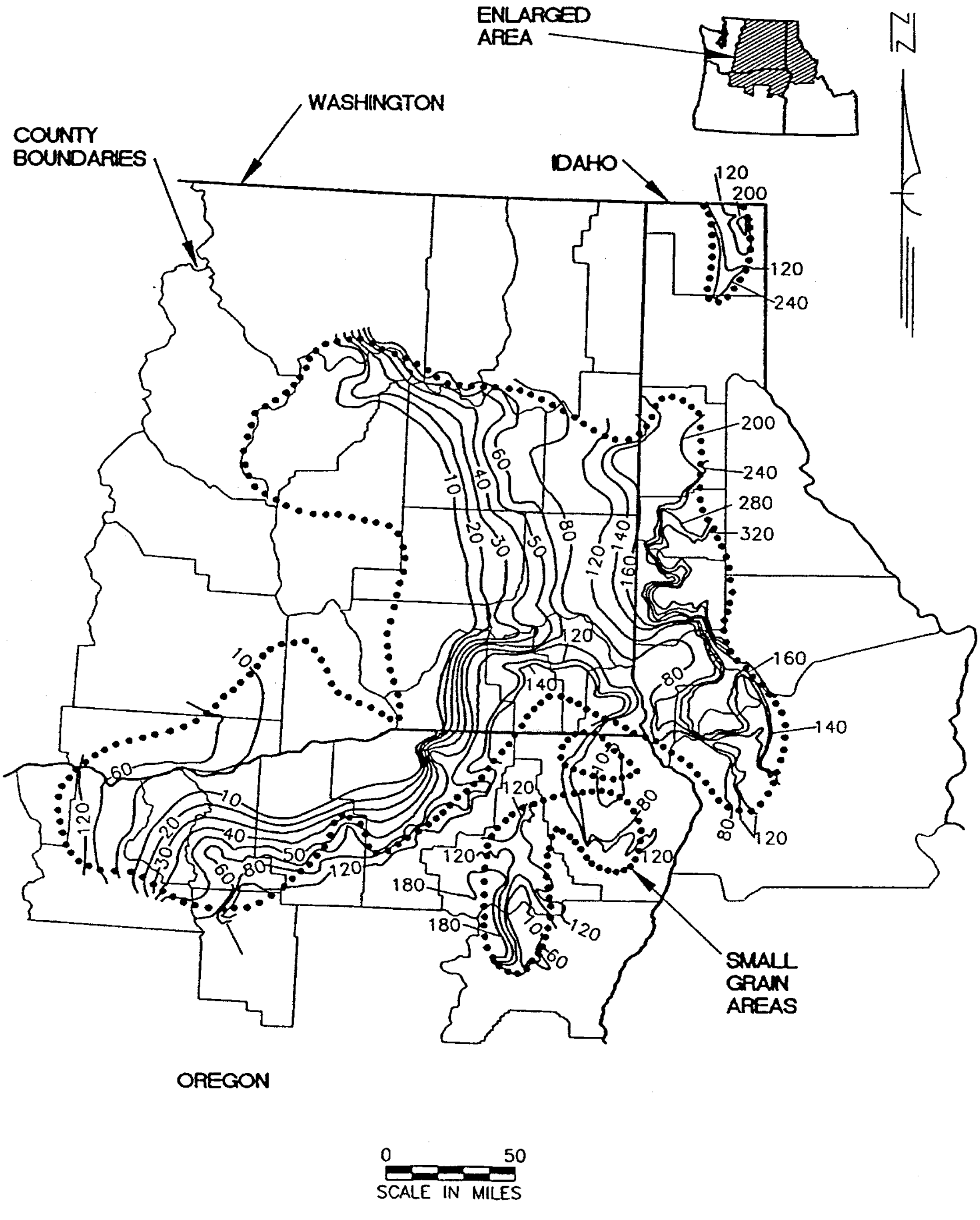

Figure 2-15. R_{eq} for cropland areas of Washington, Oregon, and northern Idaho in and adjacent to Northwestern Wheat and Range Region (Note: Some irregular contour intervals are used to preserve clarity). R_{eq} units are hundreds ft·tonf·in(ac·h)$^{-1}$.

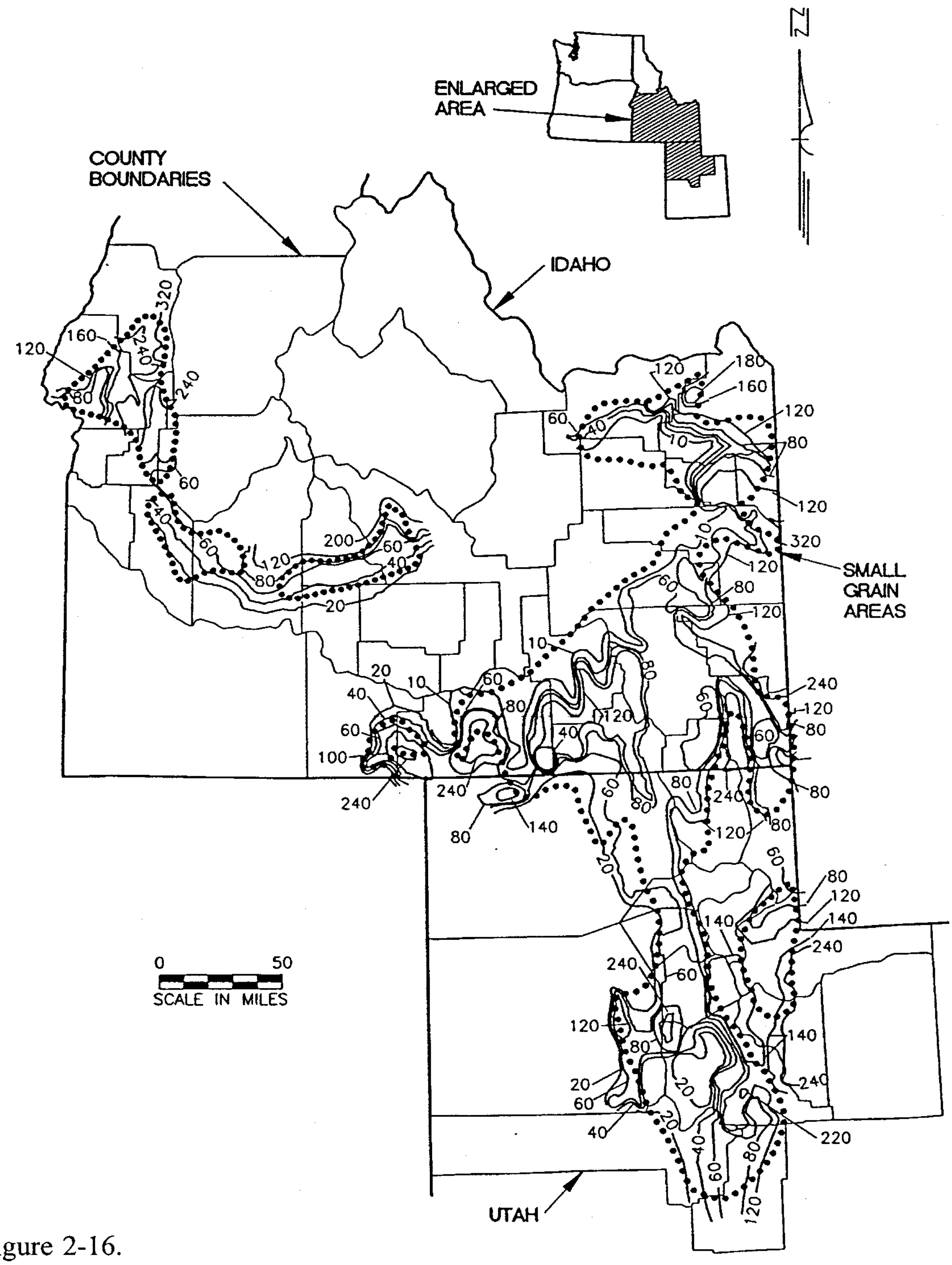

Figure 2-16.
R_{eq} for cropland areas of southern Idaho and Utah in and adjacent to Northwestern Wheat and Range Region (Note: Some irregular contour intervals are used to preserve clarity). R_{eq} units are hundreds $\text{ft}\cdot\text{tonf}\cdot\text{in}(\text{ac}\cdot\text{h})^{-1}$.

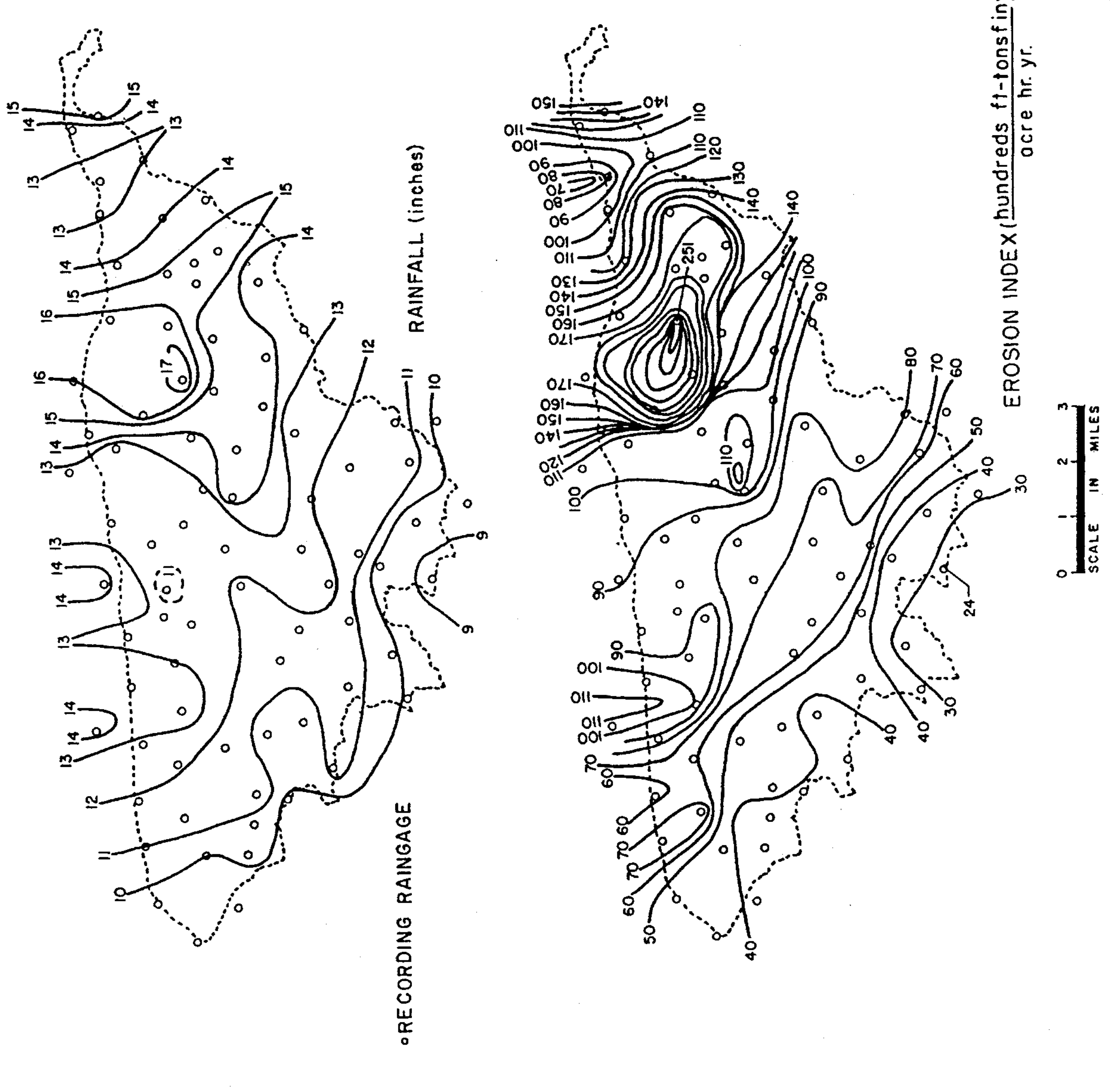

Figure 2-17. Storm precipitation (top) and isoerodent (bottom) values for storm of 7/22/64 on Walnut Gulch Experimental Watershed

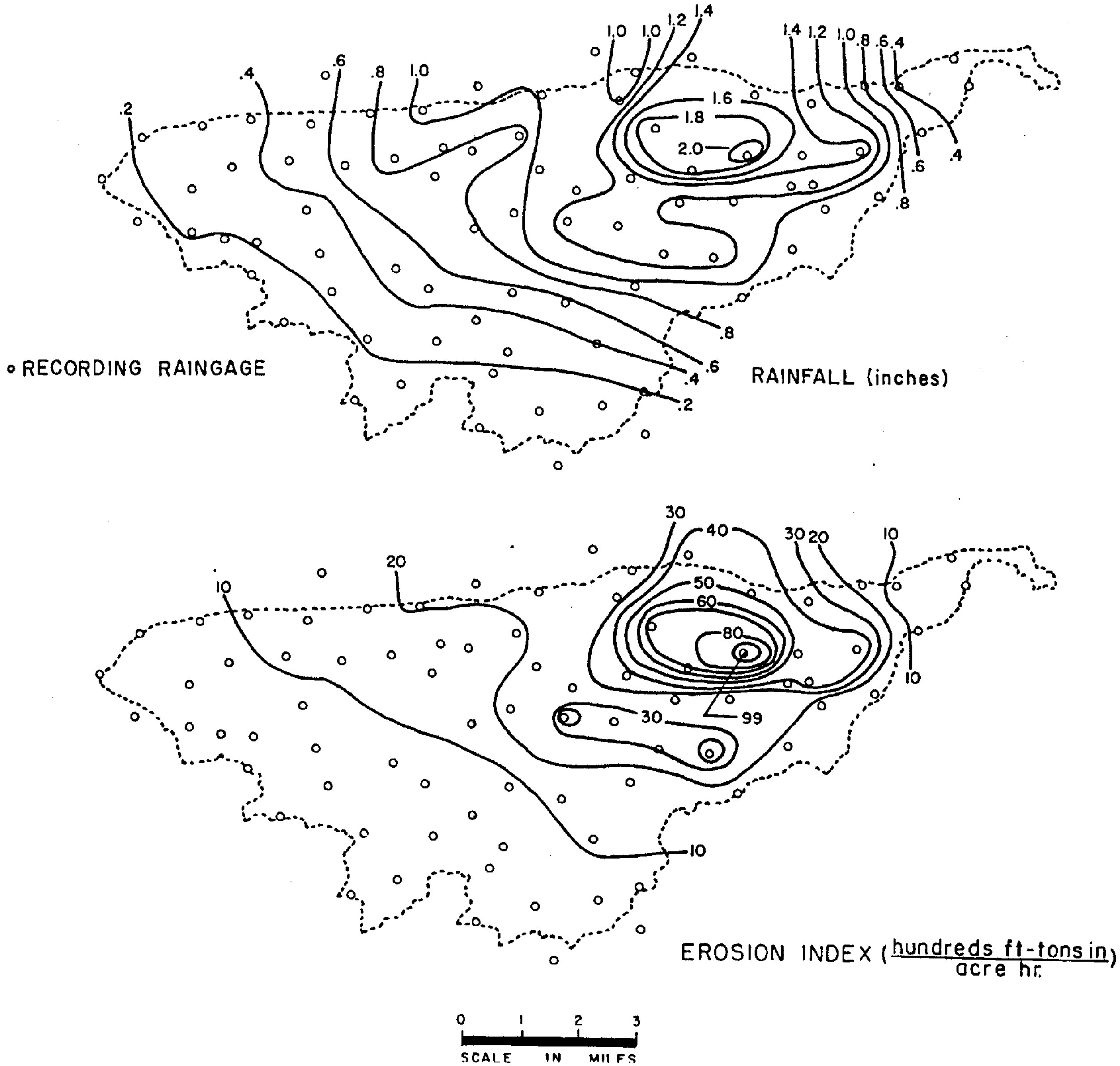

Figure 2-18. Annual precipitation (top) and isoerodent (bottom) maps for 1964 on Walnut Gulch Experimental Watershed

CHAPTER 3. SOIL ERODIBILITY FACTOR (K)

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CHAPTER 3. CONTENTS

Soil erodibility is a complex property and is thought of as the ease with which soil is detached by splash during rainfall or by surface flow or both. From a fundamental standpoint, however, soil erodibility should be viewed as the change in the soil per unit of applied external force or energy. Just as in USLE, RUSLE uses a restrictive and applied definition of soil erodibility. Soil erodibility is related to the integrated effect of rainfall, runoff, and infiltration on soil loss and is commonly called the soil-erodibility factor (K). The soil-erodibility factor (K) in RUSLE accounts for the influence of soil properties on soil loss during storm events on upland areas. In this chapter, the current state of knowledge of K-factor measurements and prediction technology is summarized. Background information is given to facilitate the estimation of K values for soils for which no direct K-value measurements are available. Specific areas of concern in evaluations of soil-erodibility factor are discussed, including seasonal variation of soil-erodibility factors (especially of soils subjected to freezing and thawing) and the evaluation of the soil-erodibility factor for soils with rock fragments.

DEFINITION AND EXPERIMENTAL GUIDELINES

The soil-erodibility factor (K) is the rate of soil loss per rainfall erosion index unit [ton· acre· h(hundreds of acre· ft-tonf· in) $^{-1}$] as measured on a unit plot. The unit plot is 72.6 ft (22.1 m) long, has a 9% slope, and is continuously in a clean-tilled fallow condition with tillage performed upslope and downslope (Wischmeier and Smith 1978). Recommended minimum plot width is 6 ft (1.83 m). Guidelines for preparation and maintenance of natural runoff plots in the United States were issued in 1961 by D.D. Smith (Römkens 1985). They are as follows: "Plow to normal depth and smooth immediately by disking and cultivating two or more times, except for areas where wind erosion during the winter poses a serious hazard. In the latter case, disking or cultivating should be delayed until spring. Plowing shall be each year at the time continuous row crop plots are plowed. Cultivation shall be at new crop planting, routine cultivating times, and when necessary to eliminate serious crust formations. Chemical weed control may be used, if cultivation does not control weed-growth. Plowing and cultivation should be upslope and downslope and should not be on an excessively wet soil."[1]

[1]Administrative communication from D.D. Smith to runoff plot managers (January 1, 1961), "Instructions for establishment and maintenance of cultivated fallow plots."

PRACTICAL INTERPRETATION

In practical terms, the soil-erodibility factor is the average long-term soil and soil-profile response to the erosive powers of rainstorms; that is, the soil-erodibility factor is a lumped parameter that represents an integrated average annual value of the total soil and soil profile reaction to a large number of erosion and hydrologic processes. These processes consist of soil detachment and transport by raindrop impact and surface flow, localized deposition due to topography and tillage-induced roughness, and rainwater infiltration into the soil profile.

INTERACTIONS WITH OTHER SOIL-LOSS FACTORS

The soil-erodibility factor (K) represents the effect of soil properties and soil profile characteristics on soil loss. Some interdependency exists between the K factor and other RUSLE factors. For instance, the traditional topographic relationships for slope length and steepness factors (LS) (Wischmeier and Smith 1978) were derived from soil-loss measurements on mostly medium-textured, poorly aggregated surface soils. It is to be expected that errors and shortcomings in the relationships for topographic effects will carry over into K values if these relationships are used to determine K values.

Similar problems exist for the rainfall-erosivity factor (R). Storm energy may vary substantially among storms due to variations in drop size and due to updraft or downdraft of wind. Some of these variations occur in areas where certain storm types prevail for part of the year (heavy thunderstorms versus gentle rains). Calculations of rainfall energy from rainfall breakpoint data for natural runoff plots using a relationship of specific intensity versus energy (Wischmeier and Smith 1978) may lead to "errors" in the computed K. Seasonal K values may offer some compensation for errors in R values computed from rainfall breakpoint data.

Interactions with the cover-management factor (C) are primarily due to the effect of organic matter or organic carbon on soil loss. The organic-carbon content of soils depends on the annual additions of surface and subsurface crop residue and manure and on their decomposition rate. No sharp delineation can be made where the effects of crop residue cease to be part of a C factor and instead become part of the K factor. Moreover, the processes of organic conversions are related to environmental factors (temperature, wetness, and so on) and thus vary among physiographic regions. A discussion of these processes is beyond the scope of this chapter. Short-term effects such as from the protective cover of mulch or from the mechanical constraints such as disturbance of surface and subsurface residues are related to the C factor, whereas long-term effects such as soil changes or soil structural alterations by organic compounds should be considered part of the K factor.

DETERMINATION OF K FACTOR

Soil-erodibility factors are best obtained from direct measurements on natural runoff plots. Rainfall simulation studies are less accurate, and predictive relationships are the least accurate (Römkens 1985). In each of these methods of determination, requirements for soil and plot conditions as well as methods of evaluation have to be met. These requirements are designed to eliminate the influence of variations in antecedent soil-water and soil-surface conditions and of variations in the rainstorm regimes on the soil-erodibility factor. Only inherent soil properties are considered determinants of the erodibility factor.

Natural Runoff Plots

The major requirement in a study using a natural runoff plot is a database that is large enough and that was obtained over a sufficiently long period. Very few studies exist for which long-term observations are available. For the eastern United States, this period is assumed to be 20-22 yr (Wischmeier 1976). Time and economic factors have limited the establishment of long-term runoff plots and therefore have promoted the development of plot research with simulated rainfall. However, simulated-rainfall procedures often fall short of the requirement of a sufficiently long fallow condition. Table 3-1 lists the soils in the United States on which natural runoff plots for K-factor determinations were established. Note that the observation period on all of these soils fell considerably short of the stated period of 20-22 yr. However, K values of many soils were obtained from long-term runoff data on cropped plots that had been adjusted for the C factor.

The second requirement for soil-erodibility-factor determinations on natural runoff plots is a fallow, tilled surface immediately before and during the observation period. This requirement stipulates the removal or natural degradation of all surface and subsurface plant residue that remained after cropping. The adequacy of this observation period should be determined relative to the climatic conditions in the United States but is usually taken to be 2 yr.

The third requirement for reliable K-value determinations is uniformity of soil and topography within the plot and also adherence to plot-size standards. Topographic uniformity is essential to avoid soil deposition or accelerated soil erosion in localized areas. The selection of plots having a standard length and steepness is important to avoid errors in soil-loss adjustments with topographic factors. Many soils do not occur with slopes of 9%, but standards, once formulated, must be adhered to in order to avoid ambiguities. Actually, the 9%-slope steepness is not rationally based, but was selected as being an average gradient of runoff plots on which early erosion studies in the United States were conducted. Similarly, the 72.6-ft (22.1-m) plot length was the result of the selection of a 1/100-acre (1/250-ha) plot area, given a two-row or 6-ft (1.83-m) plot width.

Rainfall-Simulation Plots

K-factor determinations in simulated-rainfall studies require plot standards that are the same as those for natural runoff plots with respect to size, slope, and preparation. However, the usually very short timespan allowed between cropping and rainfall-simulation runs is insufficient for the adequate degradation of surface or subsurface organic residue. Therefore, in the simulation, surface residue is often removed mechanically or manually before tillage, and corrections for subsurface-crop-residue effects are made through the C factor. Errors may be introduced in K-factor determinations for soils with incomplete removal or degradation of surface and subsurface residues or for soils with incorrect C-factor adjustments.

A second difficulty with the use of rainfall simulation in K-factor evaluations is the selection of weighting factors for soil losses on different antecedent soil-water conditions. Römkens (1985) and Barnett et al. (1965) observed that K values for different antecedent moisture levels need to be weighted in proportion to the occurrence of runoff and erosion in different climates to determine the average annual K value.

RELATIONSHIPS OF K FACTOR AND SOIL PROPERTIES

The physical, chemical, and mineralogical soil properties and their interactions that affect K values are many and varied. Moreover, several erosion mechanisms are operating at the same time, each one relating differently to a specific soil property. It is therefore unlikely that a relatively few soil characteristics will accurately describe K values for each soil. Yet several attempts have been made to relate measured K values to soil properties. Table 3-2 lists the principal studies in the United States and a summary of the results.

Of these studies, the most widely used and frequently cited relationship is the soil-erodibility nomograph (Wischmeier et al. 1971). The nomograph, shown in figure 3-1, comprises five soil and soil-profile parameters: percent modified silt (0.002-0.1 mm), percent modified sand (0.1-2 mm), percent organic matter (OM), and classes for structure (s) and permeability (p). The structure and permeability classes and groups of classes were taken from the Soil Survey Manual (USDA 1951). A useful algebraic approximation (Wischmeier and Smith 1978) of the nomograph for those cases where the silt fraction does not exceed 70% is

$$K = \left[2.1 \cdot 10^{-4}(12 - OM)\, M^{1.14} + 3.25(s-2) + 2.5(p-3)\right] / 100 \qquad [3\text{-}1]$$

where M is the product of the primary particle size fractions: (% modified silt or the 0.002-0.1 mm size fraction) $\cdot$ (% silt + % sand). K is expressed as ton$\cdot$ acre^{-1} per erosion index unit with U.S. customary units of ton$\cdot$ acre$\cdot$ h (hundreds of acre$\cdot$ ft-tonf $\cdot$ in)$^{-1}$. Division of the right side of this and subsequent K-factor equations with the factor 7.59 will yield K values expressed in SI units of t$\cdot$ ha$\cdot$ h$\cdot$ ha$^{-1}\cdot$ MJ$^{-1}\cdot$ mm^{-1}.

The nomograph relationship is derived from rainfall-simulation data from 55 midwestern, mostly (81%) medium-textured, surface soils. More than 60% of these soils had an aggregation index smaller than 0.3 (Mannering 1967). The nomograph is well suited for the less aggregated, medium-textured surface soils of the Midwest. Attempts by other investigators to apply the nomograph to other classes of soils have met with limited success. Figure 3-2 shows the relationship between the observed and nomograph-predicted soil-erodibility factors for the nomograph database and selected U.S. data sets of other soil classes. In most of these studies, aggregate sizes or aggregation indices were the most significant parameters. For details of the relationship between the soil-erodibility factor and soil properties, the reader is referred to the original publications (see table 3-2) or to a review paper by Römkens (1985).

Regression equations for specific classes of soils in the United States are those listed in table 3-2. Unfortunately, substantial intercorrelations exist among many of these variables, thereby affecting the true significance of each property in predicting K values. The relationship for volcanic soils in Hawaii (El-Swaify and Dangler 1976) is given by the expression

$$
\begin{aligned}
K = & -0.03970 + 0.00311x_1 + 0.00043x_2 \\
& + 0.00185x_3 + 0.00258x_4 - 0.00823x_5
\end{aligned}
\qquad [3\text{-}2]
$$

where x_1 is the unstable aggregate size fraction in percent less than 0.250 mm, x_2 is the product of % modified silt (0.002-0.1 mm) and % modified sand (0.1-2 mm), x_3 is the % base saturation, x_4 is the silt fraction (0.002-0.050 mm) in percent, and x_5 is the modified sand fraction (0.1-2 mm) in percent. The applicability of equation [3-2] has not been demonstrated for all tropical soils of volcanic origin. Equation [3-2] should be considered for only those soils that are similar to soils found in Hawaii.

For soils in the upper Midwest, the following relationship was developed (Young and Mutchler 1977):

$$
\begin{aligned}
K = & -0.204 + 0.385x_6 - 0.013x_7 + 0.247x_8 \\
& + 0.003x_2 - 0.005x_9
\end{aligned}
\qquad [3\text{-}3]
$$

where x_6 is an aggregation index, x_7 is the percentage montmorillonite in the soil, x_8 is the bulk density of the 50-125 mm depth in $g \cdot cm^{-3}$, and x_9 is the dispersion ratio. The presence of the montmorillonite term suggests that this clay mineral significantly impacted the aggregation and granulation characteristics of these soils--the latter by facilitating detachment during drying and transport in subsequent storm events.

For clay subsoils in the Midwest, the following relationship may be useful (Römkens et al. 1977):

$$K = 0.004 + 0.00023x_{10} - 0.108x_{11} \qquad [3\text{-}4]$$

where x_{10} is the parameter M (Wischmeier et al. 1971) and x_{11} is the citrate-dithionite-bicarbonate (= CDB) extractable percentage of Al_2O_3 plus Fe_2O_3. This relationship again suggests the importance of the particle size between 0.002 and 0.1 mm in soil-erodibility-factor evaluations for subsoils. The importance of the CDB-extractable amount of the hydrous oxides of iron and aluminum as a predictor for the soil-erodibility factor should be tempered, in view of the small amounts (<3.76%) of these substances present in the soils tested. For highly weathered or cemented soils, equation [3-4] has not been tested and presumably needs modification.

Recently, all available published global data (225 soils) of measured K values, obtained from both natural- and simulated-rainfall studies, were pooled and grouped into textural classes. Only soils with less than 10% of rock fragments by weight (>2 mm) were considered. The mean values of the soil-erodibility factor for soils within these size classes were then related to the mean geometric particle diameter of that class. The resulting relationship, shown in figure 3-3A, can be expressed as

$$K = 7.594\left\{0.0034 + 0.0405\exp\left[-\frac{1}{2}\left(\frac{\log(Dg)+1.659}{0.7101}\right)^2\right]\right\} \qquad [3\text{-}5]$$

where

$$Dg(mm) = \exp\left(0.01\sum f_i \ln m_i\right) \text{ with } r^2 = 0.983 \qquad [3\text{-}6]$$

and

Dg = geometric mean particle diameter.

Here, f_i is the primary particle size fraction in percent, and m_i is the arithmetic mean of the particle size limits of that size (Shirazi and Boersma 1984). A similar relationship, shown in figure 3-3B with $r^2 = 0.945$, was derived for 138 U.S. soils only. This relationship is

$$K = 7.594\left\{0.0017+0.0494\exp\left[-\frac{1}{2}\left(\frac{\log(Dg)+1.675}{0.6986}\right)^2\right]\right\} \qquad [3\text{-}7]$$

Figure 3-3 also indicates the variability in K values for each particle size class.

Relationships [3-5] and [3-7] are very useful for predicting K values of soils for which (1) data are limited (for instance, no information about the very-fine-sand fraction or organic-matter content) and (2) the textural composition is given in a different classification system. Also, equations [3-5] and [3-7] are useful for predicting K values of classes of soils other than those on which the nomograph was based, such as soils of textural extremes and well-aggregated soils. Of course, prediction equations [3-5] and [3-7] give an estimate of the K factor based on limited data and therefore yield less accurate values than those obtained from direct measurements or indirectly from regression data for soil types similar to those indicated in table 3-2.

CONSIDERATIONS IN SELECTION OF K VALUES

Several methods can be used to obtain estimates of the average annual value of the soil-erodibility factor. For medium-textured soils—certainly for the poorly aggregated ones of the temperate zones—the nomograph appears to be the best predictive relationship. For tropical soils of volcanic origin, relationship [3-2] may be helpful. For soils or subsoils that contain clay minerals with 2:1 expanding lattices, relationships [3-3] or [3-4] can be used. If K values are to be obtained for soils that do not readily fit any of these categories or for soils with incomplete information (that is, particle-size distribution and organic matter content), the broadly based relationships [3-5] and [3-7] can be selected.

SPECIFIC PROBLEM AREAS

Rill and Interrill Erodibility

Physically based models are being developed to explain the dynamic relationships of the erosion process (detachment, transport, deposition), and the models provide a great opportunity to improve the estimation of erosion. These models are incompatible with the empirically based RUSLE, which predicts long-term average values (effects of subprocesses are lumped). Thus, improved soil-erodibility estimates using soil properties and relating them to erosion processes are not included in this revision (Römkens et al. 1986).

Soils With Rock Fragments

In NRCS's map unit use file (MUUF), 15.6% of land area in the continental United States consists of soils with rock fragments on or in the soil surface (Miller and Guthrie 1984). These rock fragments, when present on the soil surface, significantly reduce soil detachment by rainfall. When present in a coarse-textured-soil profile (having sand and loamy sand textures), the fragments can appreciably reduce infiltration.

To account for these effects, one view has been to include the effect of rock fragments on soil loss solely in the C factor (Box and Meyer 1984, Römkens 1985), and another practice has been to include the effects solely in the K factor. Surface cover by rock fragments varies from site to site on otherwise identical soils. The fragments act as a surface mulch by protecting the soil surface from raindrop impact in a manner similar to that of surface mulches of straw and chopped stalks. Rock fragments are usually not moved by water from interrill areas but remain behind on the soil surface and act as an "armor" (Jennings and Jarrett 1985).

Subsurface rock fragments affect infiltration and thus runoff in a manner similar to that of subsurface residue by reducing the soil void space and soil hydraulic conductivity in coarse-textured soils. Moreover, because soil-mechanical-analysis procedures are based on particle-size fractions smaller than 2 mm, rock fragments larger than 2 mm are usually excluded when estimating K-factor values. However, rock fragments are part of a continuum of particle sizes in the mineral phase of the soil and therefore can be considered as part of the soil-erodibility factor.

This Agriculture Handbook separates the influence of rock fragments on soil loss into two components: (1) a surface cover component that represents the surface-protecting effect of rock fragments and that is accounted for in the C factor in a manner similar to that of crop residue and vegetative mulch, and (2) a subsurface component for sand and loamy-sand textures that represents the soil-loss increase due to the reduction in water infiltration. This latter effect is accounted for in the K factor through adjustments of the permeability class. It is shown below, however, that the subsurface effect of rock fragments can be relatively minor compared to the surface effect. Soil-profile descriptions with permeability classes that include the effect of rock fragments on permeability should not receive such an adjustment.

The hydraulic-conductivity-reducing effect of rock fragments can be determined from the relationship of the saturated hydraulic conductivity and permeability class given in the National Soils Handbook No. 430 (USDA 1983). Some clarification[2] is needed concerning the terminology and tables in that handbook. Rawls et al. (1982) proposed a relationship between the permeability class and the saturated hydraulic conductivity for different soil textures (table 3-3). Many factors other than texture determine the permeability class: for instance, structure, mineralogy, fragipans, sodium, and salinity. However, this relationship provides an estimate for relating changes in the effective hydraulic conductivity due to the presence of rock fragments to changes in the permeability class.

The rate of reduction in the saturated hydraulic conductivity with the presence of increasing amounts of coarse fragments in the soil profile was theoretically derived by Peck and Watson (unpublished data) and later verified for sand columns with inclusions of glass spheres and gravel by Dunn and Mehuys (1984). The relationship is

$$K_b / K_f = 2(1 - R_v) / (2 + R_v) \qquad [3\text{-}8]$$

---

[2]Permeability class as defined in the Soil Survey Manual of 1951 and in the USDA-SCS National Soils Handbook No. 430 is actually a hydraulic conductivity class. The relationship between permeability K_p (an intrinsic soil matrix property with dimensions L^2) and the saturated hydraulic conductivity K_h (a property that includes fluid properties of dimensions $L \cdot T^{-1}$) is $K_h = K_p \cdot \rho g \cdot \mu^{-1}$, where μ is fluid viscosity, ρ is fluid density, and g is gravitational acceleration.

where K_b is saturated hydraulic conductivity of the soil with rock fragments, K_f is saturated hydraulic conductivity of the fine soil fraction (<2 mm), and R_v is percent by volume of rock fragments >2 mm.

Brakensiek et al. (1986) simplified equation [3-8] to show that K_b of soil containing rock fragments can be reasonably related to K_f by using only the weight percent of rock fragments >2 mm. This relationship is

$$K_b/K_f = \left(1 - R_w\right) \qquad [3\text{-}9]$$

where R_w is percent by weight of rock fragments >2 mm. Using equation [3-9], a given percentage weight of rock fragments in a soil profile will result in an equal percentage reduction in the saturated hydraulic conductivity of the soil. Hence, the corresponding change in the permeability class can be estimated from table 3-3.

For example, a 40% volume of rock fragments in a severely eroding medium-textured soil (K = 0.50) will cause at best a change of one step in the permeability class or a maximum increase of 0.025 units in the soil-erodibility factor. This represents a 5% increase in soil loss. On the other hand, a 40% surface cover with rock fragments causes a reduction in soil loss of about 65% (Box 1981). For a less erodible soil (K = 0.10), a 40% volume of rock fragments represents a maximum increase of 25% in soil loss as reflected through the K value.

Seasonal K Values

K values are difficult to estimate mainly because of antecedent soil-water and soil-surface conditions and because of seasonal variations in soil properties. Because the value of these conditions and properties tends to be consistent for a season, it is thought that seasonal K values can reduce errors in soil-loss estimates. Based on this reasoning, Mutchler and Carter (1983) in the United States and Zanchi (1983) in Italy computed monthly K values. They independently proposed a periodic function of the type

$$K_r = 1 + a\cos(bt - c) \qquad [3\text{-}10]$$

where K_r is the ratio of the average seasonal (monthly) K value over the average annual K value; t is the mean monthly temperature; and a, b, and c are location-dependent constants. Similar reasoning by El-Swaify and

Dangler (1976) and Hosoyamada (1986) led to the introduction of wet/dry K values in Hawaii and cold/warm K values in Japan, respectively.

Variations in K through the seasons seem to be primarily related to three factors: soil freezing, soil texture, and soil water. Of these, the soil-freezing effect is probably the most difficult to evaluate. The effects of all three are now included in the average annual value.

The ability to more accurately predict the soil-erodibility factor for soils that are subjected to freeze-thaw cycles has been hampered by the limited understanding of the processes and temporary changes occurring in soil properties and in the soil profile during the cycles. Although no relationships have been developed, studies have shown that soil freezing and thawing can change properties that affect soil erodibility. These properties include soil structure, hydraulic conductivity, bulk density, aggregate stability, and soil strength (Benoit 1973, Benoit et al. 1986, Sillanpaa and Webber 1961, Formanek et al. 1984, Van Klaveren 1987, Kok and McCool 1990). It has been shown that the soil-water content at the time of initial freezing, the rate of soil freezing, and the number of freeze-thaw cycles can significantly affect soil aggregation and aggregate stability in spring at the time of thawing (Mostaghimi et al. 1988). Freeze-thaw cycling generally leads to low bulk density of the surface soil (Pall et al. 1982). Conditions of low density and high soil water provide a soil surface that is very susceptible to soil detachment and transport. Differences in soil density may persist even after frost layers have thawed. This, combined with intense spring rains, often results in large soil losses. Thus, freezing and thawing tend to increase the soil-erodibility factor.

High soil-water content can lead to the formation of concrete frost that is generally impermeable. Soil erodibility is then at a minimum, due to the soil's frozen conditions. When soil with a concrete frost layer thaws from the surface, drainage is almost nonexistent. Although the soil is not apt to be exposed to many freeze-thaw cycles in these areas, the spring melt period of 3 days to a month or more may still affect soil erodibility. During this period, a thawed surface layer of soil underlaid by a frost lens may exist, thereby impeding infiltration and water movement. Soil-erosion resistance is at a minimum immediately after the soil has thawed and tends to increase with time after thawing (Formanek et al. 1984). The greater the number of freeze-thaw cycles, the longer the erosion resistance of a soil is at a minimum. Because soil during the thawing period is extremely susceptible to erosion caused by snowmelt and rainfall, the soil loss is more likely to occur in that period. In regions where winter soil temperatures hover around the freezing point (such as in much of the Northwest Wheat and Range Region), the soil surface is apt to undergo many freeze-thaw cycles throughout the winter, which tends to keep erosion rates high during this period. Reductions in surface-shear strength of 50% have been measured in a Palouse silt loam immediately after one freeze-thaw cycle, resulting in increased soil detachability in rills (Formanek et al. 1984).

In the portions of the United States where frozen soil is not a problem, the value for soil erodibility gradually decreases over the course of the growing season until it reaches a minimum sometime near the end of the growing season. Then the erodibility value gradually increases until it again reaches the maximum value. This pattern generally follows the rainfall pattern for many areas. Although the actual length of the growing season varies in warmer areas, a value of 6 mo (183 d) appears to be a reasonable approximation of the time between maximum and minimum values of soil erodibility for many soils in the United States. In areas where the growing season or wet-dry periods are significantly different from 6 mo, the values must be adjusted accordingly.

An approach to modifying K values for a given soil based on seasonal variation in erodibility is to assume an exponential decay function for the rate of decrease in erodibility as the growing season progresses. The rate of change in soil erodibility would vary with different types of soil or soil textures (Kirby and Mehuys 1987). The relationship of soil erodibility to soil texture is adequately determined from the soil-erodibility nomograph (Wischmeier et al. 1971) and has already been determined for most of the significant soil series of the United States. By letting the ratio of K_{max} (the maximum value of soil erodibility for a given soil) to K_{nom} (soil erodibility as determined from the nomograph) be constant for a given soil texture, the magnitude of K_{max} also becomes a function of soil texture.

The time span between K_{max} and K_{min} (minimum value of soil erodibility) varies with location and soil. The limited available data suggest that in the North, maximum values of soil erodibility generally occur at or near the beginning of the frost-free growing season and gradually decline to a minimum value at the end of the frost-free growing season. Data also indicate that t_{max} (time of year at which the soil-erodibility factor is at a maximum) occurs progressively earlier from north to south, whereas t_{min} (time of minimum erodibility) occurs progressively later. This is especially true where frost conditions exist during the winter months. In frost-free areas or areas with only minor frost activity, the time from maximum to minimum soil erodibilities corresponds more closely with periods of high and low rainfall, but seldom exceeds 6 mo.

The magnitude of the range of soil erodibility appears to vary, at least partially, with the soil water at the time of a rainfall event. The probability of the soil being wet at any time is a function of the timing and amount of annual precipitation which, for much of the United States, is reflected in the distribution of annual R values (Wischmeier and Smith 1978). Where average R values are low and monthly R values are less uniformly distributed (as in the northern United States), the range between K_{max} and K_{min} is usually wide (>7). Where R values are high and monthly values are more uniformly distributed (as in the southern United States), the range is usually narrower (<3). Where R values exceed 400, the range approaches unity. Data from long-term natural runoff plots at Morris, Minnesota, and Holly Springs, Mississippi, indicate that in northern Mississippi, K_{max} occurs in about mid-December and K_{max}/K_{min} is approximately 3.7, whereas in central Minnesota, K_{max} occurs in about mid-April and K_{max}/K_{min} is approximately 7.6.

Using data from one eastern Canadian province and from seven states in the midwestern and eastern United States, the following relationships were derived:

Case 1: $t_{max}<t_{min}$

If $t_{max} < t_i < t_{min}$, then

$$K_i = K_{max}\left(K_{min}/K_{max}\right)^{\left(t_i - t_{max}\right)/\Delta t} \qquad [3\text{-}11]$$

where K_i = soil-erodibility factor at any time (t_i in calendar days), K_{max} and K_{min} = soil-erodibility factors at times t_{max} and t_{min}, respectively; Δt = length of frost-free period or growing period (≤183 d); and T_{av} = average daily air temperature.

If $t_i < t_{max}$ or $t_i > t_{min}$, then for $T_{av} > 27°F$,

$$K_i = K_{min}\exp\left[0.009\left(t_i - t_{min} + 365\delta\right)\right] \qquad [3\text{-}12]$$

with $\delta = 1$ if $(t_i - t_{min}) \le 0$ and $\delta = 0$ if $(t_i - t_{min}) > 0$ and for $T_{av} \le 27°F$, $K_i = K_{min}$.

Case 2: $t_{max} > t_{min}$

If $t_{max} > t_i > t_{min}$, then for $T_{av} > 27°F$,

$$K_i = K_{min} \exp\left[0.009\left(t_i - t_{min}\right)\right] \qquad [3\text{-}13]$$

and for $T_{av} \leq 27°F$, $K_i = K_{min}$.

If $t_i > t_{max}$ or $t_i < t_{min}$, then

$$K_i = K_{max}\left(K_{min}/K_{max}\right)^{\left(t_i - t_{max} + 365\delta\right)/\Delta t} \qquad [3\text{-}14]$$

with $\delta = 1$ if $(t_i - t_{max}) \leq 0$ and $\delta = 0$ if $(t_i - t_{max}) > 0$.

However, if equation [3-11], [3-12], [3-13], or [3-14] yields

$K_i > K_{max}$, then put $K_i = K_{max}$, or if $K_i < K_{min}$, then put $K_i = K_{min}$.

The constant 0.009 of equations [3-12] and [3-13] was obtained upon fitting this relationship to the database. Based on data from four southern, four midwestern, and four northern soils, the ratios of K_{max}/K_{min} and K_{max}/K_{nom} and the value of t_{max} for areas where R does not exceed 400 are as follows:

$$K_{max}/K_{min} = 8.6 - 0.019R, \qquad [3\text{-}15]$$

$$K_{max}/K_{nom} = 3.0 - 0.005R, \text{ and} \qquad [3\text{-}16]$$

$$t_{max} = 154 - 0.44R. \qquad [3\text{-}17]$$

If $t_{max} < 0$, then $t_{max} = t_{max} + 365$.

These values, plotted against the distribution of annual-erosivity values, are shown in figure 3-4. Using this method, the average annual value of erodibility (K_{av}) will normally differ slightly from K_{nom} and can be estimated from the relationship

$$K_{av} = \sum (EI_i)K_i /100 \qquad [3\text{-}18]$$

The annual EI distribution for any location in the United States can be found using figure 2-7 and table 2-1. The data from which the above relationships were derived were from the central and eastern United States and Canada. These are areas where isoerodent lines are approximated with reasonable accuracy and generally parallel each other as shown in figure 2-1 of chapter 2. There were no erodibility data available from the western states to include in the analysis. In the western United States there is a great deal more spatial variability of rainfall due to orographic effects caused by the mountain and valley topography, combined with the Pacific maritime influence. Erosivity values calculated from rainfall amount and intensity in most of the cropland areas of the western United States are lower than the ones in the central and eastern United States and Canada, where the variable K relationships were developed. Also in the western states, topography and orographic influences result in large fluctuations in local average air temperatures and length of growing season which are difficult to quantify. More research is needed on the effect of R values and fluctuations in temperature and growing season length on seasonal variation of K values in the western states. Thus it is recommended that K values for the region west of the line shown in figure 3-5 be estimated much as they have been in the past, from either the soil-erodibility nomograph or soil properties and the relationship shown in equation [3-1].

Data from volcanic soils in Hawaii suggest a somewhat different soil erodibility relationship than the one discussed above. There is little seasonal variation of K for these soils since they are not normally subject to freeze-thaw cycles. Thus, for volcanic soils in tropical areas, it is recommended that K values be estimated based on soil properties and the relationship shown in equation [3-2].

Following is an example of calculations for K_i and K_{av} for a Barnes loam (Udic Haploboroll) near Morris in west-central Minnesota with an annual EI of 90 and K_{nom} of 0.28. The frost-free period, or timespan between K_{max} and K_{min}, in west-central Minnesota is slightly less than 5 mo, or about 140 d (U.S. Department of Commerce 1968).

From figure 3-4 we arrive at

t_{max} = 154-0.44(90)=114 days (4/24) t_{min} = 114+140=254 days (9/11)

K_{max}/K_{nom} = 3.00-0.005(90)=2.55 K_{max} = 2.55(0.28)=0.714

K_{max}/K_{min} = 8.60-0.019(90)=6.89 K_{min} = 0.714/6.89=0.104

Then, for the period from November 16 through March 15, when T_{av} $\leq 27°F$ (see fig. 3-5), K_i = 0.104; from March 16 through April 15 and September 1 through November 15 ($t_i < t_{max}$ and $t_i > t_{min}$), $K_i = 0.104\exp[0.009(t_i-254+365\delta)]$; and from April 15 through August 31 ($t_{max} < t_i < t_{min}$), $K_i = 0.714\ (0.146)^{(t_i-114)/140}$

From figure 3-5

$$K_{av} = \sum (EI_i) K_i /100 = 28.507 /100 = 0.285$$

Calculation of K_{av} by use of this method provides an annual average value for soil erodibility closely resembling the nomograph value (0.28) but reflecting a more realistic representation of seasonal fluctuations in the value of K. This value is similar to an average annual value of 0.24 for Barnes soil measured from long-term natural runoff plots at Morris (Mutchler et al. 1976).

Figure 3-6 shows a plot of K versus time of year for a Barnes loam from the example shown above and for a Loring silty-clay-loam soil (Glossic Fragiudalf) near Holly Springs, Mississippi (using EI distribution values from Memphis, Tennessee). Calculated values for figure 3-6 are shown in figures 3-7 and 3-8. Figure 3-6 indicates a slight increase in soil erodibility for a Barnes loam in early November. This behavior is due to the fact that once K reaches its minimum value at about the end of the growing season (sometime in early September), erodibility begins to increase again until complete soil freezing occurs (usually in November). Once the soil is frozen, erodibility goes back to a minimum value and remains at that value until spring thawing occurs. The Loring silty-clay-loam soil from Mississippi does not reflect this behavior because complete soil freezing does not occur in that area of the country.

ACKNOWLEDGMENT

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Table 3-1.
K values obtained from natural fallow runoff plots

Soil type[1]	Location	Family	Period	Slope (%)	Length (ft)	K $\frac{ton}{acre \cdot eros.index}$	Source[2]
Bath sil.	Arnot, NY	Typic Fragiochrept	1938-45	19	72.6	0.05	(a)
Ontario l.	Geneva, NY	Glossoboric Hapludalf	1939-46	8	72.6	.27	(a)
Cecil sl.	Clemson, SC	Typic Hapludult	1940-42	7	180.7	.28	(a)
Honeoye sil.	Marcellus, NY	Glossoboric Hapludalf	1939-41	18	72.6	.28	(a)
Hagerstown sicl.	State College, PA	Typic Hapludalf	[3]NA	NA	NA	.31	(b)
Fayette sil.	LaCrosse, WI	Typic Hapludalf	1933-38	16	72.6	.38	(a)
Dunkirk sil.	Geneva, NY	Glossoboric Hapludalf	1939-46	5	72.6	.69	(a)
Shelby l.	Bethany, MO	Typic Arguidoll	1931-40	8	72.6	.53	(a)
Loring sicl.	Holly Springs, MS	Typic Fraguidalf	1963-68	5	72.6	.49	(c)
Lexington sicl.	Holly Springs, MS	Typic Paleudalf	1963-68	5	72.6	.44	(c)
Marshall sil.	Clarinda, IA	Typic Hapludoll	1933-39	9	72.6	.43	(d)
Tifton ls.	Tifton, GA	Plinthic Paleudult	1962-66	3	83.1	[4]n.c.	(d)
Caribou grav. l.	Presque Isle, ME	Alfic Haplorthod	1962-69	8	72.6	n.c.	(d)
Barnes l.	Morris, MN	Udic Haploboroll	1962-70	6	72.6	.23	(e)
Ida sil.	Castana, IA	Typic Udorthent	1960-70	14	72.6	.27	(d)
Kenyon sil.	Independence, IA	Typic Hapludoll	1962-67	4.5	72.6	n.c.	(d)
Grundy sicl.	Beaconsfield, IA	Aquic Arguidoll	1960-69	4.5	72.6	n.c.	(d)

[1]si l. = silt loam, l. = loam, sl. = sandy loam, sicl. = silty clay loam, ls. = loamy sand, grav. l. = gravelly loam
[2](a) = Olson and Wischmeier 1963
(b) = Wischmeier and Smith 1978
(c) = McGregor et al. 1969
(d) = Lombardi 1979
(e) = Mutchler et al. 1976
[3]NA = Not available.
[4]n.c. = Not calculated. However, soil-loss data for K-value computations are available from National Soil Erosion Laboratory, West Lafayette, Indiana.

Table 3-2.
Regression data of K values on soil properties

Study[1]	Number of Soils	Variables tested	Variables in regression equation	Coefficient of determination	Most significant variable	Dominant soil texture
1	17	34	8	0.87	Slope	Sand
2	55	24	24	0.98	Clay ratio/OM	Silt loam
3	13	10	5	0.90	Agg.	Loam
4	55	NA[3]	5	NA	M	Silt loam
5	7	35	2	0.95	M	Clay
6	10	20	5	0.97	0-0.25mm	Clay

[1] 1 = Barnett and Rogers 1966;
2 = Wischmeier and Mannering 1969;
3 = Young and Mutchler 1977;
4 = Wischmeier et al. 1971;
5 = Römkens et al. 1977;
6 = El-Swaify and Dangler 1976.

[2] Clay ratio = % clay/(% silt + % sand); OM = organic matter; Agg. = an aggregation index; M = (% modified silt) (% silt + % sand), where modified silt is the particle size fraction between 0.002 and 0.100 mm (Wischmeier et al. 1971)

[3]NA = Not available.
Source: Römkens (1985).

Table 3-3.
Soil-water data for major USDA soil textural classes

Texture	Permeability code[1]	Saturated hydraulic conductivity[2] (in/hr)	Hydrologic soil group[3]
Silty clay, clay	6	<0.04	D
Silty clay loam, sand clay	5	0.04-0.08	C-D
Sandy clay loam, clay loam	4	0.08-0.2	C
Loam, silt loam[4]	3	0.2-0.8	B
Loamy sand, sandy loam	2	0.8-2.4	A
Sand	1	>2.4	A+

[1]Permeability codes used in figure 3-1. See National Soils Handbook No. 430 (USDA 1983) for permeability classes.
[2]Rawls et al. (1982)
[3]See National Engineering Handbook (USDA 1972).
[4]Note: Although silt texture is missing because of inadequate data, this should be in permeability class 3.

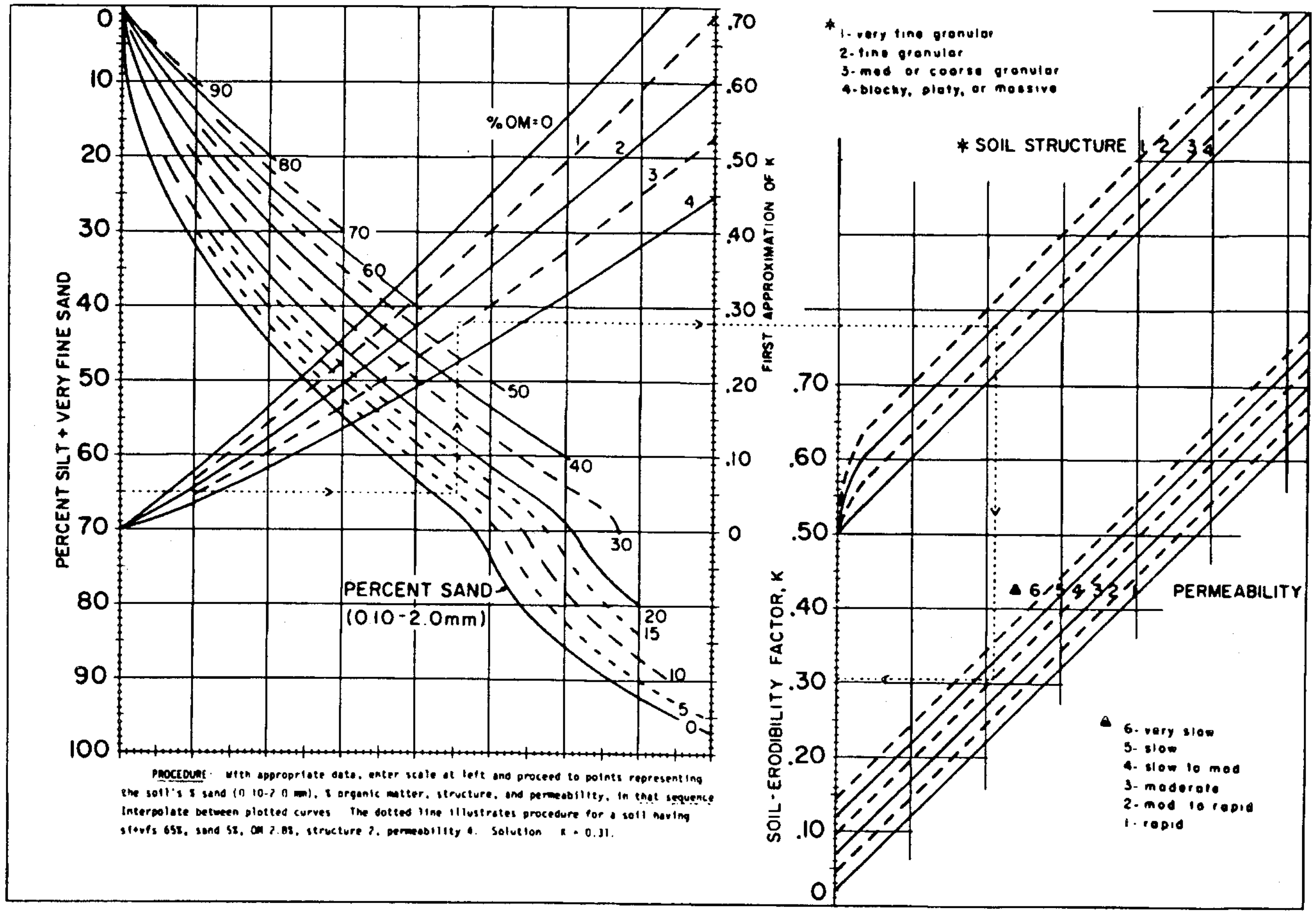


Figure 3-1. Soil-erodibility nomograph (after Wischmeier and Smith 1978). For conversion to SI divide K values of this nomograph by 7.59. K is in U.S. customary units.

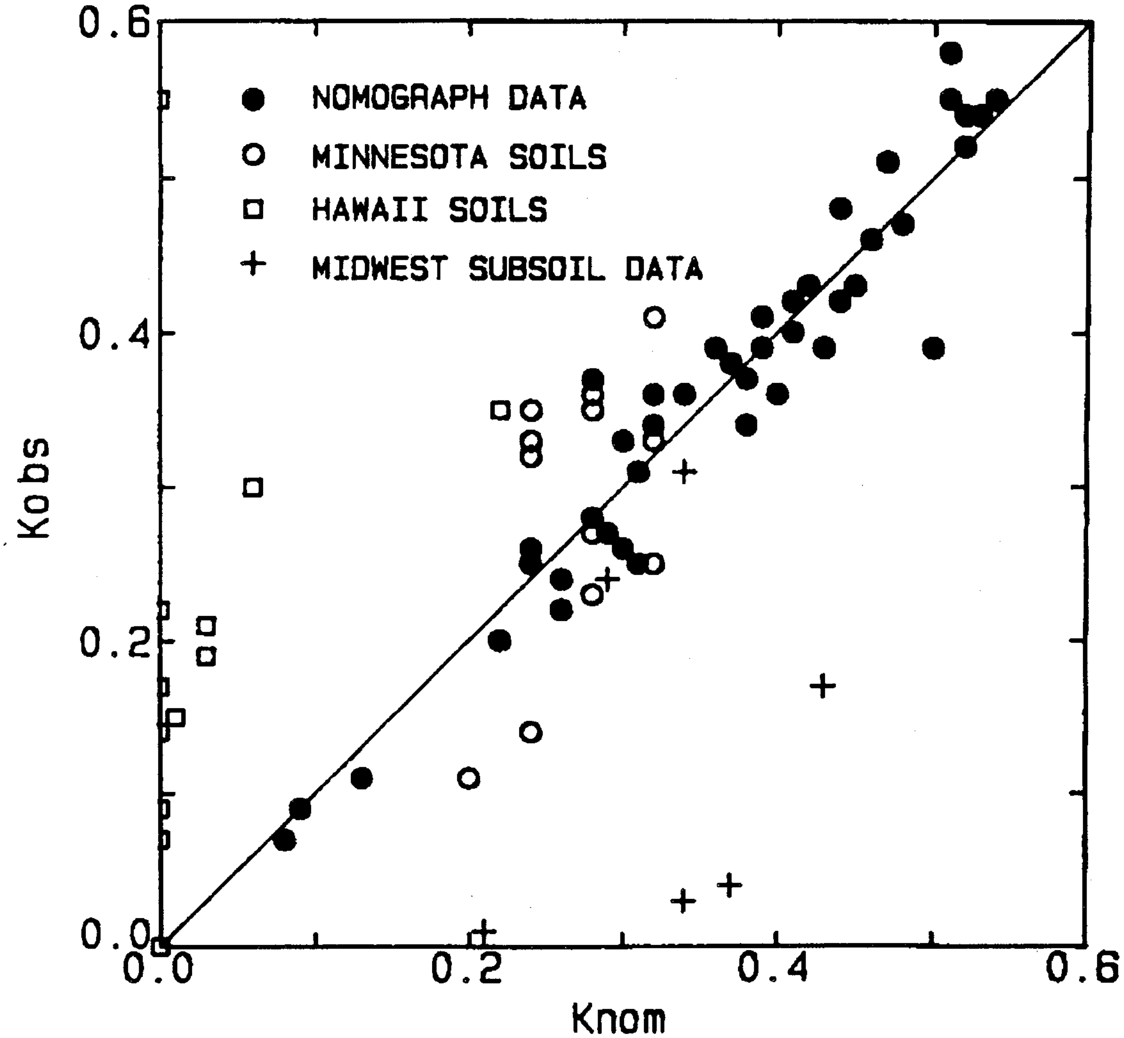
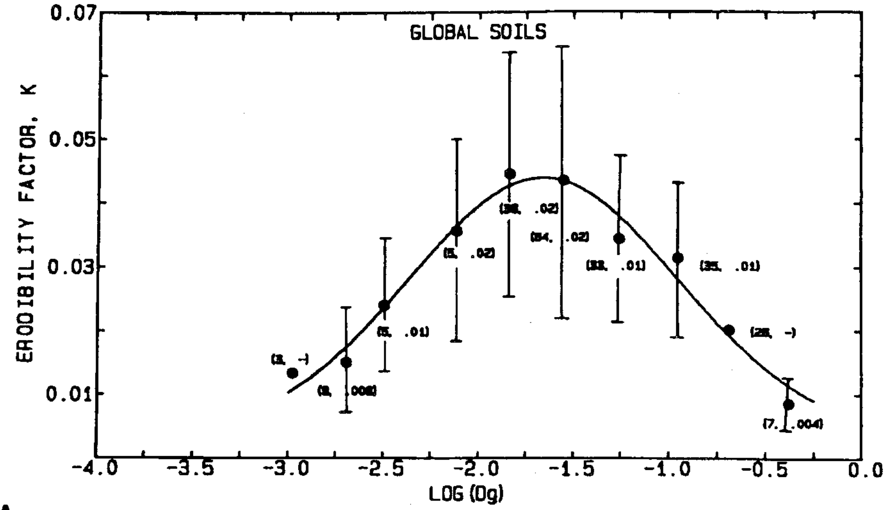
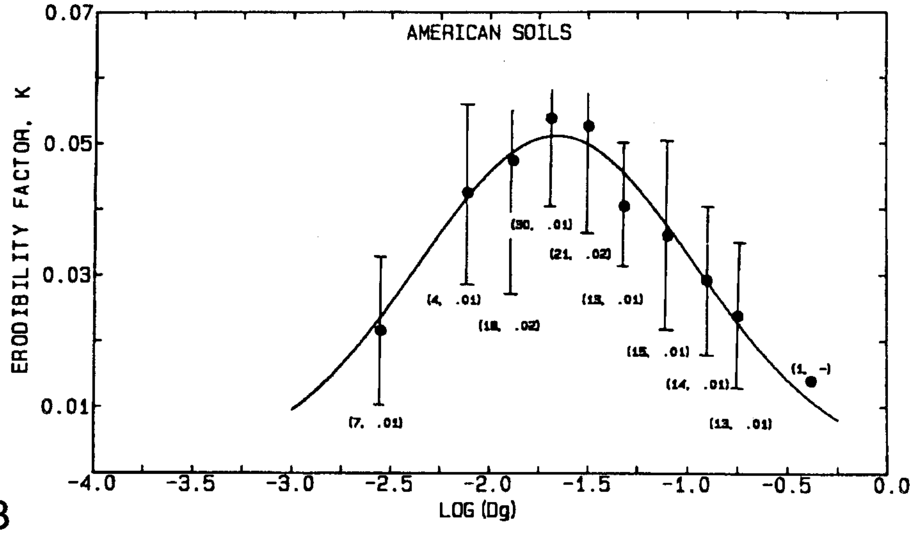


Figure 3-2. Relationship between observed and nomograph-predicted soil-erodibility factor values of several U.S. data sets (● Wischmeier et al. 1971; ○ Young and Mutchler 1977; □ El-Swaify and Dangler 1976; + Römkens et al. 1975). K_{nom} and K_{obs} have units of ton · acre · h (hundreds of acre-ft · tonf · in)$^{-1}$.



A



B

Figure 3-3. Soil-erodibility factor (K) as a function of the mean geometric particle diameter (Dg) (in mm). Values are given in SI units and should be multiplied by 7.59 to obtain U.S. customary units. Figure 3-3A represents global soil data, and figure 3-3B represents only U.S. data. Solid line was computed for averages of Dg classes with normal distribution. Vertical lines represent K values in each Dg class plus or minus 1 standard deviation. Numbers in parentheses represent number of observations and standard deviations for each Dg class.

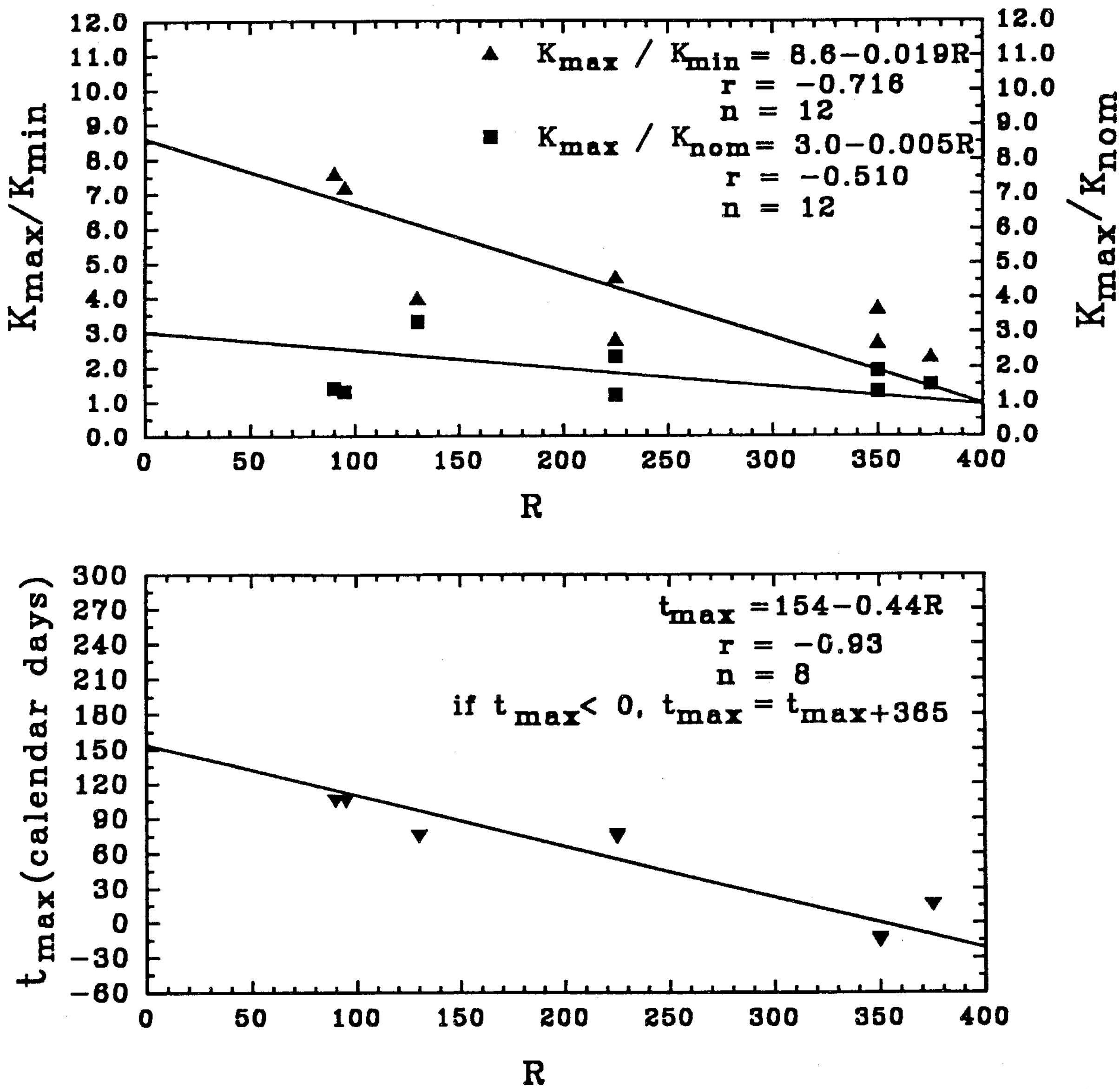


Figure 3-4. K_{max}/K_{min}, K_{max}/K_{nom}, and t_{max} relationships as a function of R for computing seasonal K-values. R is given in U.S. customary units.

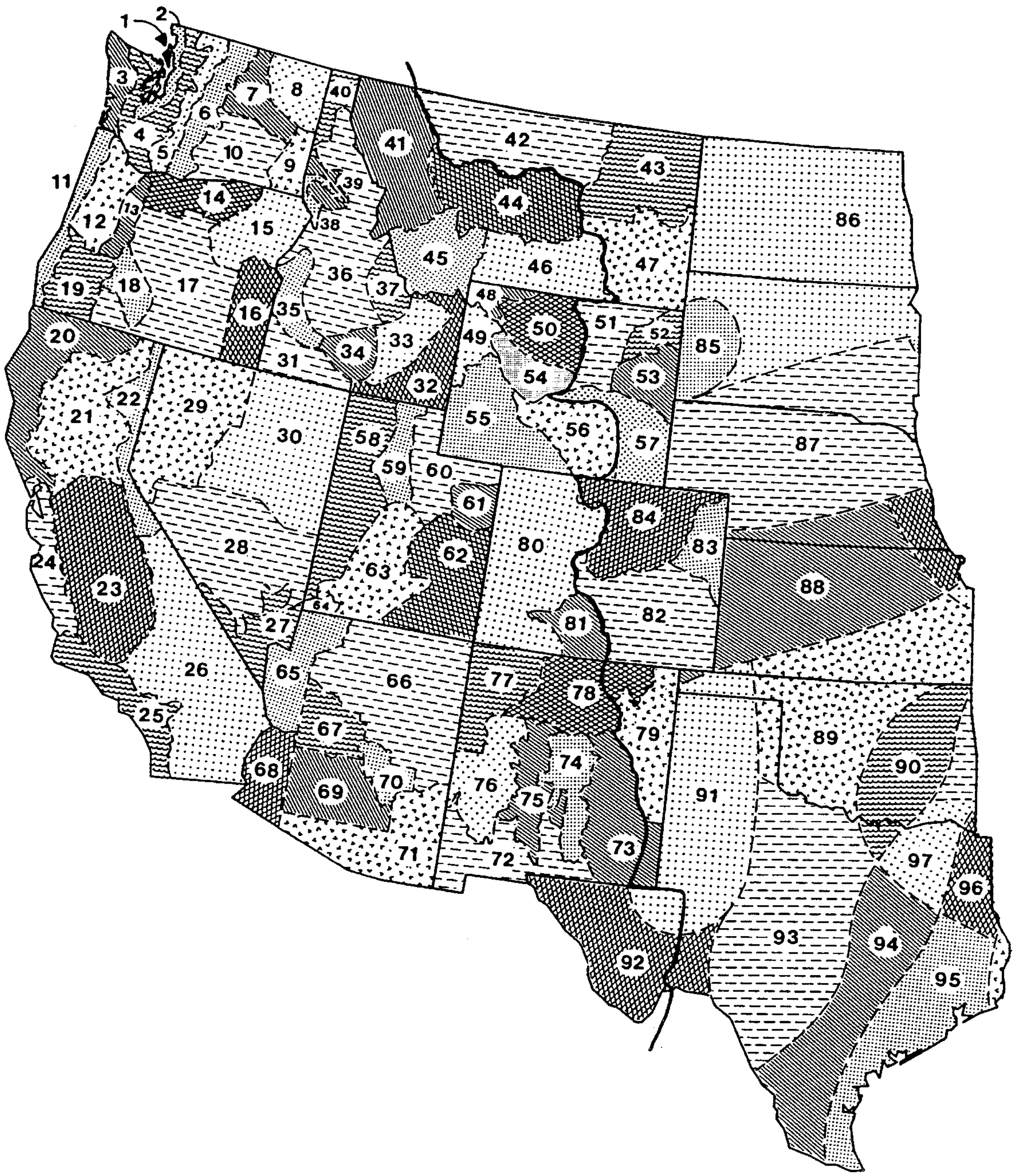


Figure 3-5. Map showing areas for which time-varying K should not be applied. Do not use time-varying K west of the dark line.

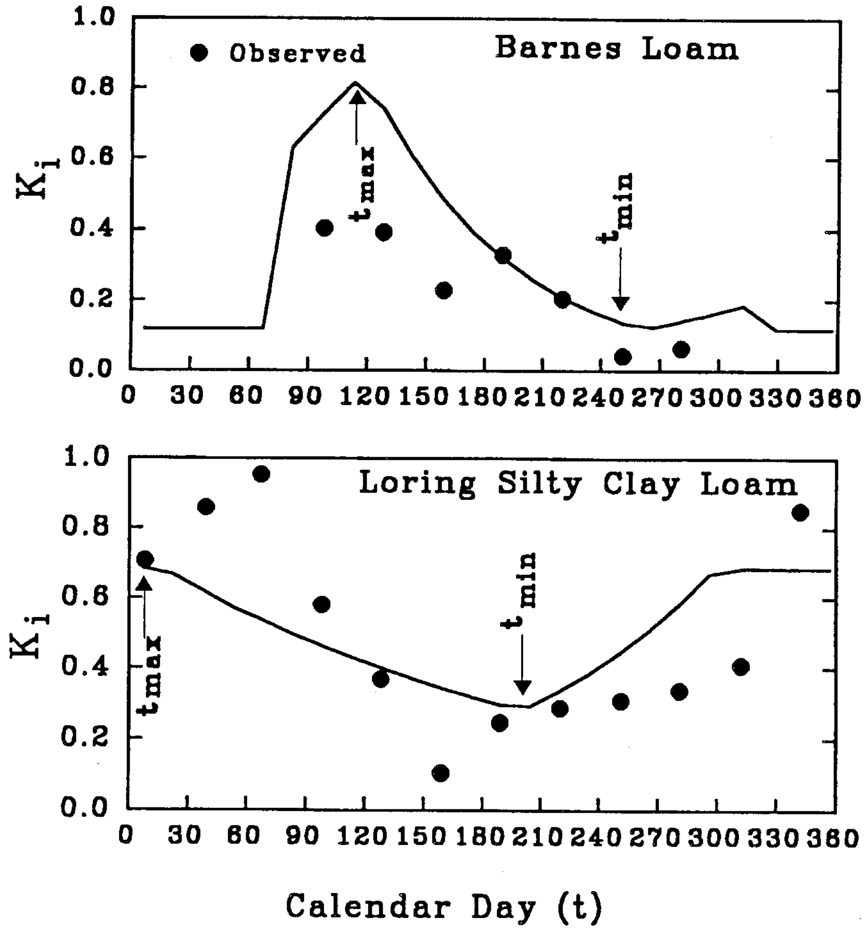


Figure 3-6. Relationship of K_i to calendar days for a Barnes loam soil near Morris, Minnesota, and a Loring silty clay loam soil near Holly Springs, Mississippi. K is given in U.S. customary units.

```
       File          Exit          Help          Screen
 ─────────────< Seasonally Variable K Factor SWCS1.02 >─────────────
     city code: 23003    MORRIS                 MN      estimated K: 0.28
  hyd. group: 1               % surface covered by rock fragments: 0
  soil series: Barnes         surface texture: 1
 ───DATE────────%EI──────K──────────DATE──────────%EI──────────K──────
   1/1-1/15         0.0     0.104   │   7/1-7/15         13.0       0.254
   1/16-1/31        0.0     0.104   │   7/16-7/31        14.0       0.206
   2/1-2/15         0.0     0.104   │   8/1-8/15         14.0       0.166
   2/16-2/28        0.0     0.104   │   8/16-8/31        13.0       0.135
   3/1-3/15         0.0     0.104   │   9/1-9/15          5.0       0.108
   3/16-3/31        1.0     0.589   │   9/16-9/30         3.0       0.115
   4/1-4/15         1.0     0.68    │   10/1-10/15        1.0       0.132
   4/16-4/30        1.0     0.714   │   10/16-10/31       1.0       0.151
   5/1-5/15         3.0     0.589   │   11/1-11/15        0.0       0.175
   5/16-5/31        5.0     0.479   │   11/16-11/30       0.0       0.104
   6/1-6/15        12.0     0.384   │   12/1-12/15        0.0       0.104
   6/16-6/30       13.0     0.312   │   12/16-12/31       0.0       0.104
                                                                    -----
    EI DIST.: 86         FREEZE-FREE DAYS: 140    AVERAGE ANNUAL K:  0.262
     R VALUE: 90      Kmin = 0.104 on 9/11     Kmax = 0.714 on 4/24
 ──────────────────────────────< Esc exits >──────────────────────────
Tab  Esc F1   F2  F3   F4   F6   F9
FUNC esc help clr cont call list info
```

```
       File          Exit          Help          Screen
 ─────────────< Create/Edit City Database Set SWCS1.02 >─────────────

   city code: 23003    city: MORRIS_____________         state: MN
   total P: 23.9"      EI curve #: 86         Freeze-Free days/year: 140
   elevation: 0        10 yr EI: 80                      R factor: 90
 ──────Mean P─────────────Tav (deg. F)───────────────%EI────────────%EI──────
        1: 0.69            1: 10                  1: 0           13: 36
        2: 0.72            2: 15                  2: 0           14: 49
        3: 1.15            3: 26.5                3: 0           15: 63
        4: 2.45            4: 40                  4: 0           16: 77
        5: 2.91            5: 57                  5: 0           17: 90
        6: 3.91            6: 66                  6: 0           18: 95
        7: 3.29            7: 72                  7: 1           19: 98
        8: 3.13            8: 71                  8: 2           20: 99
        9: 1.91            9: 60                  9: 3           21: 100
       10: 1.85           10: 50                 10: 6           22: 100
       11: 1.13           11: 30                 11: 11          23: 100
       12: 0.74           12: 17                 12: 23          24: 100

 ──────────────< F7 Saves, Esc Returns to CITY Main Menu >──────────────
Tab  Esc F1   F2  F7   F9   Del
FUNC esc help clr save info del
```

Figure 3-7. Computer screen showing calculated semimonthly K values for a Barnes loam soil near Morris, Minnesota (R = 90, K_{nom} = 0.28, freeze-free days = 140, Δt = 140).

```
        File            Exit            Help            Screen
┌─────────────────< Seasonally Variable K Factor SWCS1.02 >──────────────────┐
│    city code: 42003   MEMPHIS              TN        estimated K: 0.498     │
│ hyd. group: 1               % surface covered by rock fragments: 0          │
│ soil series: Loring        surface texture: Sicl                            │
│───DATE──────────%EI────────K────────┬─────DATE ──────────%EI────────K───────│
│  1/1-1/15        3.0       0.747    │    7/1-7/15          6.0      0.281   │
│  1/16-1/31       3.0       0.738    │    7/16-7/31         6.0      0.258   │
│  2/1-2/15        3.0       0.673    ↓    8/1-8/15          4.0      0.297   │
│  2/16-2/28       4.0       0.617    °    8/16-8/31         4.0      0.34    │
│  3/1-3/15        4.0       0.572    °    9/1-9/15          3.0      0.393   │
│  3/16-3/31       4.0       0.524    °    9/16-9/30         3.0      0.45    │
│  4/1-4/15        6.0       0.477    °    10/1-10/15        3.0      0.515   │
│  4/16-4/30       6.0       0.437    °    10/16-10/31       2.0      0.59    │
│  5/1-5/15        5.0       0.401    °    11/1-11/15        4.0      0.681   │
│  5/16-5/31       6.0       0.367    °    11/16-11/30       4.0      0.747   │
│  6/1-6/15        5.0       0.335    °    12/1-12/15        3.0      0.747   │
│  6/16-6/30       6.0       0.307    °    12/16-12/31       3.0      0.747   │
│                                                                     -----   │
│   EI DIST.: 106        FREEZE-FREE DAYS: 237   AVERAGE ANNUAL K:    0.478   │
│    R VALUE: 300     Kmin = 0.258 on 7/23     Kmax = 0.747 on 1/21           │
└──────────────────────────────< Esc exits >─────────────────────────────────┘
Tab  Esc F1   F2  F3   F4   F6   F9
FUNC esc help clr cont call list info
```

```
        File            Exit            Help            Screen
┌─────────────────< Create/Edit City Database Set SWCS1.02 >─────────────────┐
│                                                                            │
│  city code: 42003    city: MEMPHIS_____________           state: TN       │
│  total P: 51.6"      EI curve #: 106            Freeze-Free days/year: 237 │
│  elevation: 263      10 yr EI: 90                           R factor: 300  │
│─────Mean P──────────────Tav (deg. F)────────────────────%EI─────────%EI─────│
│      1: 4.61            1: 41.6                      1: 0          13: 55  │
│      2: 4.33            2: 44.5                      2: 3          14: 61  │
│      3: 5.44            3: 52                        3: 6          15: 67  │
│      4: 5.77            4: 61.75                     4: 9          16: 71  │
│      5: 5.06            5: 70.05                     5: 13         17: 75  │
│      6: 3.58            6: 78.3                      6: 17         18: 78  │
│      7: 4.03            7: 81.2                      7: 21         19: 81  │
│      8: 3.74            8: 80.25                     8: 27         20: 84  │
│      9: 3.62            9: 74.25                     9: 33         21: 86  │
│     10: 2.37           10: 63.55                    10: 38         22: 90  │
│     11: 4.17           11: 50.6                     11: 44         23: 94  │
│     12: 4.85           12: 43.25                    12: 49         24: 97  │
│                                                                            │
└──────────────────< F7 Saves, Esc Returns to CITY Main Menu >───────────────┘
Tab  Esc F1   F2  F7   F9   Del
FUNC esc help clr save info del
```

Figure 3-8. Computer screen showing calculated semimonthly K values for a Loring silty clay loam soil near Holly Springs, Mississippi (R = 300, K_{nom} = 0.50, freeze-free days = 237, Δt = 183). Nearby Memphis climate data used in Holly Springs.

CHAPTER 4. SLOPE LENGTH AND STEEPNESS FACTORS (LS)

Principal contributors:

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G.R. Foster
G.A. Weesies

CHAPTER 4. CONTENTS

The effect of topography on erosion in RUSLE is accounted for by the LS factor. Erosion increases as slope length increases, and is considered by the slope length factor (L). Slope length is defined as the horizontal distance from the origin of overland flow to the point where either (1) the slope gradient decreases enough that deposition begins or (2) runoff becomes concentrated in a defined channel (Wischmeier and Smith 1978). Surface runoff will usually concentrate in less than 400 ft, which is a practical slope-length limit in many situations, although longer slope lengths of up to 1,000 ft are occasionally found. Unless the surface has been carefully graded into ridges and furrows that maintain flow for long distances, few slope lengths as long as 1,000 ft should be used in RUSLE. Slope length is best determined by pacing or measuring in the field. For steep slopes, these lengths should be converted to horizontal distance for use in RUSLE. Slope lengths estimated from contour maps are usually too long because most maps do not have the detail to indicate all concentrated flow areas that end RUSLE slope lengths. Figure 4-1 illustrates some typical slope lengths. Hints and guidelines for choosing slope lengths are given in a following section.

The slope steepness factor (S) reflects the influence of slope gradient on erosion. Slope is estimated in the field by use of an inclinometer, Abney level, or similar device. Slope may be estimated from contour maps having 2-ft contour intervals if considerable care is used.

Both slope length and steepness substantially affect sheet and rill erosion estimated by RUSLE. The effects of these factors have been evaluated separately in research using uniform-gradient plots. However, in erosion prediction, the factors L and S are usually evaluated together, and values can be selected from tables 4-1, 4-2, 4-3, or 4-4 for uniform slopes. The following sections give the relationships used to develop these tables. Also, a section explains how to apply RUSLE to nonuniform slopes.

SLOPE LENGTH FACTOR (L)

Plot data used to derive the slope length factor (L) have shown that average erosion for the slope length λ (in ft) varies as

$$L = (\lambda/72.6)^m \qquad [4\text{-}1]$$

where 72.6 = the RUSLE unit plot length in ft and m = a variable slope-length exponent (Wischmeier and Smith 1978). The slope length λ is the horizontal projection, not distance parallel to the soil surface.

The slope-length exponent m is related to the ratio β of rill erosion (caused by flow) to interrill erosion (principally caused by raindrop impact) by the following equation (Foster et al. 1977):

$$m = \beta/(1 + \beta) \qquad [4\text{-}2]$$

Values for the ratio β of rill to interrill erosion for conditions when the soil is moderately susceptible to both rill and interrill erosion were computed from (McCool et al. 1989)

$$\beta = (\sin \theta/0.0896) \,/\, \left[3.0(\sin \theta)^{0.8} + 0.56\right] \qquad [4\text{-}3]$$

where θ = slope angle. Given a value for β, a value for the slope-length exponent m is calculated from equation [4-2].

The middle column in table 4-5, calculated from equations [4-3] and [4-2], gives values for m that are typical of agricultural fields in seedbed condition. When runoff, soil, cover, and management conditions indicate that the soil is highly susceptible to rill erosion, the exponent m should be increased as shown in the right column of table 4-5. This condition is most likely to occur on steep, freshly prepared construction slopes. These values for m were determined by doubling the β values from equation [4-3] before applying equation [4-2].

Conversely, when the conditions favor less rill erosion than interrill erosion, m should be decreased as shown in the left column of table 4-5. Values for m and LS for rangelands are usually taken from tables for the low ratio of rill to interrill erosion; those values were computed by halving the β values from equation [4-3] before applying equation [4-2]. Values in table 4-5 are based on an analysis by McCool et al. (1989).

When deposition occurs in furrows between ridges and in depressions, soil loss is independent of slope length; therefore the slope-length exponent is zero. Chapter 6 on the RUSLE P factor describes how to apply RUSLE to these conditions.

The slope-length exponent for the erosion of thawing, cultivated soils by surface flow (common in the Northwestern Wheat and Range Region described in ch. 2) differs from the values given in table 4-5. For the erosion of thawing soil by surface flow alone (McCool et al. 1989, 1993), a constant value of 0.5 should be used for the slope length exponent m, and LS values from table 4-4 should be used. When runoff on thawing soils is accompanied by rainfall sufficient to cause significant interrill erosion, values from table 4-5 for the low ratio of rill to interrill erosion should be used for the slope-length exponent m, and LS values from table 4-1 should be used.

SLOPE STEEPNESS FACTOR (S)

Soil loss increases more rapidly with slope steepness than it does with slope length. The slope steepness factor (S) is evaluated from (McCool et al. 1987)

$$S = 10.8 \sin \theta + 0.03 \qquad s < 9\% \qquad [4\text{-}4]$$

$$S = 16.8 \sin \theta - 0.50 \qquad s \geq 9\% \qquad [4\text{-}5]$$

Equation [4-5] is based on the assumption that runoff is not a function of slope steepness, which is strongly supported by experimental data for steepness greater than about 9%. The extent of the effect of slope on runoff is highly variable on cultivated soils. Runoff is assumed to be unaffected by slope steepness on rangelands not recently treated with mechanical practices such as ripping. The effect of slope on runoff and erosion as a result of mechanical disturbance is considered in the support practices factor (P) (ch. 6).

McIsaac et al. (1987a) examined soil-loss data from several experiments on disturbed lands at slopes of up to 84%. They recommended an equation of a form similar to that of equations [4-4] and [4-5]. Their coefficient of sin θ was a range that encompassed equations [4-4] and [4-5]. Thus these equations should also be valid for disturbed-land applications.

Equations [4-4] and [4-5] are not applicable to slopes shorter than 15 ft. For those slopes, the following equation should be used to evaluate S (McCool et al. 1987):

$$S = 3.0 (\sin \theta)^{0.8} + 0.56 \qquad [4\text{-}6]$$

This equation applies to conditions where water drains freely from the end of the slope.

For the slope steepness factor given by equation [4-6], it is assumed that rill erosion is insignificant on slopes shorter than 15 ft and that interrill erosion is independent of slope length. Therefore, equation [4-6] should not be applied to slopes where rill erosion is expected to occur. Rill erosion is assumed to begin with a slope length of 15 ft, although it will occur on shorter slopes that are especially susceptible. Conversely, rill erosion will not begin until longer slope lengths are reached on soils that are consolidated and resistant to detachment by flow.

When recently tilled soil is thawing, in a weakened state, and subjected primarily to surface flow, the following equations for S of McCool et al. (1987, 1993) should be used:

$$S = 10.8 \sin \theta + 0.03 \qquad s < 9\% \qquad [4\text{-}7]$$

$$S = (\sin \theta \,/\, 0.0896)^{0.6} \qquad s \geq 9\% \qquad [4\text{-}8]$$

Equations [4-7] and [4-8] were used to construct table 4-4.

TOPOGRAPHIC FACTOR (LS)

The combined LS factor in RUSLE represents the ratio of soil loss on a given slope length and steepness to soil loss from a slope that has a length of 72.6 ft and a steepness of 9%, where all other conditions are the same. LS values are not absolute values but are referenced to a value of 1.0 at a 72.6-ft slope length and 9% steepness.

Procedures are developed in this section for predicting soil loss on uniform slopes, where steepness is the same over their entire length; on irregular or nonuniform slopes that may be concave, convex, or complex; and on a particular segment of a slope.

LS Factor Values for Uniform Slopes

Tables 4-1, 4-2, 4-3, and 4-4 give LS values for uniform slopes. These tables should be used for RUSLE-type slopes with a fairly uniform surface. Table 4-1 is used for rangeland and pasture where the ratio of rill to interrill erosion is low. Table 4-2 is used for cropland where the ratio of rill to interrill erosion is moderate. Table 4-3 is used for construction sites where the ratio of rill to interrill erosion is high and the soil has a strong tendency to rill. Table 4-4 is used for thawing soil where most of the erosion is caused by surface flow.

In tables 4-1, 4-2, and 4-3 for slopes longer than 15 ft, S is calculated from equations [4-4] and [4-5]. For slope lengths of 3-15 ft and steepness greater than or equal to 9%, LS values were calculated for the 3-ft slope length using the short-slope equation [4-6] for S and equations [4-3], [4-2], and [4-1] with λ = 15 ft for L. Then for a given slope length of 3-15 ft and a given steepness, a linear relationship (based on the logarithm of length) was used to interpolate between the logarithm of LS at 3 ft and the logarithm of LS at 15 ft to provide intermediate LS values. For slopes of less than 9%, equation [4-4] was used for S, and equations [4-3], [4-2], and [4-1] with λ = 15 ft were used for L. The short-slope equation [4-6] was not used because for very low slopes, the criterion of free draining would not be met. The inapplicability of equation [4-6] is illustrated by the fact that for very low slopes, the use of equation [4-6] indicates a larger LS value at 3 ft than does the use of equation [4-4] at 20 ft.

The range of LS values for slope lengths of 15-1,000 ft is much greater in table 4-3 than in table 4-1, indicating that the range in L is smaller when interrill erosion is dominant than when rill erosion is dominant. Use of the

72.6-ft slope length and 9% steepness as unit conditions in RUSLE leads to the unexpected result that LS values on short slopes for highly erodible conditions (table 4-3) are smaller than those for less erodible conditions (table 4-1). The difference in overall soil loss is accounted for in the K and C factors. Conditions where soil loss varies little with slope length generally have relatively low C-factor values: less than 0.15. Conditions where soil loss varies greatly with slope length typically have high C-factor values. No LS values for slopes shorter than 15 ft are given in table 4-4. At this time, there are no data to use to develop relationships for short slopes under thawing soil conditions.

Irregular and Segmented Slopes

The shape of a slope affects the average soil loss and the soil loss along the slope. For example, the average soil loss from a convex slope can easily be 30% greater than that for a uniform slope with the same steepness as the average steepness of the convex slope. The difference in soil loss is much greater for maximum erosion on the slopes. The average erosion on a concave slope that does not flatten enough to cause deposition is less than that on a uniform slope that is equivalent to the average concave-slope steepness. Maximum erosion along a concave slope, which occurs about one-third of the way along the slope, may nearly equal the maximum erosion on a uniform slope. Therefore, when the slope shape is significantly curved, use of the procedure for an irregularly shaped slope (outlined below) should be considered (Foster and Wischmeier 1974).

If a nonuniform slope of unit width is broken into a number of segments, each with similar characteristics, an equation for sediment yield from the ith segment is (Foster and Wischmeier 1974)

$$E_i = RK_iC_iP_iS_i\left(\lambda_i^{m+1} - \lambda_{i-1}^{m+1}\right) / (72.6)^m \qquad [4\text{-}9]$$

where

E_i = sediment yield from ith segment from top of slope,
R = rainfall and runoff factor,
K_i = soil erodibility for ith segment,
C_i = cover-management factor for ith segment,
P_i = support practice factor for ith segment,
S_i = slope steepness factor for ith segment, and
λ_i = length (ft) from top of slope to lower end of ith segment.

The soil loss per unit area, A_i, for the ith segment is then the sediment yield from that segment divided by the segment length, as follows:

$$A_i = RK_iC_iP_iS_i\left(\lambda_i^{m+1} - \lambda_{i-1}^{m+1}\right) / \left(\lambda_i - \lambda_{i-1}\right) (72.6)^m \qquad [4\text{-}10]$$

The term $S_i \left(\lambda_i^{m+1} - \lambda_{i-1}^{m+1}\right) / \left(\lambda_i - \lambda_{i-1}\right) (72.6)^m$ in equation [4-10] is the effective LS for the segment.

These relationships are applicable to any slope that meets the criteria for the application of RUSLE. The slope segments can be of unequal length. Computations with unequal slope lengths are most easily handled with a digital computer, for example, by use of the RUSLE computer program. However, to illustrate application of the method, slopes of equal segment length will be used. The term for effective segment LS becomes

$$\begin{aligned} LS_i &= S_i\left\{(ix)^{m+1} - [(i-1)x]^{m+1}\right\} / \left[ix - (i-1)x\right] (72.6)^m \\ &= S_i x^m \left[i^{m+1} - (i-1)^{m+1}\right] / (72.6)^m \end{aligned} \qquad [4\text{-}11]$$

where

LS_i = effective LS for ith segment, and
x = length in ft of each segment.

An additional relationship that proves useful is the soil loss per unit area, A_i, from any segment of a uniform slope, as follows:

$$A_i = RK_iC_iP_iS_i\left\{(ix)^{m+1} - [(i-1)x]^{m+1}\right\} / (72.6)^m \; x \qquad [4\text{-}12]$$

The total soil loss per unit area from a uniform slope of n segments of length x is

$$A = RKCPS(nx)^m \; / \; (72.6)^m \qquad [4\text{-}13]$$

If equal RKCP values along the slope are assumed, the ratio of soil loss from any segment to soil loss from the total slope is

$$A_i/A = \left\{ \left[(ix)^{m+1} - ((i-1)x)^{m+1}\right] / (72.6)^m \ x \right\} \cdot \left\{(72.6)^m/(nx)^m\right\}$$
$$= \left[i^{m+1} - (i-1)^{m+1}\right] / (n)^m \qquad [4\text{-}14]$$

Values of A_i/A for a range of values of m appear in table 4-6.

The simplest irregular-slope case is for soil and cover to be constant along the slope. To apply the irregular-slope procedure, the convex, concave, or complex slope is divided into equal-length segments and the segments are listed in the order in which they occur on the slope, beginning at the upper end (as shown in table 4-7). The number of segments depends on how many are required to treat each segment as uniform for practical purposes. In many situations, three segments are sufficient, and more than five are seldom needed.

The segments and their slopes are listed in order from the top of the slope, columns 1 and 2 of table 4-7. Then the LS values for the entire slope length at the segment slopes are selected from tables 4-1, 4-2, 4-3, or 4-4 and are listed in column 3. In this example, a moderate ratio of rill to interrill erosion is assumed; thus table 4-2 is used. The ratio of soil loss from the segment to total soil loss is selected from table 4-6, based on the m value from table 4-5, and listed in column 4. Interpolation may be required. (If the evaluation is from a thawing soil, an m value of 0.5 is used.) Column 5 is the product of columns 3 and 4 divided by the number of segments. The total of the values in column 5 is the LS value for the entire slope. The segment LS is given in column 6 as the product of columns 3 and 4. This value will predict average soil loss in a given segment.

In this example, the LS value that gives the average soil loss for the convex slope is 3.76 versus a value of 2.84 for a 400-ft-long uniform slope with a gradient of 10%, the average steepness of the convex slope. Average soil loss on the convex slope is about 32% greater than that on the uniform slope.

The maximum erosion in this example occurs at the end of both the uniform and convex slopes. From table 4-7, the maximum segment LS is 7.58 for the convex slope and (2.84 x 1.38 =) 3.92 for the uniform slope (enter table 4-6 with an exponent value of 0.52 for segment 3). That is, soil loss over the lower third of the convex slope is almost double that for the lower third of the uniform slope.

For a concave slope of the same length with the segments in reverse order, the values in column 3 would be listed in reverse order. The data for a concave slope are given in table 4-8. The weighted average LS for the concave slope is about 15% smaller than that for an equivalent uniform slope. The maximum soil loss for a segment, as indicated by the segment LS values in column 6, is greatest from the middle segment of the slope. Maximum erosion on this segment is about 76% of maximum erosion on the lower length of the uniform slope. Average soil loss on the concave slope is about 85% of that on the uniform slope.

CHANGES IN SOIL TYPE OR COVER ALONG THE SLOPE

The procedure for irregular slopes can include the evaluation of changes in soil type along a slope. The values in column 5 of table 4-7 or 4-8 are multiplied by the respective values of the soil erodibility factor (K) before summing. The procedure is illustrated in table 4-9. In the example, by use of the data from table 4-7, the erosion on the last segment is seen to be 14 times that on the first segment, whereas it was only 10 times that when K was uniform along the convex slope. This example illustrates how erosion can be great if an erodible soil occurs on the lower end of a convex slope. Average soil loss for the convex slope, based on the sum of values in column 6, is 45% greater than that estimated for the average K (0.32) on an equivalent uniform slope.

Within limits, the procedure can be further extended to account for changes in the C and P factors along the slope by adding a column of segment C and P values. The procedure applies to the segments experiencing net erosion but not to the segments experiencing net deposition. The amount of deposition cannot be estimated by RUSLE.

The soil loss from any segment of a slope can be estimated by the irregular-slope procedure previously presented (column 6 in tables 4-7 and 4-8 is the segment LS). This value can be used with the pertinent RKCP value for the slope to estimate average soil loss from the particular segment. Similarly, column 7 in table 4-9 is the segment KLS and can be used with the RCP value for the slope to estimate average soil loss from the particular segment.

ALTERNATIVE METHOD FOR ESTIMATING LS FOR A SEGMENT

One application of the irregular-slope procedure is to estimate soil loss on a slope segment and compare that against a soil-loss-tolerance value. The irregular-slope procedure was illustrated previously to show how average erosion for segments along a slope can be computed.

A modification of the procedure can also be used. The slope is divided into equal-length segments like the three segments for the convex slope in table 4-7. Assume that a soil-loss estimate is needed for segment 3. Find the LS value from table 4-2 for a uniform slope having the steepness of the segment and total slope length to the lower end of the segment (400 ft). In this example, this LS value is 5.34. Multiply this value by the soil loss factor, 1.42, in table 4-6 using the value for the third segment in a three-segment slope. The product is 7.58, which is the LS value to use for computing erosion for the segment.

Computation of LS for the second segment requires obtaining the LS value for the uniform slope based on the segment steepness and the length to the lower end of the particular segment (267 ft). The LS value is 2.29 in this example. The third segment has no effect on what happens on the upslope segments; when the user is working on the second segment with this approach, the problem becomes a two-segment slope. Therefore, the factor value, 1.30, chosen from table 4-6 is for the end segment of a two-segment slope. The LS for the second segment is (2.29 x 1.30 =) 2.98, which is the same value obtained earlier in table 4-7.

RELATION OF SOIL-LOSS-TOLERANCE VALUES TO SEGMENT EROSION

Soil-loss-tolerance values given in soil surveys are based on average soil loss along a uniform slope (Schertz 1983). Even on a uniform slope, soil loss on the lowest segment of the slope may be as much as 70% greater than the average value for the slope. Slope-average soil-loss-tolerance values must first be adjusted before soil-loss values for segments along an irregular slope are compared to them. This adjustment takes into account the position on the slope and is made by multiplying the slope-average soil-loss-tolerance value by soil-loss-factor values from table 4-6. The procedure is illustrated for a uniform slope on cropland where RKCP = 1.0 is assumed and the soil-loss- tolerance value, T, is 2.0 ton$\cdot$ acre$^{-1}\cdot$ yr^{-1}. The adjusted soil-loss-tolerance values for three segments along a 10% uniform slope of 400-ft length are 2.0 x 0.57 = 1.14 ton $\cdot$ acre$^{-1}\cdot$ yr^{-1} for segment 1, 2.0 x 1.05 = 2.10 ton $\cdot$ acre$^{-1}\cdot$ yr^{-1} for segment 2, and 2.0 x 1.38 = 2.76 ton$\cdot$ acre$^{-1}\cdot$ yr^{-1} for segment 3. The soil-loss-adjustment factor for each segment is determined by entering table 4-5 with the appropriate slope and rill to interrill ratio, obtaining an m value (0.52 for a 10% slope and moderate rill/interrill ratio), and then selecting the appropriate factor for each segment from table 4-5. In this example, interpolation is required. The average soil loss for this slope is the product of (LS)(RKCP) or (2.84)(1.0) = 2.84 ton $\cdot$ acre$^{-1}\cdot$ yr^{-1}. Soil-loss values along the slope are found by multiplying this value by the same factor values from table 4-6 that are used to adjust T values for position on the slope. These products give the values of 1.62, 2.98, and 3.92 ton$\cdot$ acre$^{-1}\cdot$ yr^{-1} for segments 1, 2, and 3, respectively. The soil-loss values are now uniform with respect to the adjusted soil-loss-tolerance values along the slope.

For the convex slope in table 4-7, the initial adjusted T values are 1.28, 2.10, and 2.84 ton$\cdot$ acre$^{-1}\cdot$ yr^{-1} for segments 1, 2, and 3, respectively. The mean of these initial segment values is 2.07 ton$\cdot$ acre$^{-1}\cdot$ yr^{-1}, greater than the tolerance for a uniform slope of steepness equal to the average of the segment steepness. Therefore, the user should multiply each segment adjusted T value by the ratio of 2.00/2.07 = 0.96 to produce an average slope tolerance of 2.0 ton$\cdot$ acre$^{-1}\cdot$ yr^{-1}. The final segment adjusted tolerance values are then 1.23, 2.03, and 2.74 ton$\cdot$ acre$^{-1}\cdot$ yr^{-1} for segments 1, 2, and 3, respectively, whereas the soil-loss values for the segments are 0.72, 2.98, and 7.58 ton$\cdot$ acre$^{-1}\cdot$ yr^{-1}. The user should note that soil loss on the upper segment is much less than the adjusted T value;

therefore, erosion on the first segment is considered to be within allowable limits. However, the soil loss on the last segment is much greater than the adjusted T value, so soil loss is judged to be excessive on the last segment of the convex slope.

For the concave slope in table 4-8, the initial adjusted T values are 1.06, 2.10, and 2.60 ton· $acre^{-1}$· yr^{-1} for segments 1, 2, and 3, respectively. The mean of these initial segment values is 1.92 ton· $acre^{-1}$· yr^{-1}, less than the tolerance for a uniform slope of steepness equal to the average of the segment steepness. Therefore, the user should multiply each initial segment adjusted T value by the ratio of 2.00/1.92 = 1.04 to produce an average slope tolerance of 2.00 ton· $acre^{-1}$· yr^{-1}. The final segment adjusted tolerance values are then 1.10, 2.19, and 2.71 ton· $acre^{-1}$· yr^{-1} for segments 1, 2, and 3, respectively, whereas the soil losses along the slope are 2.83, 2.98, and 1.47 ton· $acre^{-1}$· yr^{-1}. The soil-loss values for the upper two segments exceed the adjusted T value, and management practices are chosen to reduce these values to the adjusted T value.

GUIDES FOR CHOOSING SLOPE LENGTHS

In training sessions, more questions are asked about slope length than about any other RUSLE factor. Slope length is the factor that involves the most judgment, and length determinations made by users vary greatly. Figure 4-1 illustrates the major slope-length situations that are found in the field. However, additional guides are useful, especially for rangelands and forest lands.

Actually, an infinite number of slope lengths exist in the field. To apply RUSLE, erosion can be calculated for several of them and the results averaged according to the area represented by each slope length. Sometimes a particular position on the landscape is chosen as the location for a slope length. To establish the ends of the slope length, the user walks upslope from that position, moving perpendicular to the contour, until the origin of overland flow is reached. Often this point is not at the top of the hill but at a divide down the nose of a ridge (illustrated in fig. 4-2).

The lower end of the slope length is located by walking downslope perpendicular to the contour until a broad area of deposition or a natural or constructed waterway is reached. These waterways are not necessarily eroded or incised channels, and this lack of channels can make it difficult to determine the end of slope. One aid is to visualize the locations on the landscape where eroded channels or gullies would naturally form. Figure 4-2 illustrates one area where such waterways are located.

If a slope flattens enough near its end, deposition may occur. When erosion and deposition rates are low and erosion has not recently occurred, deposition begins at the point where slope has decreased to about 5%. Deposition does not necessarily occur everywhere a slope flattens.

Sometimes slope decreases as shown in figure 4-3. On those slopes, deposition can end and erosion can occur on the lower end of the slope. To approximate where deposition ends, the user should do the following: First calculate the ratio of the slope steepness at the end to the slope steepness where deposition begins. Subtract that ratio from 1.0, multiply that difference by the distance from where deposition begins to the end of the slope, and add that product to the distance where deposition begins. To illustrate, assume a 400-ft-long slope with a 2% slope at the end. Assume that deposition begins at 250 ft, where the slope is 5%.

The ratio of the slope steepness is 0.40, and the distance from where deposition begins to the end of the slope is 150 ft. The location where deposition ends is 250+(1.0-0.40)(150) = 340 ft. This procedure, an approximation to results of CREAMS simulations, is for gently curving slopes. When the change of slope is very abrupt, deposition may occur over only a 20- to 40-ft distance.

In the case just described, the water is assumed to flow uniformly as broad sheet flow over the depositional area and onto the downslope eroding area, or from a relatively flat area at the top of the slope onto a steep area. The distance to the origin of flow must be considered in computing soil loss. To compute average erosion for the slope, only the segments experiencing erosion are used in the computations. In this case, RUSLE does not compute sediment yield for the slope. Of course, a diversion ditch across the slope would end the slope length and a new one would begin immediately below the ditch. Also, broad sheet flow does not occur in natural riparian vegetation.

All the situations discussed previously have been simplified. A few specific examples may help the user visualize field slope length. Figure 4-4 is a photo of rill erosion on a steep small-grain field in the Pacific Northwest. Although the small watershed is concave, a relatively straight, closely spaced rill pattern has resulted on most of the slope. The pattern is from the top to the bottom of the slope or to the flow concentration at the bottom of the swale. For these particular conditions alone, slope length can be obtained fairly accurately from U.S. Geological Survey (USGS) 7½-min contour maps with a 20-ft contour interval.

Figure 4-5A shows a row cropped watershed after a series of storms during the early stages of crop growth. The concentrated flow channels are spaced rather closely together, leading to fairly short slope lengths for RUSLE computation. Even with the 1-ft contour interval map in figure 4-5B, realistic slope lengths are difficult to estimate without the aerial photograph for guidance.

The effect of different crop managements on the upper and lower portions of a slope is illustrated in figure 4-6. The boundary between the two managements occurs at about the middle of the slope. Presence of the snow drift on the upper part of the slope causes measured slope length to be a poor predictor of soil loss; the distance to the top of the ridge does not provide a realistic estimate of the length that actually provides the snowmelt. Other than the area where a drill wheel track diverts the runoff and creates a flow concentration, the rill pattern is fairly straight and closely spaced. The bottom of the slope where the runoff collects into a larger channel, or deposits sediment at the toe of the slope, is not shown.

Determination of slope lengths on rangeland and forested watersheds is generally more difficult than determination of slope lengths on cropland because of the permanent vegetation and the frequently irregular topography of the former. Three selected small watersheds from the Lydle Gulch and Blacks Creek drainages east of Boise, Idaho, are shown on a portion of the 7½-min USGS quad sheet for Indian Creek Reservoir in figure 4-7. Figure 4-8 is an example of a steep rangeland watershed with little shrubby permanent vegetation. Because of the steepness of the watershed, there are few depositional areas. However, the hillslopes are rough and the ridgetops rounded, slightly complicating the determination of slope length. Even for this simple case, the determination of slope lengths by inspecting a 7½-min quad sheet with a 20-ft contour interval would lead to slope lengths longer than those determined in the field or from a low-level aerial photograph. The slopes of the transects are irregular, but to conserve space in this publication, LS in figure 4-8 was calculated from the total horizontal slope length and total fall.

Figure 4-9 is a photograph of a more complex rangeland watershed. The slope is flatter than that on the area in figure 4-8, and numerous large mounds make the topography very uneven. The drainage channels are rather broad, vegetated, and poorly defined, and the watershed boundaries are difficult to delineate. The shrubby permanent vegetation is more prevalent than that on figure 4-8, obscuring the flow paths on aerial or oblique photographs. Slope lengths are best determined by field inspection. The use of maps with even a 2-ft contour interval will lead to slope lengths much longer than those determined in the field.

The complex and irregular rangeland watershed that appears on figure 4-10 exemplifies conditions frequently found in the field. The watershed is of low slope, has undulating topography with numerous hummocks or mounds, and has shrubby permanent vegetation that masks the drainages. The determination of slope lengths even by field inspection is difficult, particularly when the grass cover is at its maximum and not yet reduced by grazing.

Figure 4-10 shows a complicated flow system where shrubs, grass clumps, and litter are isolated in hummocks scattered over rangeland, and in effect where water flows down a local slope to a locally concentrated flow area. This flow system may be treated as follows: If flow patterns around and among the hummocks are basically parallel, do not treat the flow concentrations as the end of a short slope length. Choose slope lengths by visualizing the surface as being smooth without the hummocks. If, however, major deposition occurs upstream of the hummocks and/or the flow pattern meanders without a direction, treat the slope lengths as short. Note that on figure 4-10, some of the transects pass through clumps of shrubby vegetation.

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Table 4-1.
Values for topographic factor, LS, for low ratio of rill to interrill erosion.[1]

Slope (%)	Horizontal slope length (ft)															
	<3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
0.5	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09	0.09
1.0	0.12	0.12	0.12	0.12	0.12	0.13	0.13	0.14	0.14	0.15	0.15	0.15	0.15	0.16	0.16	0.17	0.17
2.0	0.20	0.20	0.20	0.20	0.20	0.21	0.23	0.25	0.26	0.27	0.28	0.29	0.30	0.31	0.33	0.34	0.35
3.0	0.26	0.26	0.26	0.26	0.26	0.29	0.33	0.36	0.38	0.40	0.43	0.44	0.46	0.48	0.52	0.55	0.57
4.0	0.33	0.33	0.33	0.33	0.33	0.36	0.43	0.46	0.50	0.54	0.58	0.61	0.63	0.67	0.74	0.78	0.82
5.0	0.38	0.38	0.38	0.38	0.38	0.44	0.52	0.57	0.62	0.68	0.73	0.78	0.81	0.87	0.97	1.04	1.10
6.0	0.44	0.44	0.44	0.44	0.44	0.50	0.61	0.68	0.74	0.83	0.90	0.95	1.00	1.08	1.21	1.31	1.40
8.0	0.54	0.54	0.54	0.54	0.54	0.64	0.79	0.90	0.99	1.12	1.23	1.32	1.40	1.53	1.74	1.91	2.05
10.0	0.60	0.63	0.65	0.66	0.68	0.81	1.03	1.19	1.31	1.51	1.67	1.80	1.92	2.13	2.45	2.71	2.93
12.0	0.61	0.70	0.75	0.80	0.83	1.01	1.31	1.52	1.69	1.97	2.20	2.39	2.56	2.85	3.32	3.70	4.02
14.0	0.63	0.76	0.85	0.92	0.98	1.20	1.58	1.85	2.08	2.44	2.73	2.99	3.21	3.60	4.23	4.74	5.18
16.0	0.65	0.82	0.94	1.04	1.12	1.38	1.85	2.18	2.46	2.91	3.28	3.60	3.88	4.37	5.17	5.82	6.39
20.0	0.68	0.93	1.11	1.26	1.39	1.74	2.37	2.84	3.22	3.85	4.38	4.83	5.24	5.95	7.13	8.10	8.94
25.0	0.73	1.05	1.30	1.51	1.70	2.17	3.00	3.63	4.16	5.03	5.76	6.39	6.96	7.97	9.65	11.04	12.26
30.0	0.77	1.16	1.48	1.75	2.00	2.57	3.60	4.40	5.06	6.18	7.11	7.94	8.68	9.99	12.19	14.04	15.66
40.0	0.85	1.36	1.79	2.17	2.53	3.30	4.73	5.84	6.78	8.37	9.71	10.91	11.99	13.92	17.19	19.96	22.41
50.0	0.91	1.52	2.06	2.54	3.00	3.95	5.74	7.14	8.33	10.37	12.11	13.65	15.06	17.59	21.88	25.55	28.82
60.0	0.97	1.67	2.29	2.86	3.41	4.52	6.63	8.29	9.72	12.16	14.26	16.13	17.84	20.92	26.17	30.68	34.71

[1]Such as for rangeland and other consolidated soil conditions with cover (applicable to thawing soil where both interrill and rill erosion are significant).

Table 4-2.
Values for topographic factor, LS, for moderate ratio of rill to interrill erosion.[1]

Slope (%)	Horizontal slope length (ft) 3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.09	0.10	0.10	0.10	0.10
1.0	0.11	0.11	0.11	0.11	0.11	0.12	0.13	0.14	0.14	0.15	0.16	0.17	0.17	0.18	0.19	0.20	0.20
2.0	0.17	0.17	0.17	0.17	0.17	0.19	0.22	0.25	0.27	0.29	0.31	0.33	0.35	0.37	0.41	0.44	0.47
3.0	0.22	0.22	0.22	0.22	0.22	0.25	0.32	0.36	0.39	0.44	0.48	0.52	0.55	0.60	0.68	0.75	0.80
4.0	0.26	0.26	0.26	0.26	0.26	0.31	0.40	0.47	0.52	0.60	0.67	0.72	0.77	0.86	0.99	1.10	1.19
5.0	0.30	0.30	0.30	0.30	0.30	0.37	0.49	0.58	0.65	0.76	0.85	0.93	1.01	1.13	1.33	1.49	1.63
6.0	0.34	0.34	0.34	0.34	0.34	0.43	0.58	0.69	0.78	0.93	1.05	1.16	1.25	1.42	1.69	1.91	2.11
8.0	0.42	0.42	0.42	0.42	0.42	0.53	0.74	0.91	1.04	1.26	1.45	1.62	1.77	2.03	2.47	2.83	3.15
10.0	0.46	0.48	0.50	0.51	0.52	0.67	0.97	1.19	1.38	1.71	1.98	2.22	2.44	2.84	3.50	4.06	4.56
12.0	0.47	0.53	0.58	0.61	0.64	0.84	1.23	1.53	1.79	2.23	2.61	2.95	3.26	3.81	4.75	5.56	6.28
14.0	0.48	0.58	0.65	0.70	0.75	1.00	1.48	1.86	2.19	2.76	3.25	3.69	4.09	4.82	6.07	7.15	8.11
16.0	0.49	0.63	0.72	0.79	0.85	1.15	1.73	2.20	2.60	3.30	3.90	4.45	4.95	5.86	7.43	8.79	10.02
20.0	0.52	0.71	0.85	0.96	1.06	1.45	2.22	2.85	3.40	4.36	5.21	5.97	6.68	7.97	10.23	12.20	13.99
25.0	0.56	0.80	1.00	1.16	1.30	1.81	2.82	3.65	4.39	5.69	6.83	7.88	8.86	10.65	13.80	16.58	19.13
30.0	0.59	0.89	1.13	1.34	1.53	2.15	3.39	4.42	5.34	6.98	8.43	9.76	11.01	13.30	17.37	20.99	24.31
40.0	0.65	1.05	1.38	1.68	1.95	2.77	4.45	5.87	7.14	9.43	11.47	13.37	15.14	18.43	24.32	29.60	34.48
50.0	0.71	1.18	1.59	1.97	2.32	3.32	5.40	7.17	8.78	11.66	14.26	16.67	18.94	23.17	30.78	37.65	44.02
60.0	0.76	1.30	1.78	2.23	2.65	3.81	6.24	8.33	10.23	13.65	16.76	19.64	22.36	27.45	36.63	44.96	52.70

[1]Such as for row-cropped agricultural and other moderately consolidated soil conditions with little-to-moderate cover (not applicable to thawing soil)

Table 4-3.
Values for topographic factor, LS, for high ratio of rill to interrill erosion.[1]

Slope (%)	Horizontal slope length (ft)															
	<3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.11	0.12	0.12	0.13
1.0	0.09	0.09	0.09	0.09	0.09	0.10	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.22	0.24	0.26	0.27
2.0	0.13	0.13	0.13	0.13	0.13	0.16	0.21	0.25	0.28	0.33	0.37	0.40	0.43	0.48	0.56	0.63	0.69
3.0	0.17	0.17	0.17	0.17	0.17	0.21	0.30	0.36	0.41	0.50	0.57	0.64	0.69	0.80	0.96	1.10	1.23
4.0	0.20	0.20	0.20	0.20	0.20	0.26	0.38	0.47	0.55	0.68	0.79	0.89	0.98	1.14	1.42	1.65	1.86
5.0	0.23	0.23	0.23	0.23	0.23	0.31	0.46	0.58	0.68	0.86	1.02	1.16	1.28	1.51	1.91	2.25	2.55
6.0	0.26	0.26	0.26	0.26	0.26	0.36	0.54	0.69	0.82	1.05	1.25	1.43	1.60	1.90	2.43	2.89	3.30
8.0	0.32	0.32	0.32	0.32	0.32	0.45	0.70	0.91	1.10	1.43	1.72	1.99	2.24	2.70	3.52	4.24	4.91
10.0	0.35	0.37	0.38	0.39	0.40	0.57	0.91	1.20	1.46	1.92	2.34	2.72	3.09	3.75	4.95	6.03	7.02
12.0	0.36	0.41	0.45	0.47	0.49	0.71	1.15	1.54	1.88	2.51	3.07	3.60	4.09	5.01	6.67	8.17	9.57
14.0	0.38	0.45	0.51	0.55	0.58	0.85	1.40	1.87	2.31	3.09	3.81	4.48	5.11	6.30	8.45	10.40	12.23
16.0	0.39	0.49	0.56	0.62	0.67	0.98	1.64	2.21	2.73	3.68	4.56	5.37	6.15	7.60	10.26	12.69	14.96
20.0	0.41	0.56	0.67	0.76	0.84	1.24	2.10	2.86	3.57	4.85	6.04	7.16	8.23	10.24	13.94	17.35	20.57
25.0	0.45	0.64	0.80	0.93	1.04	1.56	2.67	3.67	4.59	6.30	7.88	9.38	10.81	13.53	18.57	23.24	27.66
30.0	0.48	0.72	0.91	1.08	1.24	1.86	3.22	4.44	5.58	7.70	9.67	11.55	13.35	16.77	23.14	29.07	34.71
40.0	0.53	0.85	1.13	1.37	1.59	2.41	4.24	5.89	7.44	10.35	13.07	15.67	18.17	22.95	31.89	40.29	48.29
50.0	0.58	0.97	1.31	1.62	1.91	2.91	5.16	7.20	9.13	12.75	16.16	19.42	22.57	28.60	39.95	50.63	60.84
60.0	0.63	1.07	1.47	1.84	2.19	3.36	5.97	8.37	10.63	14.89	18.92	22.78	26.51	33.67	47.18	59.93	72.15

[1] Such as for freshly prepared construction and other highly disturbed soil conditions with little or no cover (not applicable to thawing soil)

Table 4-4.
Values for topographic factor, LS, for thawing soils where most of the erosion is caused by surface flow.

Slope (%)	Horizontal slope length (ft)												
	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.02	0.03	0.04	0.05	0.06	0.07	0.09	0.10	0.10	0.12	0.15	0.17	0.19
0.5	0.04	0.05	0.07	0.09	0.10	0.12	0.14	0.16	0.17	0.20	0.24	0.28	0.31
1.0	0.06	0.08	0.11	0.14	0.16	0.20	0.23	0.26	0.28	0.32	0.40	0.46	0.51
2.0	0.11	0.14	0.20	0.25	0.29	0.35	0.41	0.46	0.50	0.58	0.71	0.82	0.91
3.0	0.16	0.21	0.29	0.36	0.42	0.51	0.59	0.66	0.72	0.83	1.02	1.17	1.31
4.0	0.21	0.27	0.38	0.47	0.54	0.66	0.77	0.86	0.94	1.08	1.33	1.53	1.71
5.0	0.26	0.33	0.47	0.58	0.67	0.82	0.94	1.06	1.16	1.34	1.64	1.89	2.11
6.0	0.31	0.40	0.56	0.69	0.79	0.97	1.12	1.26	1.38	1.59	1.95	2.25	2.51
8.0	0.41	0.52	0.74	0.91	1.05	1.28	1.48	1.65	1.81	2.09	2.56	2.96	3.31
10.0	0.48	0.62	0.88	1.08	1.25	1.53	1.77	1.98	2.16	2.50	3.06	3.54	3.95
12.0	0.54	0.70	0.98	1.21	1.39	1.71	1.97	2.20	2.41	2.78	3.41	3.94	4.40
14.0	0.59	0.76	1.08	1.32	1.53	1.87	2.16	2.41	2.64	3.05	3.74	4.31	4.82
16.0	0.64	0.82	1.17	1.43	1.65	2.02	2.33	2.61	2.86	3.30	4.04	4.67	5.22
20.0	0.73	0.94	1.33	1.63	1.88	2.30	2.66	2.97	3.25	3.76	4.60	5.31	5.94
25.0	0.83	1.07	1.51	1.85	2.13	2.61	3.02	3.37	3.69	4.27	5.23	6.03	6.75
30.0	0.91	1.18	1.67	2.05	2.36	2.89	3.34	3.73	4.09	4.72	5.78	6.68	7.47
40.0	1.07	1.38	1.95	2.39	2.75	3.37	3.90	4.36	4.77	5.51	6.75	7.79	8.71
50.0	1.19	1.54	2.18	2.67	3.08	3.77	4.35	4.87	5.33	6.16	7.54	8.71	9.74
60.0	1.30	1.67	2.37	2.90	3.35	4.10	4.74	5.30	5.80	6.70	8.20	9.47	10.59

Table 4-5.
Slope-length exponents (m) for a range of slopes and rill/interrill erosion classes[1]

Slope (%)	Rill/interrill ratio Low	Moderate	High
0.2	0.02	0.04	0.07
0.5	0.04	0.08	0.16
1.0	0.08	0.15	0.26
2.0	0.14	0.24	0.39
3.0	0.18	0.31	0.47
4.0	0.22	0.36	0.53
5.0	0.25	0.40	0.57
6.0	0.28	0.43	0.60
8.0	0.32	0.48	0.65
10.0	0.35	0.52	0.68
12.0	0.37	0.55	0.71
14.0	0.40	0.57	0.72
16.0	0.41	0.59	0.74
20.0	0.44	0.61	0.76
25.0	0.47	0.64	0.78
30.0	0.49	0.66	0.79
40.0	0.52	0.68	0.81
50.0	0.54	0.70	0.82
60.0	0.55	0.71	0.83

[1]Not applicable to thawing soils

Source: McCool et al. (1989).

Table 4-6.
Soil loss factor to estimate soil loss on a segment of a uniform slope.

		Slope-length exponent (m)								
Number of segments	Sequential number of segments	.05	.1	.2	.3	.4	.5	.6	.7	.8
2	1	0.97	0.93	0.87	0.81	0.76	0.71	0.66	0.62	0.57
	2	1.03	1.07	1.13	1.19	1.24	1.29	1.34	1.38	1.43
3	1	0.95	0.90	0.80	0.72	0.64	0.58	0.52	0.46	0.42
	2	1.01	1.02	1.04	1.05	1.06	1.05	1.05	1.04	1.03
	3	1.04	1.08	1.16	1.23	1.30	1.37	1.43	1.50	1.55
4	1	0.93	0.87	0.76	0.66	0.57	0.50	0.44	0.38	0.33
	2	1.00	1.00	0.98	0.96	0.94	0.92	0.88	0.85	0.82
	3	1.03	1.05	1.09	1.13	1.16	1.18	1.2	1.22	1.23
	4	1.04	1.08	1.17	1.25	1.33	1.40	1.48	1.55	1.62
5	1	0.92	0.85	0.73	0.62	0.53	0.45	0.38	0.32	0.28
	2	0.99	0.97	0.94	0.90	0.86	0.82	0.77	0.73	0.69
	3	1.01	1.03	1.04	1.05	1.06	1.06	1.06	1.05	1.03
	4	1.03	1.06	1.12	1.17	1.21	1.25	1.29	1.32	1.35
	5	1.05	1.09	1.17	1.26	1.34	1.42	1.50	1.58	1.65

Soil-loss factors = $[i^{m+1} - (i - 1)^{m+1}]/n^m$ where i = sequential number of segment, m = slope length exponent, and n = number of segments. Values are forced to give a factor total equal to number of segments. Values from RUSLE computer program may differ slightly due to round-off.

Table 4-7.
Illustration of irregular-slope procedure where only gradient changes along a 400-ft convex slope of n segments on cropland

Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6)
Segment	Gradient (%)	LS from table 4-2	Soil-loss factor from table 4-6	[1](3)· (4)/n	LS for segment (3)· (4)
1	5	1.13	0.64	0.24	0.72
2	10	2.84	1.05	0.99	2.98
3	15	5.34	1.42	2.53	7.58

[1]Total LS for slope = 3.76.

Table 4-8.
Illustration of irregular slope procedure where only gradient changes along a 400-ft concave slope of n segments on cropland

Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6)
Segment	Gradient (%)	LS from table 4-2	Soil-loss factor from table 4-6	[1](3)· (4)/n	LS for segment (3)· (4)
1	15	5.34	0.53	0.94	2.83
2	10	2.84	1.05	0.99	2.98
3	5	1.13	1.30	0.49	1.47

[1]Total LS for slope = 2.42.

Table 4-9.
Evaluation of a change in K along a 400-ft convex slope of n segments on cropland

Column (1)	Column (2)	Column (3)	Column (4)	Column (5)	Column (6)	Column (7)
Segment	Gradient (%)	LS from table 4-2	Soil-loss factor from table 4-6	K	[1](3)·(4)·(5)/n	KLS for segment (3)·(4)·(5)
1	5	1.13	0.64	0.27	0.065	0.20
2	10	2.84	1.05	0.32	0.318	0.95
3	15	5.34	1.42	0.37	0.935	2.81

[1]Total KLS for slope = 1.32.

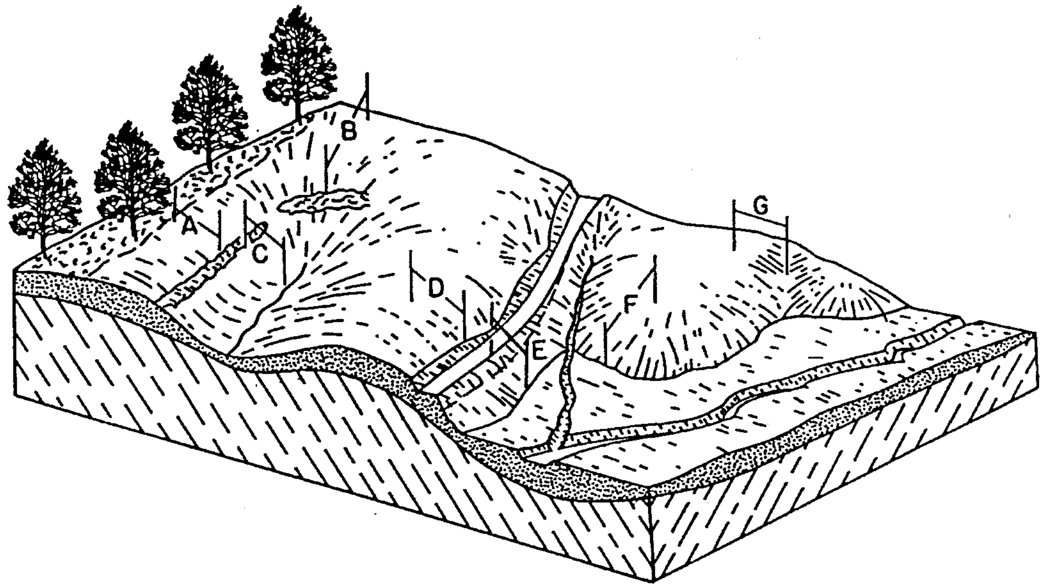


Figure 4-1. Typical slope lengths (Dissmeyer and Foster 1980). Slope A— If undisturbed forest soil above does not yield surface runoff, the top of slope starts with edge of undisturbed forest soil and extends down slope to windrow if runoff is concentrated by windrow. Slope B—Point of origin of runoff to windrow if runoff is concentrated by windrow. Slope C—From windrow to flow concentration point. Slope D—Point of origin of runoff to road that concentrates runoff. Slope E—From road to flood plain where deposition would occur. Slope F—On nose of hill, from point to origin of runoff to flood plain where deposition would occur. Slope G—Point of origin of runoff to slight depression where runoff would concentrate.

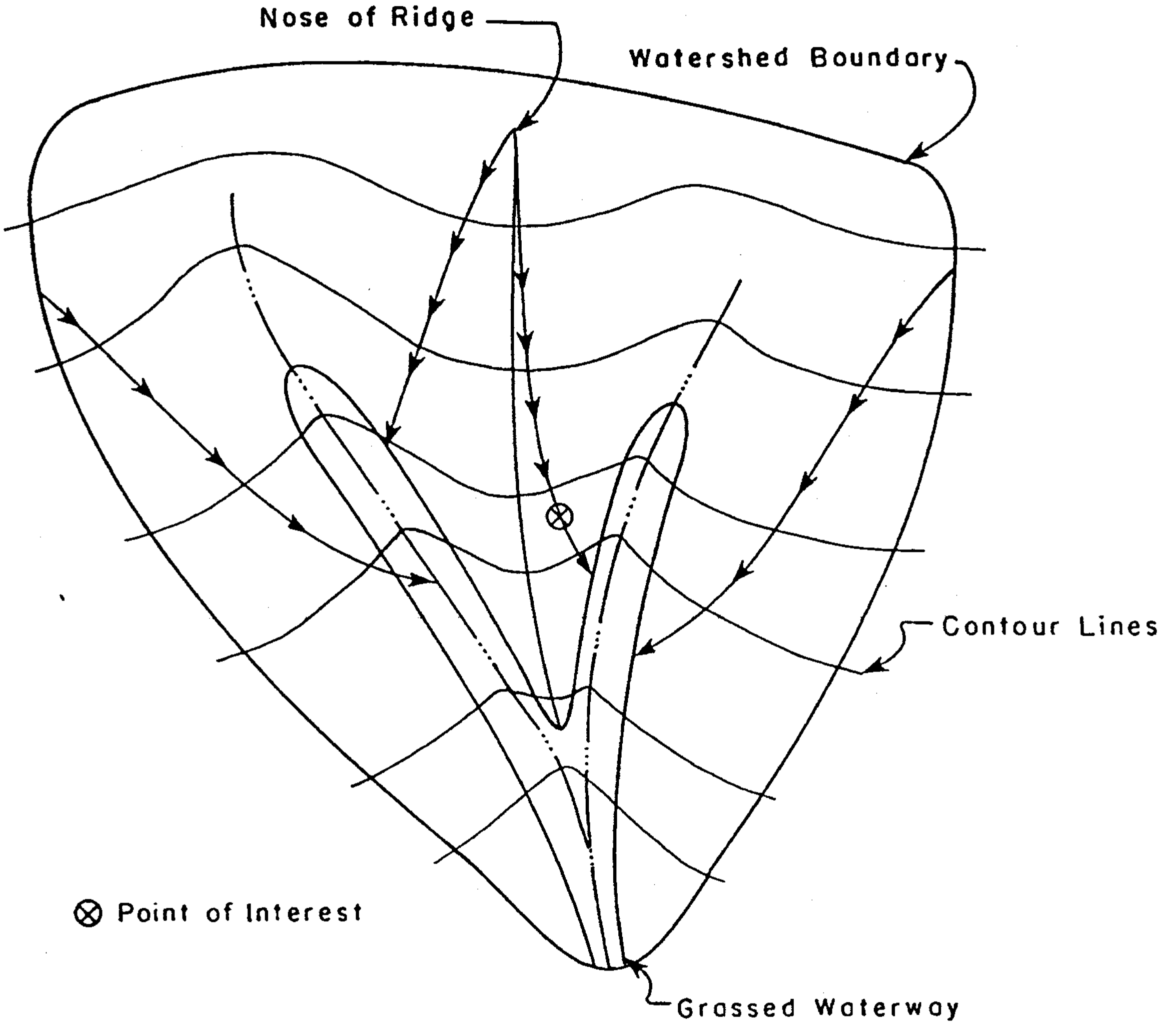


Figure 4-2. Illustration of some RUSLE slope lengths

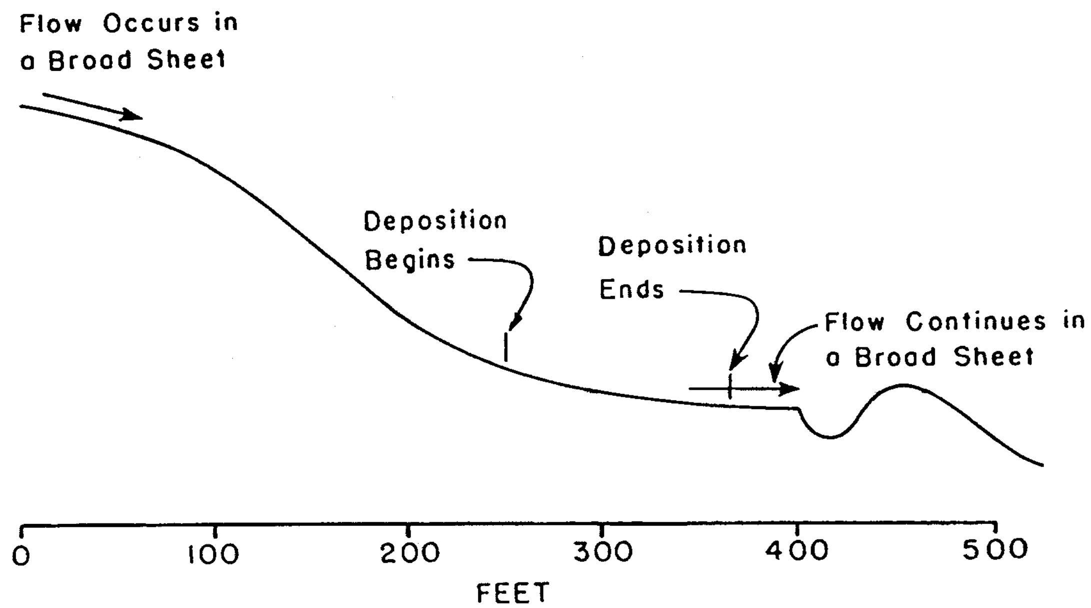


Figure 4-3. Illustration of deposition beginning and ending on a slope

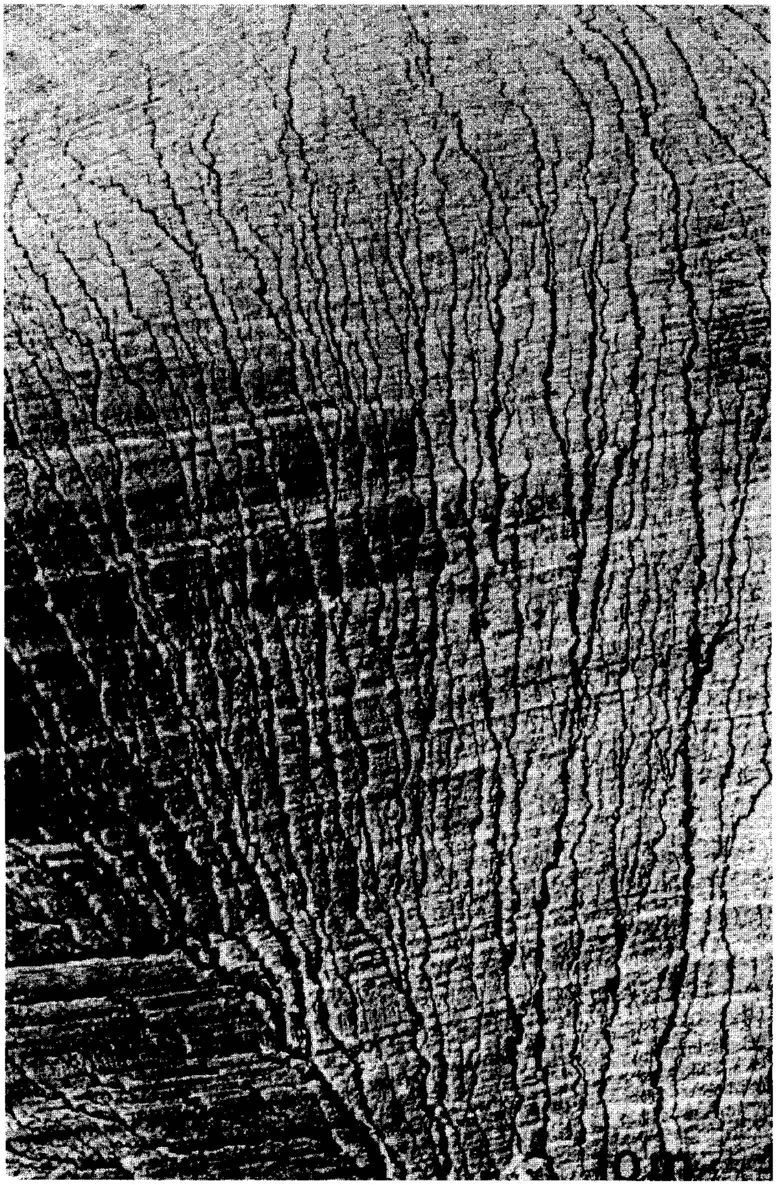
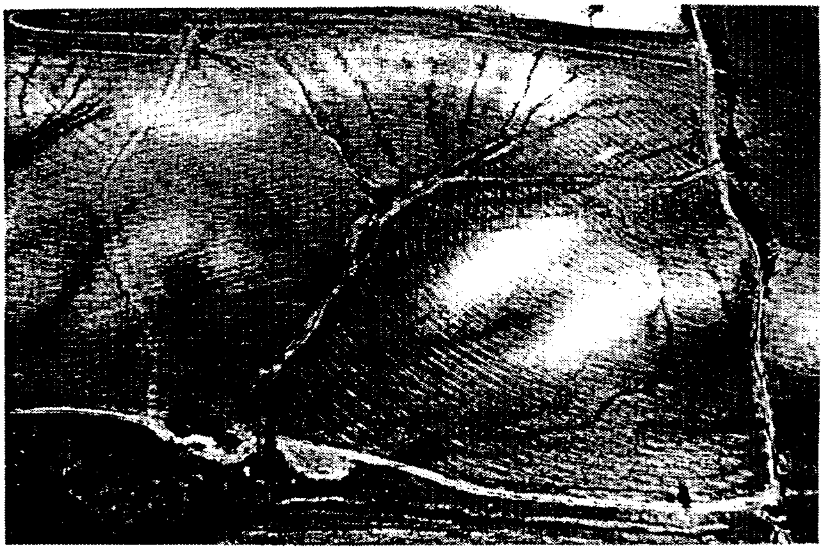


Figure 4-4. Dendritic rill pattern on a concave, north-facing slope. Estimated soil loss was 82 ton · acre^{-1}. From Frazier et al. (1983), reprinted by permission of Soil and Water Conservation Society.



Transcect	Slope length (λ) (ft)	Slope steepness (s) (%)	LS
1	280	12	3.14
2	325	13	3.84
3	240	11	2.53
4	205	13	2.97

Figure 4-5A. Erosion resulting from a series of storms on a row crop field during early stages of crop growth

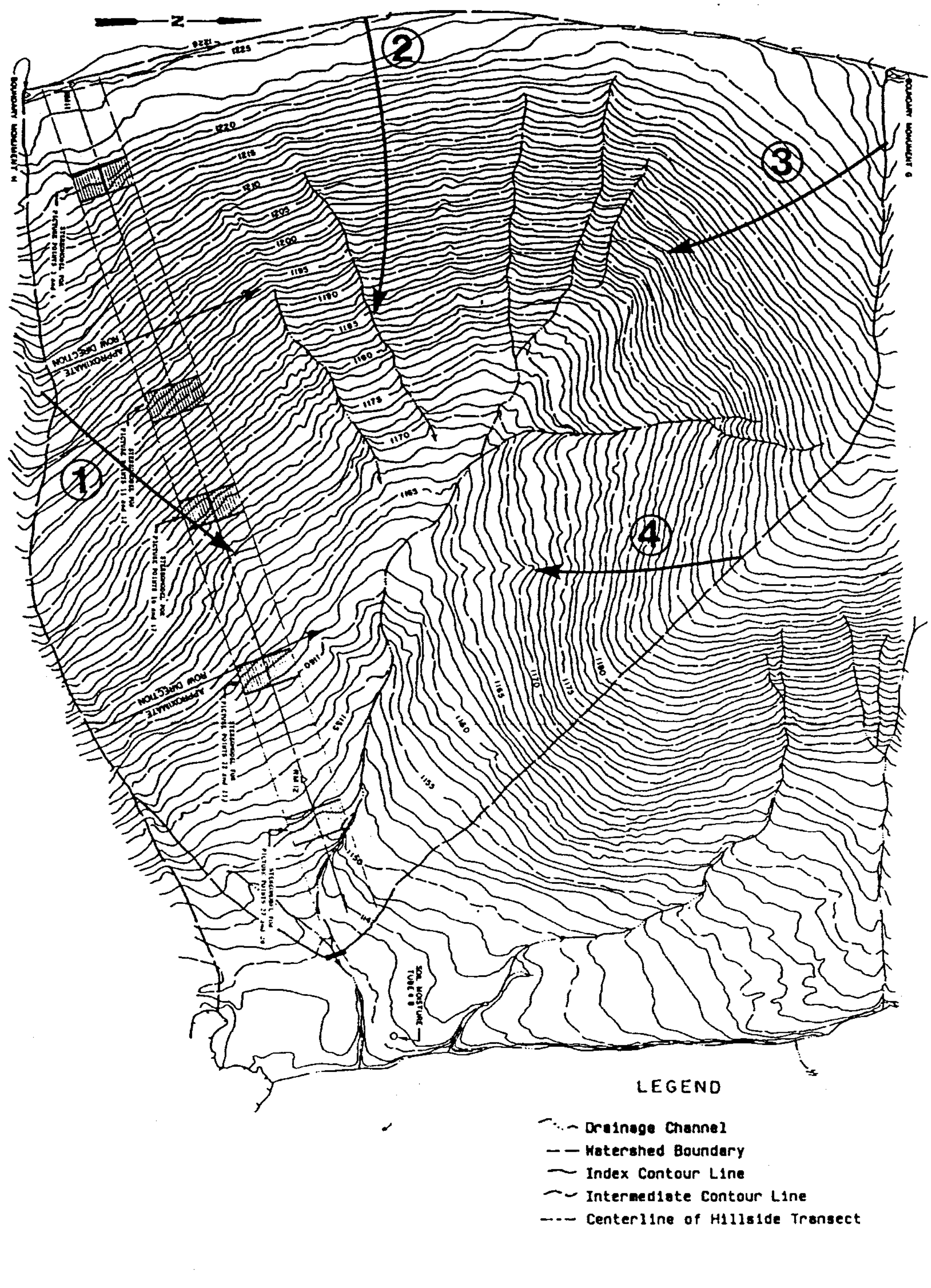


Figure 4-5B. One-ft contour interval map of the row crop field shown in figure 4-5A

Figure 4-6. Erosion from different crop managements on upper and lower halves of a slope. A large snow drift complicated the situation. From Frazier et al. (1983), reprinted by permission of Soil and Water Conservation Society.

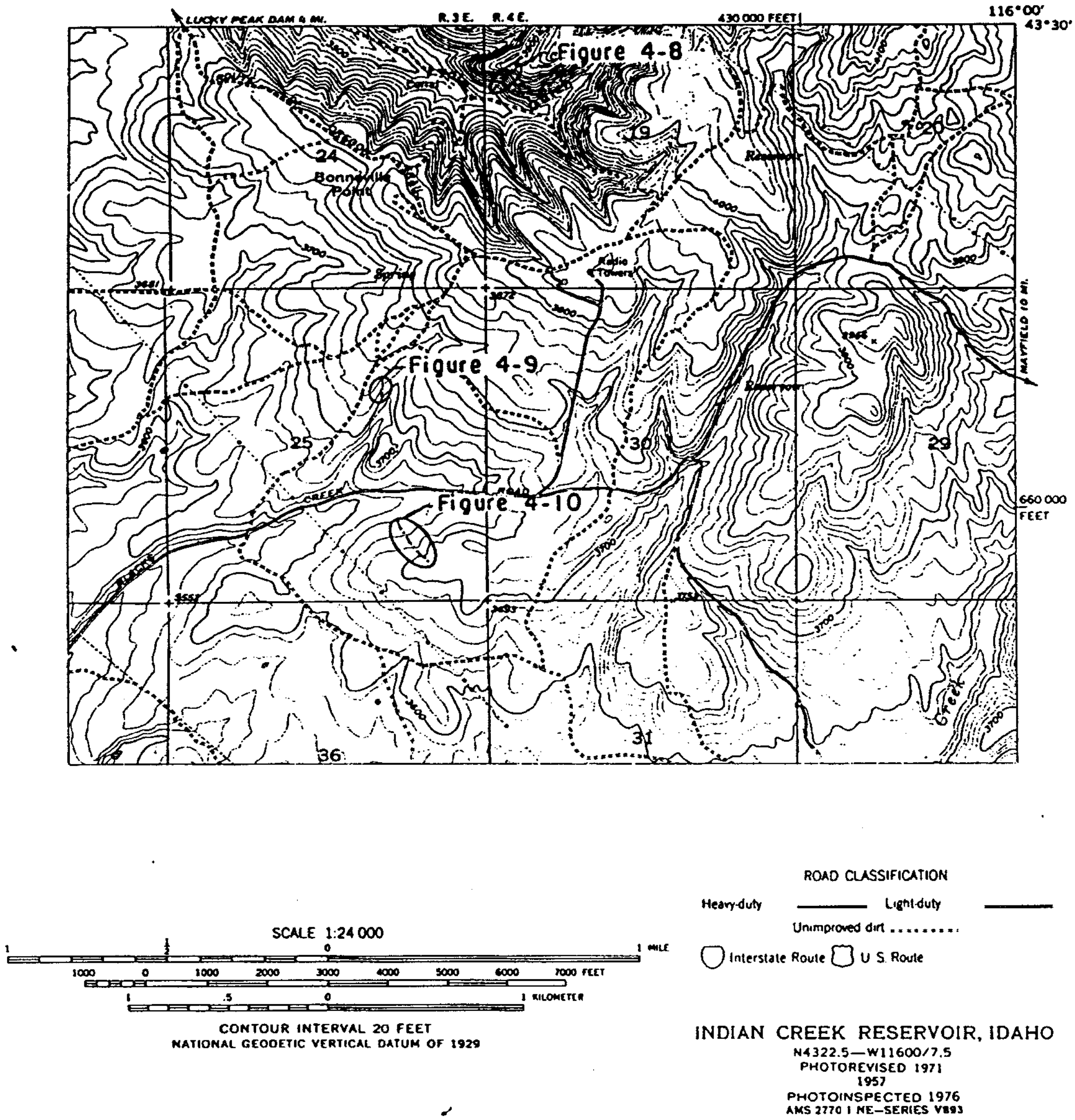
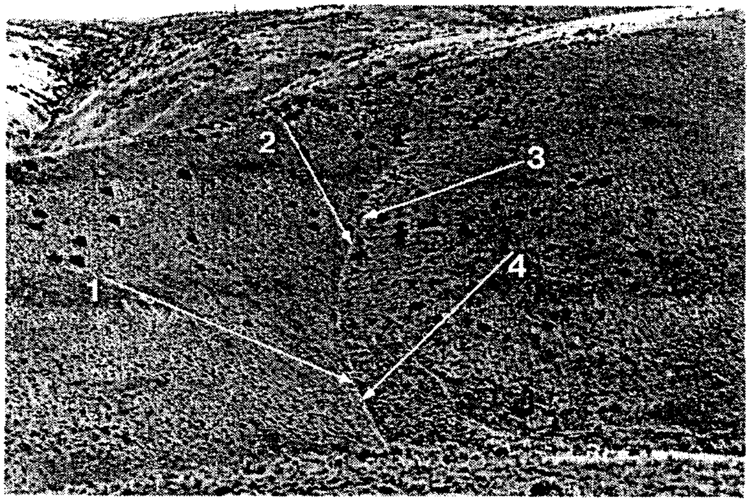
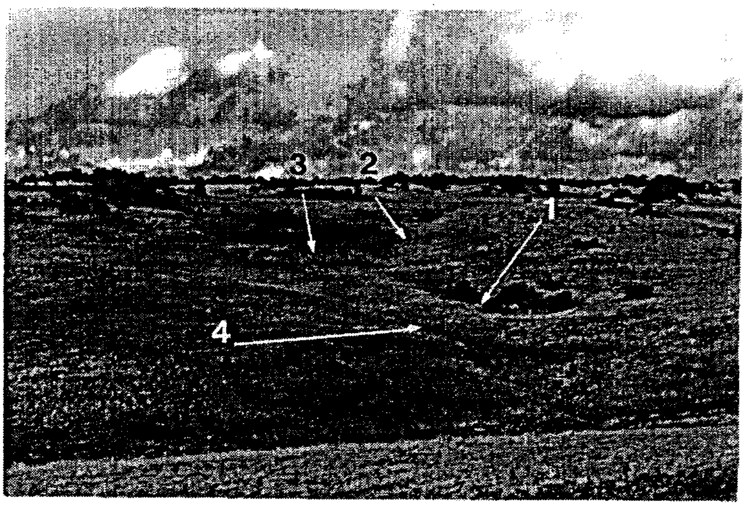


Figure 4-7. Portion of Indian Creek Reservoir USGS 7½-min Quad Sheet showing an area east of Boise, Idaho



Transect	Slope length (λ) (ft)	Slope steepness (s) (%)	LS
1	225	61	15.44
2	135	53	10.32
3	150	45	9.39
4	375	60	20.18

Figure 4-8. Small rangeland watershed on Lydle Creek east of Boise, Idaho



Transect	Slope length (λ) (ft)	Slope steepness (s) (%)	LS
1	165	14	2.53
2	30	6	0.53
3	50	16	1.85
4	60	14	1.70

Figure 4-9. Small rangeland watershed on Blacks Creek east of Boise, Idaho

Transect	Slope length (λ) (ft)	Slope steepness (s) (%)	LS
1	135	10	1.46
2	45	14	1.51
3	65	21	2.81
4	100	11	1.50
5	40	10	0.95

Figure 4-10. Small rangeland watershed on Blacks Creek east of Boise, Idaho

CHAPTER 5. COVER-MANAGEMENT FACTOR (C)

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CHAPTER 5. CONTENTS

The C factor is used within both the Universal Soil Loss Equation (USLE) and the Revised USLE (RUSLE) to reflect the effect of cropping and management practices on erosion rates, and is the factor used most often to compare the relative impacts of management options on conservation plans. The C factor indicates how the conservation plan will affect the average annual soil loss and how that soil-loss potential will be distributed in time during construction activities, crop rotations, or other management schemes.

As with most other factors within RUSLE, the C factor is based on the concept of deviation from a standard, in this case an area under clean-tilled continuous-fallow conditions. The soil loss ratio (SLR) is then an estimate of the ratio of soil loss under actual conditions to losses experienced under the reference conditions. Work by Wischmeier (1975) and Mutchler et al. (1982) indicated that the general impact of cropping and management on soil losses can be divided into a series of subfactors. Within RUSLE, this technique is used as modified by Laflen et al. (1985) and Weltz et al. (1987). In this approach the important parameters are the impacts of previous cropping and management, the protection offered the soil surface by the vegetative canopy, the reduction in erosion due to surface cover and surface roughness, and in some cases the impact of low soil moisture on reduction of runoff from low-intensity rainfall. As used in RUSLE, each of these parameters is assigned a subfactor value, and these values are multiplied together to yield a SLR.

An individual SLR value is thus calculated for each time period over which the important parameters can be assumed to remain constant. Each of these SLR values is then weighted by the fraction of rainfall and runoff erosivity (EI) associated with the corresponding time period, and these weighted values are combined into an overall C factor value.

USE OF TIME-VARYING OR AVERAGE ANNUAL VALUES

For areas such as pasture or rangeland that have reached a relative equilibrium, the parameters used in computing SLR values may change very slowly with time, so calculated SLR values will also change little. In these cases, it may prove adequate to calculate a C factor based on a single average SLR representing the entire year. RUSLE provides this option to simplify calculations, but this capability must be used with caution, as the result will no longer reflect changes in the climate's erosive potential through the year.

In almost all cropland scenarios and in many cases where rangeland or pasture are being managed, the crop and soil parameters change with time due to either specific management practices or natural cyclic effects such as winter knockdown and spring growth. This demands that the SLR values be calculated frequently enough over the course of a year or a crop rotation to provide an adequate measure of how they change. This is especially important because the erosion potential is also changing with time, as indicated by the EI distributions discussed in chapter 2. The calculated average annual soil loss should be high if a cropping or management scheme happens to leave the soil susceptible to erosion at a time of high rainfall erosivity. USLE incorporated this effect into calculations of SLR values based on crop-growth stages (Wischmeier and Smith 1978). These values were usually assigned based on tillage type, elapsed time since a tillage operation, canopy development, and date of harvest.

Following the lead of the USLE approach, RUSLE calculations are based on a 15-day time step. This means that SLR values are calculated every 15 days throughout the year, and that the important parameters are assumed to remain constant during those 15 days. In order to maintain a total of 24 periods in a year, the first 15 days of each month are placed in one period, and the remainder in another. Period lengths thus range from 13 days for the second period in February to 16 days for the second period in any month having 31 days.

If a management operation occurs within the period, the parameters can no longer be assumed constant; the half-month period is then broken into two segments and two SLR values are calculated. These segments can in turn be broken into smaller time increments by other management operations. A recalculation of the SLR can therefore be forced by either of two occurrences. The first is the end of a half-month period, because conditions are presumed to have changed sufficiently to require new calculations. The other occurrence is any field operation or sudden climatic change that affects the soil/vegetation/residue system, thereby changing the value of the SLR. These are handled by dividing the entire time period of interest into time *segments*. Each segment is bracketed by two *events*, which are defined as either a field operation or the beginning of a new half-month period. A segment can therefore range in length from 0 days (if two events occur on the same day) to a 16-day maximum if a month has 31 days and there are no field operations within a period. A zero-length segment is kept track of for accounting purposes, but requires no SLR calculation because there is no associated EI.

Calculations of the SLR for the average annual and time-varying approaches are the same and require the same input parameters; the difference lies in how often the calculation is performed. In the time-varying approach, the SLR value is calculated at a date in the middle of each time segment, and this value is then weighted by the percentage of EI associated with that segment. In the average annual approach, everything is assumed constant, so the calculation is made once.

COMPUTATION OF HALF-MONTH CLIMATE VARIABLES

Calculation of the time-varying SLR requires values for the rainfall, average air temperature, and fraction of total EI associated with each of the half-month periods throughout the year. This forces additional calculations in order to get smooth half-month values when the available data are supplied on a monthly basis.

Known: M, (M-1), and (M+1), which are monthly values for the month of interest (M), the previous month (M-1), and the subsequent month (M+1).

Wanted: P_1 and P_2, which are calculated values of the variable for the first and second half-month periods in the month, respectively.

For the temperature variables,

$$P_1 = 2 \cdot M \left(\frac{.75(M-1)+.25(M+1)}{(M-1)+(M+1)} \right) ;$$

$$P_2 = 2 \cdot M \left(\frac{.25(M-1)+.75(M+1)}{(M-1)+(M+1)} \right) \qquad [5\text{-}1]$$

This works out so that the average of the two period temperatures is equal to the monthly average. For rainfall,

$$P_1 = M \left(\frac{.75(M-1)+.25(M+1)}{(M-1)+(M+1)} \right) ;$$

$$P_2 = M \left(\frac{.25(M-1)+.75(M+1)}{(M-1)+(M+1)} \right) \qquad [5\text{-}2]$$

This leaves the sum of the two period rainfalls equal to the monthly rainfall.

COMPUTATION OF SOIL-LOSS RATIOS

Based on new descriptions of cropping and management practices and their influence on soil loss (Laflen et al. 1985), soil-loss ratios are computed as

$$SLR = PLU \cdot CC \cdot SC \cdot SR \cdot SM \tag{5-3}$$

where SLR is the soil-loss ratio for the given conditions, PLU is the prior-land-use subfactor, CC is the canopy-cover subfactor, SC is the surface-cover subfactor, SR is the surface-roughness subfactor, and SM is the soil-moisture subfactor.

Each subfactor contains cropping and management variables that affect soil erosion. Individual subfactors in equation [5-3] are expressed as functions of one or more variables, including residue cover, canopy cover, canopy height, surface roughness, below-ground biomass (root mass plus incorporated residue), prior cropping, soil moisture, and time.

RUSLE uses a CROP database to store the values required to calculate the impact on soil loss of any vegetation within the management plan. These user-defined sets of values specify the growth characteristics of the vegetation, the amount of residue the vegetation will produce, and the characteristics of that residue. The program uses that information to calculate the change with time of the variables listed above and their impact on the subfactors. RUSLE contains another database to store user-supplied information defining the impacts of management operations on the soil, vegetation, and residues, and uses that information to modify the variables accordingly. The relationships of these databases to the subfactor calculations are explained in more detail in the following sections. Published values used in defining some basic crop and operation database sets are shown in tables 5-1 through 5-7. These values are not suitable for all conditions and will need to be adjusted accordingly. This adjustment can be readily accomplished within the RUSLE program by use of procedures described in chapter 7, using estimates as described in appendix D.

The RUSLE program contains a third database that represents the climate for the area of interest. This is important to the C-factor calculations in two ways: first, the EI distribution within the database set is used to weight each SLR value in calculating the overall C-factor value. Second, the set also contains temperature and rainfall data, which are needed to calculate the rate of residue decomposition. Note that the climatic data are not used to modify the crop growth characteristics, because these are already defined in the crop database.

In addition to the databases, the RUSLE program contains a module that is important to several of the subfactor calculations. This is a subroutine that calculates the rate of residue decomposition as a function of residue characteristics and climate variables. Based on work by Stott et al. (1990) and Stott and Barrett (1991), this is derived as a first-order rate equation, and is calculated as

$$M_e = M_b \exp(-a\,D) \qquad [5\text{-}4]$$

where M_e is residue mass at end of a time period, M_b is mass at beginning of the period, D is period length in days, and

$$a = p \cdot [\text{minimum of } (W, F)] \qquad [5\text{-}5]$$

where p is a coefficient depending on residue characteristics (taken from the CROP database), and W and F are precipitation and temperature factors defined subsequently. The database sets provided with the RUSLE program contain empirically derived values of p for specific crops; new values of p must be found either by experimentation or by modifying existing values to reflect known differences in decomposition rates. See appendix D for more information on this modification. The decomposition relationships continue with

$$W = \frac{R}{R_o} \qquad [5\text{-}6]$$

and

$$F = \frac{2\left(T_a + A\right)^2 \cdot \left(T_o + A\right)^2 - \left(T_a + A\right)^4}{\left(T_o + A\right)^4} \qquad [5\text{-}7]$$

where R is rainfall in the half-month period, R_o is minimum average half-month rainfall required for optimum decomposition, T_a is average temperature in the half-month period, T_o is optimum temperature for decomposition, and A is a coefficient used to describe the shape of the decomposition response to temperature. Calibration of these constants against decomposition data yields the values $R_o = 2.6$ in, $T_o = 90$ °F, and A = 46 °F. These values provide decomposition rates that seem to accurately reflect data from various regions of the United States, including the Pacific Northwest, Texas, Indiana, and Mississippi. The corresponding values of the crop decomposition constant p are shown in table 5-1. There are not sufficient data to distinguish between the decomposition rates of residue under surface and subsurface conditions, so the values shown in table 5-1 can be used for both. These values can be changed when further tests yield more complete information on p values for surface and subsurface conditions. The program treats the two values separately to allow for these changes.

Because SLR values are for half-month periods, they are calculated for the average residue level during the period, which is defined as

$$M_a = \left[\frac{M_b}{a\ D}\right]\left[\ 1 - \exp(-a\ D)\right] \qquad [5\text{-}8]$$

where M_a is average residue mass during the time period, and the other terms are as defined above. Note that D may be up to 16 days but can be smaller if the half-month period is divided by one or more management operations. Note also that the units of mass need not be specified as long as they are consistent. The RUSLE program calculates residue mass in units of (lb · acre^{-1}).

The RUSLE program separately calculates the amount of residue both on the surface and within the soil, and decomposes each according to climatic conditions and residue characteristics. It also accounts for additions of residue to the surface by harvests, senescence, or other management operations, and for incorporation of residue by tillage operations.

The calculations within RUSLE include three additional assumptions concerning residue incorporation and decomposition. First, it is assumed that residue incorporation cannot occur within a soil depth of less than 2 in, regardless of the depth of tillage defined for the field operation. Next, it is assumed that the residue is evenly incorporated throughout the depth of tillage. Finally, it is assumed that all subsurface residue will decompose at the same rate, without regard for the depth to which it is buried. While these assumptions are of limited validity, they provide an appropriate simplified basis on which to make the calculations.

The effectiveness of both surface and incorporated residues in controlling erosion rates has been found to depend on the mechanism by which the soil tends to erode. In general, soils that erode primarily through the formation of rills are substantially more protected by both surface and buried residues than are soils that erode primarily through sheet erosion in the interrill areas. Examples of soils that rill easily include those with naturally weak structure and those whose structure has been destroyed by disturbance and are in an unconsolidated state. Consolidated soils, or those with good structure, usually have a low ratio of rill to interrill erosion.

For permanent pasture or rangeland, the amounts of canopy cover, surface and subsurface residues, and root mass are relatively constant when compared to the widely varying amounts seen with most agronomic crops. This is especially true for permanent pasture or grassland, where the changes in residue and root mass are likely to be a small fraction of the total masses. If the assumption of constant values for these variables is thought to be adequate, RUSLE allows for calculation of the SLR values based on their average annual values. In this case, there are assumed to be no residue additions or decomposition. The program does allow for some disruption by tillage or other practices on a one-time basis and calculates an exponential decay of this effect.

Prior-Land-Use Subfactor (PLU)

The prior-land-use subfactor (PLU) expresses (1) the influence on soil erosion of subsurface residual effects from previous crops and (2) the effect of previous tillage practices on soil consolidation. The relationship is of the form

$$PLU = C_f \cdot C_b \cdot \exp[(-c_{ur} \cdot B_{ur}) + (c_{us} \cdot B_{us} / C_f^{c_{uf}})] \qquad [5\text{-}9]$$

where PLU is the prior-land-use subfactor (which ranges from 0 to 1), C_f is a surface-soil-consolidation factor, C_b represents the relative effectiveness of subsurface residue in consolidation, B_{ur} is mass density of live and dead roots found in the upper inch of soil ($lb \cdot acre^{-1} \cdot in^{-1}$), B_{us} is mass density of incorporated surface residue in the upper inch of soil ($lb \cdot acre^{-1} \cdot in^{-1}$), c_{uf} represents the impact of soil consolidation on the effectiveness of incorporated residue, and c_{ur} and c_{us} are calibration coefficients indicating the impacts of the subsurface residues.

The variable C_f expresses the effect of tillage-induced surface density changes on soil erosion. Tillage operations tend to break soil aggregate bonds, increasing the potential for erosion. This is reflected in the lower erosion rates associated with the undisturbed soils of rangeland or no-till systems. Based on the work of Dissmeyer and Foster (1981), the value of C_f for freshly tilled conditions is 1.0. If the soil is left undisturbed, this value decays exponentially to 0.45 over 7 yr, or over some other length of time specified by the user. The impact of a field operation on this factor is determined by the portion of the surface disturbed. For example, if a planting operation disturbs only 30% of the surface that had already consolidated to the point where $C_f = 0.6$, then 70% of the field would have a value of $C_f = 0.6$, and the disturbed 30% would have a value of $C_f = 1.0$; the overall value would be $[(70\%)(0.6) + (30\%)(1.0)]/(100\%) = 0.72 = C_f$.

The B_u variables are used to calculate the impact on erosion rates of live and dead roots and incorporated residue. The effectiveness of such materials can take two forms. First, roots and residue can control erosion directly by physically binding soil particles together and by acting as mechanical barriers to soil and water movement. Second, roots and residue exude binding agents and serve as a food source for microorganisms that produce other organic binding agents. These serve to increase soil aggregation and thereby reduce its susceptibility to erosion.

It is the subsurface biomass (incorporated residue and roots) near the surface that is most effective in resisting erosion, so the values of B_u are in terms of biomass density ($lb \cdot acre^{-1} \cdot in^{-1}$) in the top inch of soil. The depth of soil that has these biomass densities will be defined by the pattern of field operations. If the most recent operation affects 100% of the surface and has a disturbance depth of 6 in, the B_u values will be the subsurface biomass densities to a depth of 6 in. It is assumed in RUSLE that residue cannot be mixed into a soil depth of less than 2 in, which makes this the least depth to which the B_u values can apply.

The surface residue is assumed to be evenly incorporated into the soil to the depth of tillage, and the root mass at that depth is also assumed to be mixed in.

Inputs provide information on root mass to a depth of only 4 in, but the assumption of no roots below this will lead to incorrect dilution of the residue if mixing occurs to a depth greater than 4 in. RUSLE therefore includes the assumption that the soil depth of 4-8 in contains a root mass equal to 80% of that in the layer at 0-4 in. Note here that soil layers are defined not by soil characteristics or morphology, but by where the roots grow and how deeply the soil is disturbed.

This concept of the B_u values and soil layers can best be clarified with an example, beginning with 6,000 $lb \cdot acre^{-1}$ of surface residue and 1,000 $lb \cdot acre^{-1}$ of root mass in the top 4 in. This gives $B_{ur} = 1{,}000/4 = 250$ $lb \cdot acre^{-1} \cdot in^{-1}$ throughout the top 4 in, a biomass density of $(1{,}000 \cdot 0.8)/(8\text{-}4) = 200$ $lb \cdot acre^{-1} \cdot in^{-1}$ for the layer at 4-8 in, and $B_{us} = 0$ because no surface residue has been buried. Assume then a field operation that disturbs 100% of the surface, leaves 70% of the surface residue on the surface, and has a tillage depth (and therefore an incorporation depth) of 6 in. Following the operation, there are two soil layers; the top layer is from the surface down to 6 in, below which is a layer from 6 to 8 in. The top layer has a total root mass of $(250 \cdot (4\text{-}0)) + (200 \cdot (6\text{-}4)) = 1{,}400$ $lb \cdot acre^{-1}$, or $B_{ur} = 1{,}400/6 = 233$ $lb \cdot acre^{-1} \cdot in^{-1}$, while the bottom layer still has a root mass density of 200 $lb \cdot acre^{-1} \cdot in^{-1}$. The top layer also contains $(6{,}000 \cdot 0.3) = 1{,}800$ $lb \cdot acre^{-1}$ of incorporated surface residue, leaving $(6{,}000 \cdot 0.7) = 4{,}200$ $lb \cdot acre^{-1}$ on the surface, and yielding $B_{us} = 1{,}800/6 = 300$ $lb \cdot acre^{-1} \cdot in^{-1}$. If this is followed immediately with another tillage that disturbs 100% of the surface, leaves 75% of the residue on the surface, and has a tillage depth of 2 in, we end up with three soil layers: one from 0-2 in, one from 2-6 in, and one from 6-8 in. The top layer has a total root mass of $233 \cdot 2 = 466$ $lb \cdot acre^{-1}$ and a total incorporated residue of $(300 \cdot 2) + (4{,}200 \cdot 0.25) = 1{,}650$ $lb \cdot acre^{-1}$, resulting in $B_{ur} = 466/2 = 233$ $lb \cdot acre^{-1} \cdot in^{-1}$ and $B_{us} = 1{,}650/2 = 825$ $lb \cdot acre^{-1} \cdot in^{-1}$. The layers at 2-6 and 6-8 in will still have root mass biomass densities of 233 and 200 $lb \cdot acre^{-1} \cdot in^{-1}$, and incorporated biomass densities of 300 and 0 $lb \cdot acre^{-1} \cdot in^{-1}$, respectively.

The RUSLE program keeps track of the biomass in each soil layer, continuously adjusting the root mass and subsurface residue to account for additions and decomposition.

Additional complications arise when a field operation does not disturb 100% of the surface, because the residue incorporation and mixing will vary over the field. The program needs to account for the fact that some portions of the field will be protected by additional subsurface biomass, while other portions will not. As it handles the field operation for B_{ur}, the program calculates three values: one overall without considering spatial variability, one for just those areas with the added incorporation and mixing, and one for the areas without the additional incorporation and mixing. Equation [5-9] is used to calculate the PLU values associated with each of these last two densities, which are then weighted by the associated surface fraction and added. This average PLU value is put back into equation [5-9] to calculate an equivalent weighted B_{ur}. This is divided by the first overall B_{ur}, which yields an adjustment ratio. Until it is changed by the next tillage operation, this ratio is used to adjust the calculated overall B_{ur} (which changes with residue decay and root growth); B_{ur} is multiplied by the ratio before it is put into equation [5-9]. This simplifies calculations during the time between operations by requiring only calculation of the overall B_{ur}, and by accounting for spatial variability with the adjustment ratio. If this procedure is followed, an operation that disturbs 100% of the surface simply yields an adjustment ratio of 1.0. A similar adjustment is used for B_{us}.

As an example of this adjustment, assume that an operation disturbs 20% of the surface, that in the disturbed area $B_{ur} = 500$ lb · acre^{-1} · in^{-1}, in the undisturbed area $B_{ur} = 200$ lb · acre^{-1} · in^{-1}, and that the overall $B_{ur} = 260$ lb · acre^{-1} · in^{-1}. If the first two values are put back into equation [5-9] with an assumed $c_{ur} =$ 0.0014 acre · in · lb^{-1}, the weighted average PLU is PLU = (0.2 · 0.497) + (0.8 · 0.756) = 0.70. This corresponds to an equivalent density of 251 lb · acre^{-1} · in^{-1}, which yields an adjustment ratio of 251 / 260 = 0.97. This indicates that in this case the uneven residue incorporation is only slightly less effective at controlling erosion than if it were incorporated evenly.

The coefficients C_b, c_{ur}, c_{us}, and c_{uf} describe the relative effectiveness of subsurface biomass in reducing erosion. These were calibrated using information from Van Liew and Saxton (1983), values from table 5 and 5-D in Agriculture Handbook 537 (Wischmeier and Smith, 1978), and an extensive data set collected from a broad series of no-till experiments. This analysis yields C_b = 0.951, $c_{ur} = 0.00199$ acre · in · lb^{-1}, $c_{us} = 0.000416$ acre · in · lb^{-1}, and $c_{uf} =$ 0.5. For soils that erode primarily as a result of rainfall and snowmelt on frozen or thawing soils (such as many in the Northwest Wheat and Range Region), subsurface residue has been found to be even more effective, yielding $c_{ur} =$ 0.00398 acre · in · lb^{-1}, $c_{us} = 0.000832$ acre · in · lb^{-1}, and $c_{uf} = 0.5$.

The amount of incorporated residue is calculated from the additions of residue to the surface and its subsequent burial by tillage operations. The total subsurface biomass is made up of this incorporated surface residue (B_{us} in equation [5-9]), and the total live and dead root mass (B_{ur} in equation [5-9]). The program keeps track of the live roots as described later, and adds this amount to the root residue when the vegetation is killed. The root residue is decayed through use of the decomposition subroutine.

The impact of surface residue on soil organic matter is described by adding a portion of the decayed surface residue mass to the root-mass residue. Based on analysis of no-till erosion data, this fraction is defined as 0.5.

The amount of live roots in the top 4 in is usually taken directly from the CROP database set. The user is responsible for supplying these values, but estimates of root mass at various times in the growing season for selected agronomic crops are given in table 5-2, and suggested values for pasture and meadow crops are shown in table 5-3. In addition, the program assumes that the soil layer at 4-8 in will contain a root mass concentration equal to 80% of that in the top 4 in. This assumption is required to reflect the mixing of soil layers by tillage operations and the resulting redistribution of root mass.

For many rangeland conditions, values of live root mass are not available. Weltz et al. (1987) developed data for estimating root biomass on rangelands. The effective below-ground root biomass (B_b) is given as

$$B_b = B_a \cdot n_i \qquad [5\text{-}10]$$

where B_a is total average annual site production potential (lb · acre^{-1}), and n_i is the ratio of effective root mass to annual site production potential. Suggested values of n_i for many plant communities in western U.S. rangelands and eastern pastures are found in table 5-4. Estimates of B_a can be made using standard production potential techniques, or by use of such guides as Natural Resources Conservation Service (NRCS) range-site descriptions.

On croplands, the amount of above- and below-ground biomass present at a given time depends on initial mass of the residue, root mass, fraction of crop residue incorporated by field operations, and decomposition rate of residue and roots. If the initial residue mass at harvest is not known, it can be estimated by multiplying the grain yield by the residue-to-yield ratio (table 5-1). The percentages of residue cover left on the soil surface after various field operations are shown in table 5-5. These values may vary considerably, depending on crop type, implement speed, and soil and residue conditions. If more than one type of residue cover exists on the surface, this percentage of each of the residues will be left after the field operation.

Canopy-Cover Subfactor (CC)

The canopy-cover subfactor expresses the effectiveness of vegetative canopy in reducing the energy of rainfall striking the soil surface. Although most rainfall intercepted by crop canopy eventually reaches the soil surface, it usually does so with much less energy than does rainfall that strikes the ground without having been intercepted. The intercepted raindrops fracture into smaller drops with less energy, or drip from leaf edges, or travel down crop stems to the ground. The canopy-cover effect is given as

$$CC = 1 - F_c \cdot \exp(-0.1 \cdot H) \qquad [5\text{-}11]$$

where CC is the canopy-cover subfactor ranging from 0 to 1, F_c is fraction of land surface covered by canopy, and H (ft) is distance that raindrops fall after striking the canopy.

This relationship was given graphically by Wischmeier and Smith (1978) and is shown in figure 5-1 for several heights. It is based on the assumptions that the rainfall fraction intercepted by the canopy is equal to the fraction of the land surface beneath the canopy, and that any rainfall intercepted will leave the canopy at a height H (ft) with a mean drop diameter of 0.1 in. Although Quinn and Laflen (1983) found that stem flow was quite significant and that drop sizes differed from those assumed by Wischmeier and Smith, they did find that the relationship given in equation [5-11] was satisfactory for corn. Others have noted the different effects of various kinds of crops (Armstrong and Mitchell 1987, 1988; Finney 1984; Haynes 1940). Values for F_c and H for each crop are defined by the user. Some suggested values for several crops are listed in table 5-2.

Surface-Cover Subfactor (SC)

Surface cover affects erosion by reducing the transport capacity of runoff water (Foster 1982), by causing deposition in ponded areas (Laflen 1983), and by decreasing the surface area susceptible to raindrop impact. It is perhaps the single most important factor in determining SLR values. Surface cover includes crop residue, rocks, cryptogams, and other nonerodible material that is in direct contact with the soil surface (Simanton et al. 1984, Box 1981, Meyer et al. 1972). The effect of surface cover on soil erosion is given by

$$SC = \exp\left[-b \cdot S_p \cdot \left(\frac{0.24}{R_u}\right)^{0.08}\right] \qquad [5\text{-}12]$$

where SC is the surface-cover subfactor, b is an empirical coefficient, S_p is percentage of land area covered by surface cover, and R_u is surface roughness (in) as defined by equation [5-16].

The b value indicates the effectiveness of surface cover in reducing soil erosion. Laflen et al. (1980) and Laflen and Colvin (1981) found that b values ranged from 0.030 to 0.070 for row crops, and Dickey et al. (1983) found b values of 0.024-0.032 in a rainfall-simulation study on small grains. Within the Northwestern Wheat and Range Region, b values greater than 0.050 have been found for small grains. Simanton et al. (1984) recommended a b value of 0.039 for rangeland conditions with the impact of subsurface biomass removed. The relationship given in equation [5-12] is shown in figures 5-2 and 5-3 for several values of R_c and b.

Even though experimental data reflect a wide variance in b values, additional analyses using modeling techniques have indicated that the selection of an appropriate b value can be made more accurately if the dominant erosion process is known. When rill erosion is the primary mechanism of soil loss (such as for irrigation or snowmelt or for highly disturbed soils), b values should be about 0.050. Fields dominated by interrill erosion have a b value of around 0.025. For typical cropland erosion conditions, a b value of 0.035 is suggested. For rangeland and permanent pasture communities, the b value depends on the general type of vegetation.

The percentage of land area covered by residue can be estimated from residue weight by use of the relationship developed by Gregory (1982), as follows:

$$S_p = \left[1 - \exp\left(-\alpha \cdot B_s \right) \right] \cdot 100 \qquad [5\text{-}13]$$

where S_p is percent residue cover, α is the ratio of the area covered by a piece of residue to the mass of that residue (acre $\cdot$ lb^{-1}), and B_s is the dry weight of crop residue on the surface (lb $\cdot$ acre^{-1}). Typical values for α are given in table 5-1. Percent residue covers for various residue weights from the use of equation [5-13] are illustrated in figure 5-4. If more than one type of residue is present, the resulting total surface cover is calculated by modifying equation [5-13] as

$$S_p = \left\{ 1 - \exp\left[- \sum_{i=1}^{N} \left(\alpha_i \, B_{si} \right) \right] \right\} \cdot 100 \qquad [5\text{-}14]$$

where N is number of residue types and α_i is ratio of the area covered to the mass of that residue for each type encountered.

Within RUSLE, rather than entering a value for α, the program asks for residue weights associated with specific values of residue cover and calculates the corresponding α value. The program asks for residue weights at 30%, 60%, and 90% surface cover. Only one of these needs to be entered to calculate an α value. If more than one weight is entered, the program will calculate an α value for each and then average them.

Surface-Roughness Subfactor (SR)

Surface roughness has been shown to directly affect soil erosion (Cogo et al. 1984), and to indirectly affect it through the impact on residue effectiveness, implied in equation [5-12]. In either case, this is a function of the surface's random roughness, which is defined as the standard deviation of the surface elevations when changes due to land slope or nonrandom tillage marks (such as dead furrows, traffic marks, and disk marks) are removed from consideration (Allmaras et al. 1966). A rough surface has many depressions and barriers. During a rainfall event, these trap water and sediment, causing rough surfaces to erode at lower rates than do smooth surfaces under similar conditions. Increasing the surface roughness decreases the transport capacity and runoff detachment by reducing the flow velocity.

Roughness and cloddiness of soils also affect the degree and rate of soil sealing by raindrop impact. Soils that are left rough and cloddy typically have higher infiltration rates. Soils that are finely pulverized are usually smooth, seal rapidly, and have low infiltration rates (Sumner and Stewart 1992).

Values of random roughness vary, depending on the type and degree of surface disturbance. Typical values are given in table 5-5 for cropland and table 5-6 for rangeland conditions. These core values may be modified as described in appendix D. Roughness conditions for a given field operation may vary, depending on previous tillage, implement speed, and field conditions.

The impact of surface roughness on erosion is defined by a baseline condition, which sets SR equal to 1 for unit plot conditions of clean cultivation smoothed by extended exposure to rainfall of moderate intensity. These conditions yield a random roughness of about 0.24 in. This makes it possible to get SR values of greater than 1 for practices in which the soil is very finely pulverized and smoothed to a smaller random roughness, as might be the case for some rototilling operations or for repeated cultivations of silt loam soils under dry fallow conditions. For conditions in which repeated disturbance leaves a rougher surface (for example, for continuous cattle-grazing), this final roughness value of 0.24 can be replaced. Chapter 7 describes how this is done.

Except in these cases of fine pulverization, it is assumed that the roughness left after field operations is smoothed by the effects of raindrop impact, approaching a random roughness of 0.24 in as the cumulative rainfall increases. This smoothing is modeled by expanding on the relationship described by Onstad et al. (1984)

$$D_r = \exp\left[1/2\ (-0.14 \cdot P_t) + 1/2\ (-0.012 \cdot EI_t)\right] \qquad [5\text{-}15]$$

where D_r is the dimensionless roughness decay coefficient, P_t is the total inches of rainfall since the most recent operation that disturbed the entire surface, and EI_t is the total EI amount since that same operation. The value of D_r ranges exponentially from a value of 1.0 for a surface that has experienced no rainfall to a value approaching 0.0 for a surface that has experienced extensive rainfall and has lost most of its roughness.

If the initial roughness is defined as R_i (in inches), the surface roughness just before the current tillage operation (R_u) can be defined as

$$R_u = 0.24 + [D_r\ (R_i - 0.24)] \qquad [5\text{-}16]$$

where R_u is in inches. Since many field operations affect only a portion of the surface, R_u is also the roughness of the portion of the field that is undisturbed by the current field operation.

For that portion of the surface that is affected by the field operation, the resulting roughness has been found to be a function of subsurface biomass present in the top 4 in of soil. This relationship is described by

$$R_a = 0.24 + (R_t - 0.24)\{0.8\ [1 - \exp(-0.0012\ B_u)] + 0.2\} \qquad [5\text{-}17]$$

where R_a is the roughness after biomass adjustment (in), R_t is the original tillage roughness based on the assumption of ample subsurface biomass such as that found with high-yielding midwestern corn (in), and B_u is total subsurface biomass density in the top inch of soil ($lb \cdot acre^{-1} \cdot in^{-1}$). $B_u = B_{ur} + B_{us}$ as defined for equation [5-9]. Researchers in the Northwestern Wheat and Range Region indicate that the strong relationship of tillage roughness to subsurface biomass does not hold for their conditions (D.K. McCool, personal communication 1994). In that area of the country, equation [5-17] is not used, leaving simply $R_a = R_t$.

This adjusted tillage roughness is then combined with that of the undisturbed portion of the surface as

$$R_n = R_a F_d + R_u F_u \qquad [5\text{-}18]$$

where R_n is the net roughness following the field operation (in). F_d and F_u are the fractions of the surface disturbed and undisturbed, respectively, so their sum equals one.

Similarly, the decay coefficient must be adjusted to reflect the fact that only a portion of the field was disturbed. This is done using the relationship

$$D_e = D_r F_u + 1.0 F_d \qquad [5\text{-}19]$$

where D_e is the equivalent roughness decay coefficient. Under the assumption that the ratio EI_t/P_t before the operation equals that after, the P_t and EI_t values corresponding to the equivalent roughness decay coefficient are

$$\begin{aligned} P_t &= -2 \cdot \ln(D_e) \,/\, \left[0.14 + 0.012 \left(\frac{EI_{t,b}}{P_{t,b}}\right)\right]; \\ EI_t &= EI_{t,b} \cdot P_t/P_{t,b} \end{aligned} \qquad [5\text{-}20]$$

where the subscript b indicates the value before the operation.

These values for the decay coefficient and corresponding precipitation and EI describe a point on a new roughness decay curve, asymptotic to zero at infinite amounts of precipitation, and with a new initial roughness at $P_t = 0$. This new initial roughness R_i (in) is calculated from

$$R_i = 0.24 + \frac{(R_n - 0.24)}{D_e} \qquad [5\text{-}21]$$

thereby completely describing the decay curve.

As the computer program steps through each time segment in the rotation, the total rainfall and EI since tillage (P_t and EI_t) are incremented by the amounts in that segment. The value of the roughness decay coefficient for that segment is then calculated by use of equation [5-15], and the current surface roughness is calculated by equation [5-16].

The surface random roughness is affected not only by the soil clods resulting from tillage, but also by the vegetation. If a site is clean-tilled and then left without human intervention, two things will happen: (1) the tillage roughness will decrease as defined previously, and (2) as the years go by, the vegetation will trend toward its climax community, with attendant roughness caused by protruding roots, soil mounded around old basal areas, rocks, and so on.

RUSLE assumes that the formation of this vegetative roughness follows a typical sigmoidal growth curve increasing from the minimum soil roughness (r_{min}, with a default of 0.24 in) to the total roughness when the soil is fully consolidated (r_{max}) over the time required for consolidation (t_{con}). At any time after disturbance (t_d), the relationship will be

$$r_{nat} = r_{min} + \left[\frac{(r_{max} - r_{min})}{1 + \exp \dfrac{\left(0.5 - \dfrac{t_d}{t_{con}}\right)}{0.1}} \right] \qquad [5\text{-}22]$$

where r_{nat} is the roughness caused by the community (in). For each time period the program calculates r_{nat}, and compares its value to R_u as calculated for that same period. If r_{nat} is larger, then R_u is set equal to r_{nat}. In general, this will only occur if the site has not been disturbed for quite some time.

The surface roughness subfactor is then

$$SR = \exp[-0.66(R_u - 0.24)] \qquad [5\text{-}23]$$

Soil-Moisture Subfactor (SM)

Antecedent soil moisture has a substantial influence on infiltration and runoff and hence on soil erosion. In general, antecedent moisture effects are an inherent component of continuous-tilled fallow plots, and these effects are reflected in variation in soil erodibility throughout the year. In most of the continental United States, soil moisture is usually high during susceptible crop stages in spring and early summer, when much of the erosion occurs. Hence the antecedent soil moisture on cropped plots parallels that on the continuous-tilled fallow plots from which soil-erodibility factors are derived, so no adjustment is made for changes in soil moisture.

In the nonirrigated portions of the Northwestern Wheat and Range Region (Austin 1981) (including eastern Oregon, eastern Washington, and Idaho), soil moisture during critical crop periods depends on crop rotation and management. Winter wheat may be seeded after a previous crop of winter wheat, or after a more shallow-rooted crop, or after summer fallow. When a full year of fallow is used in the rotation, part of the moisture stored over the previous winter is retained in the soil profile. This is particularly true when an effective mulch system is used: either a loose soil and residue mulch in conjunction with a rodweeder, or an untilled residue mulch with direct stubble seeding. These systems are in contrast to continuous cropping, in which soil moisture is at or below the wilting point in the fall before the fall and winter precipitation. Addition of a soil-moisture subfactor (SM) is suggested for this region of the Northwestern Wheat and Range Region (McCool, personal communication 1994). SM reflects these dry fall conditions and the increase in soil moisture over the winter. The soil moisture decrease over the summer depends on the crop rooting depth and soil depth, and the soil moisture replenishment depends on the precipitation amount and soil depth.

When the soil profile is at or near field capacity, SM is 1.0 (such as on April 1 of fig. 5-5), indicating response equivalent to that of a continuous-fallow plot. When the profile is near wilting point to a 6-ft depth, the SM value is 0 (as on September 1 in fig. 5-5), indicating that no runoff and erosion are expected. This assumes that infiltration is not limited by surface conditions. SM increases over the winter from October 1 to March 31. Suggested replenishment-rate relationships are given in figure 5-6. Growing-season (April 1 to July 31) depletion rates for typical crops appear in table 5-7. These relationships and values are typical and may need adjustment for shallow-soil conditions or other considerations.

COMPUTATION OF C FACTOR

Once the SLR's have been calculated for each time interval, they are multiplied by their corresponding percentage of annual EI (Wischmeier and Smith 1978) as seen in table 2-1. These values are then summed and divided by the total percentage of annual EI value for the entire time period being investigated, as

$$C = \left(SLR_1\ EI_1 + SLR_2\ EI_2 + \ldots\ SLR_n\ EI_n\right) / EI_t \qquad [5\text{-}24]$$

where C is average annual or crop value, SLR_i is the value for time period i, EI_i is percentage of the annual or crop EI occurring during that time period, n is number of periods used in the summation, and EI_t is sum of the EI percentages for the entire time period.

For those systems where conditions are not rapidly changing (such as for rangeland, or continuous pasture or meadow), the PLU, CC, SC, and SR subfactor values are assumed to be annual averages, and are simply multiplied together to yield the overall C-factor value. If the assumption of nearly steady-state conditions does not hold, the weighted procedure used for cropland is more appropriate.

COMPUTATION OF C FACTORS FOR SINGLE DISTURBANCES AND FOR ROTATIONS

RUSLE technology can be used to estimate erosion under two very different sets of circumstances. The first circumstance is the one-time disturbance of an area, such as for a construction site, a rangeland under an improvement plan, or a disturbed forest site. In this case, the soil/vegetation/residue system is drastically disturbed but is then allowed to reconsolidate and return to more stable conditions.

The other general circumstance under which RUSLE can be used is a normal cropping rotation, in which the soil/vegetation/residue system is disturbed repeatedly in a cycle of one or more years. For example, a conventionally tilled corn-soybean rotation would have the same field operation (for example, planting of corn) at roughly the same time of year (perhaps May 15) every second year.

For the situation of a single disturbance, proper use of the RUSLE program requires definition of all the important soil/vegetation/residue parameters immediately after the disturbance. This process is described in more detail in chapter 7. For a crop rotation, matters are somewhat more complicated, because the disturbance is usually not so severe and the previous crops and field operations can still have a significant impact. The RUSLE program handles this by running three times through the calculations for the entire rotation, and by returning the calculated SLR values on only the third time through. This procedure allows the system to stabilize and minimizes the impact of the assumed initial conditions on the resulting SLR values.

COMPUTATION OF C FACTORS FOR HILLSLOPES UNDER STRIPCROPPING OR BUFFER STRIPS

For management schemes such as those modeling stripcropping and buffer strips, the vegetation and cropping schemes cause the SLR values to vary not only with time but also with position on the hillslope. For example, in a stripcropping scheme with alternating strips of conventionally tilled corn and good sod-forming grass, at any time half of the field would be under each crop.

The impact of such a scheme on the movement of runoff and the deposition of sediment is taken into account in the P factor (see ch. 6), but this does not account for the protection given the soil by the important parameters within the C factor: things such as random roughness, root mass, surface residue cover, and canopy cover. These must still be represented through the C factor.

This is done by calculating an individual C factor for each strip, and then weighting these by their area on the hillslope. For example, in any true stripcropping rotation scheme, each strip is rotated through the same pattern, so we need make only one C-factor calculation. On the other hand, for buffer strips, we can calculate a C factor for the buffer strips themselves and then calculate a C factor for the cropped areas between the buffer strips. We then calculate an overall C factor by multiplying each of the C factors by the percentage of the hillslope under that practice.

ACKNOWLEDGMENT

The authors acknowledge the kind assistance of Jim Cropper, NRCS, Chester, PA, for his extensive work in developing the CROP database information for forage crops.

Table 5-1.
Parameter values of typical crops[1]

Crop	Residue/yield ratio[2]	Surface p[3]	α^4 (acre · lb^{-1})	Residue at 30% cover[5] (lb · acre^{-1})	Yield	Row spacing[6] (in)	Plant population[6] (plants acre^{-1})
Alfalfa	0.15	0.020	0.00055	650	6 ton · acre^{-1}	(drilled)	180,000
Bromegrass	0.15	0.017	0.00055	650	5 ton · acre^{-1}	7 (drilled)	330,000
Corn	1.00	0.016	0.00038	950	130 bu · acre^{-1}	30	25,000
Cotton	1.00	0.015	0.00022	1,600	900 lb · acre^{-1}	38	35,000
Oats	2.00	[7]0.008	0.00059	600	65 bu · acre^{-1}	7 (drilled)	890,000
Peanuts	1.30	0.015	0.00030	1,200	2,600 lb · acre^{-1}	36	558,000
Rye	1.50	[7]0.008	0.00055	650	30 bu · acre^{-1}	(drilled)	890,000
Sorghum	1.00	0.016	0.00036	1,000	65 bu · acre^{-1}	30	41,000
Soybeans	1.50	0.025	0.00059	600	35 bu · acre^{-1}	30	110,000
Sunflowers	1.50	0.016	0.00024	1,500	1,100 lb · acre^{-1}	30	20,000
Tobacco	1.80	0.015	0.00036	1,000	2,200 lb · acre^{-1}	48	6,000
Wheat (spring)	1.30	[7]0.008	0.00059	600	30 bu · acre^{-1}	7 (drilled)	890,000
Wheat (winter)	1.70	[7]0.008	0.00059	600	45 bu · acre^{-1}	7 (drilled)	890,000

[1] Values in table are taken from Alberts et al. (1989), Ghidey et al. (1985), Gregory (1982), Gregory et al. (1985), Larson et al. (1978), National Research Council (1975), USDA (1990), and USDA-SCS (1991).

[2] Weight ratio of crop residue at harvest to crop yield,

[3] A constant that controls the exponential decomposition rate or surface residue from this crop. There are not enough data to justify different values for subsurface decay p values, so default values in program show identical decay rates for surface and buried residue. This can be changed by user.

[4] Ratio of area covered by a piece of residue to its mass.

[5] Mass of residue required to cover 30% of the surface area, corresponding to given value of α.

[6] Not currently used in program; is simply an aid in defining cropping patterns and likely residue levels

[7] Use 0.017 for the Northwestern Wheat and Range Region, or for small grain cover killed in the vegetative state.

Table 5-2.
Typical values of root mass, canopy cover, and canopy-droplet-fall-height for row crops and small-grain crops

Number of days after planting	Root mass in upper 4 in of soil ($lb \cdot ac^{-1}$)						Land surface covered by canopy (%)						Canopy-droplet-fall-height (ft)					
	Corn[1]	Soybeans[2]	Cotton[3]	Sorghum[4]	Winter small grain[5,6]	Spring small grain[5,7]	Corn	Soybeans	Cotton	Sorghum	Winter small grain	Spring small grain	Corn	Soybeans	Cotton	Sorghum	Winter small grain	Spring small grain
15	50	20	30	50	30	100	5	5	5	5	5	10	0.1	0.1	0.1	0.1	0.1	0.1
30	180	50	60	180	120	300	10	20	15	10	20	35	0.5	0.2	0.2	0.5	0.2	0.3
45	350	90	90	350	300	500	50	40	35	50	35	60	1.0	0.5	0.5	1.0	0.2	0.8
60	530	180	180	530	320	700	80	70	55	80	35	90	1.7	1.0	1.0	1.5	0.2	1.3
75	840	360	310	800	320	900	100	100	85	100	35	100	2.5	1.3	1.4	2.0	0.2	1.5
90	1060	360	360	1060	320		100	100	100	100	35		3.0	1.6	1.8	2.2	0.2	
105	1060	360	360		320		100	90	100		35		3.0	1.6	1.8		0.2	
120	1060	360	360		320		100	50	60		35		3.0	1.6	1.8		0.2	
135	1060	360	360		320		100	35	20		35		3.0	1.6	1.8		0.2	
150	1060				320		90				35		3.0				0.2	
165	1060				320		70				35		3.0				0.2	
180					340						40						0.5	
195					400						60						1.0	
210					660						90						1.3	
225					1000						100						1.5	
240					1200						100						1.5	

[1] 125 bu/ac yield, 30 in rows, 120 d, adjust duration of full canopy for different lengths of growing season
[2] 35 bu/ac yield, 30 in rows, full season
[3] 750 lbs/ac lint yield, 30 in rows, solid seeded
[4] 65 bu/ac yield, 30 in rows
[5] These are specific to areas with a spring and summer precipitation regime, a winter dormant period, and are not applicable to the Northwest Wheat and Range Region, adjust period of dormancy and growth of crop during dormant period according to growth patterns typical of region
[6] 45 bu/ac yield
[7] 60 bu/ac yield

Table 5-3.
Typical values for established forage stands[1]

Common name	Root mass in top 4 in ($lbs \cdot acre^{-1}$)	Canopy cover just prior to harvest (%)	Effective fall height (ft)	Average annual yield ($tons \cdot acre^{-1}$)
Grasses:				
Bahiagrass	1,900	95	0.1	4
Bermudagrass, coastal	3,900	100	0.2	8
Bermudagrass, common	2,400	100	0.1	3
Bluegrass, Kentucky	4,800	100	0.1	3
Brome grass, smooth	4,500	100	0.1	5
Dallisgrass	2,500	100	0.1	3
Fescue, tall	7,000	100	0.1	5
Orchardgrass	5,900	100	0.1	5
Timothy	2,900	95	0.1	5
Legumes:				
Alfalfa	3,500	100	0.2	6
Clover, ladino	1,400	100	0.2	3
Clover, red	2,100	100	0.1	4
Clover, sweet	1,200	90	2.0	2
Clover, white	1,900	100	0.1	2
Lespedeza, sericea	1,900	100	0.5	3
Trefoil, birdsfoot	2,400	100	0.3	4

[1]These values are for mature, full pure stands on well-drained nonirrigated soils with moderate-to-high available water-holding capacity. These values hold for species shown only within their range of adaptation. Except for biennials, most forages do not attain a fully-developed root system until end of second growing season. Root mass values listed can be reduced by as much as half on excessively drained or shallow soils and in areas where rainfall during growing season is less than 18 in. The values listed are from Bennett and Doss (1960), Denison and Perry (1990), Doss et al. (1960), Holt and Fisher (1960), Kramer and Weaver (1936), Lamba et al. (1949), MacDonald (1946), and Pavlychenko (1942).

Table 5-4.
Parameter values for estimating below-ground root mass in western U. S. rangelands

	Ratio of root mass in upper 4 in to total root mass		Ratio of root mass to above-ground biomass		Ratio of effective root mass to annual site production potential
Vegetation type	Best estimate	Range	Best estimate	Range	[1](n_i)
Southern mixed grass prairie	0.50	NA[2]	4.0	NA	1.1
Northern mixed grass prairie	0.34	0.22-0.77	30.0	0.64-119.6	1.5
Tallgrass prairie	0.74	0.73-0.75	7.4	0.23-20.3	0.3
Shortgrass prairie	0.41	0.24-0.64	3.2	1.12-10.7	1.0
Desert grasslands	0.60	0.36-0.73	3.4	2.0-4.9	2.7
Southeastern grasses and forbs	0.40	0.23-0.68	0.7	0.4-1.5	5.6
Cold desert shrubs	0.46	NA	5.0	4.09-11.0	3.25
Sandy shinnery oak with herbaceous interspaces	0.45	0.20-0.70	5.5	3.44-18.6	0.9
Southern desert shrubs	0.56	0.20-0.72	2.5	0.20-18.4	2.84
Chaparral	[3]0.13	0.08-0.30	0.8	0.30-1.9	6.5
California annual grassland	0.33	NA	3.0	NA	1.2
Pasture, bunchgrass	NA	NA	NA	NA	0.8
Pasture, sod-forming grass	NA	NA	NA	NA	1.3
Pasture, weeds	NA	NA	NA	NA	0.5

[1]Based on calibration against WEPP plot erosion data.
[2]NA = Data are not available.
[3]Root crowns and burls were excluded from root-biomass calculations.

Table 5-5.
Parameter values of typical cropland field operations

Field operations[1]	Random roughness[2] (in)	Residue left on surface[3,4] (%)	Depth of incorporation[5] (in)	Soil surface disturbed (%)
Chisel, sweeps	1.2	70	6	100
Chisel, straight point	1.5	60	6	100
Chisel, twisted shovels	1.9	45	6	100
Cultivator, field	0.7	75	3	100
Cultivator, row	0.7	80	2	85
Cultivator, ridge till	0.7	40	2	90
Disk, 1-way	1.2	30	4	100
Disk, heavy plowing	1.9	35	6	100
Disk, tandem	0.8	50	4	100
Drill, double disk	0.4	90	2	85
Drill, deep furrow	0.5	70	3	90
Drill, no-till	0.4	80	2	60
Drill, no-till into sod	0.3	90	2	20
Fertilizer applicator, anhydrous knife	0.6	80	2	15
Harrow, spike	0.4	80	2	100
Harrow, tine	0.4	85	2	100
Lister	0.8	20	4	100
Manure injector[5]	1.5	50	6	40
Moldboard plow	1.9	5	8	100
Mulch treader	0.4	75	2	100
Planter, no-till	0.4	85	2	15
Planter, row	0.4	90	2	15
Rodweeder	0.4	90	2	100
Rotary hoe	0.4	85	2	100
Vee ripper	1.2	80	3	20

[1]See American Society of Agricultural Engineers Standards 414 and 477.
[2]Zobeck and Onstad 1987.
[3]Stott and Barrett 1991.
[4]Percentage of before-operation cover for nonfragile residue. Values will be lower for fragile residues.
[5]The depth in which 75% of the residue is buried.

Table 5-6.
Roughness values for rangeland field conditions

Condition	Random roughness (in)
California annual grassland	0.25
Tallgrass prairie	0.30
Clipped and bare	0.60
Pinyon/Juniper interspace	0.60
Cleared	0.70
Natural shrub	0.80
Seeded rangeland drill	0.80
Shortgrass, desert	0.80
Cleared and pitted	1.00
Mixed grass, prairie	1.00
Pitted	1.10
Sagebrush	1.10
Root-plowed	1.30

Table 5-7.
Growing-season soil-moisture depletion rates for use in calculation of soil moisture subfactor for use in the Northwestern Wheat and Range Region.

Crop	Depletion rate
Winter wheat and other deep-rooted crops	1.00
Spring wheat and barley	0.75
Spring peas and lentils	0.67
Shallow-rooted crops	0.50
Summer fallow	0.00

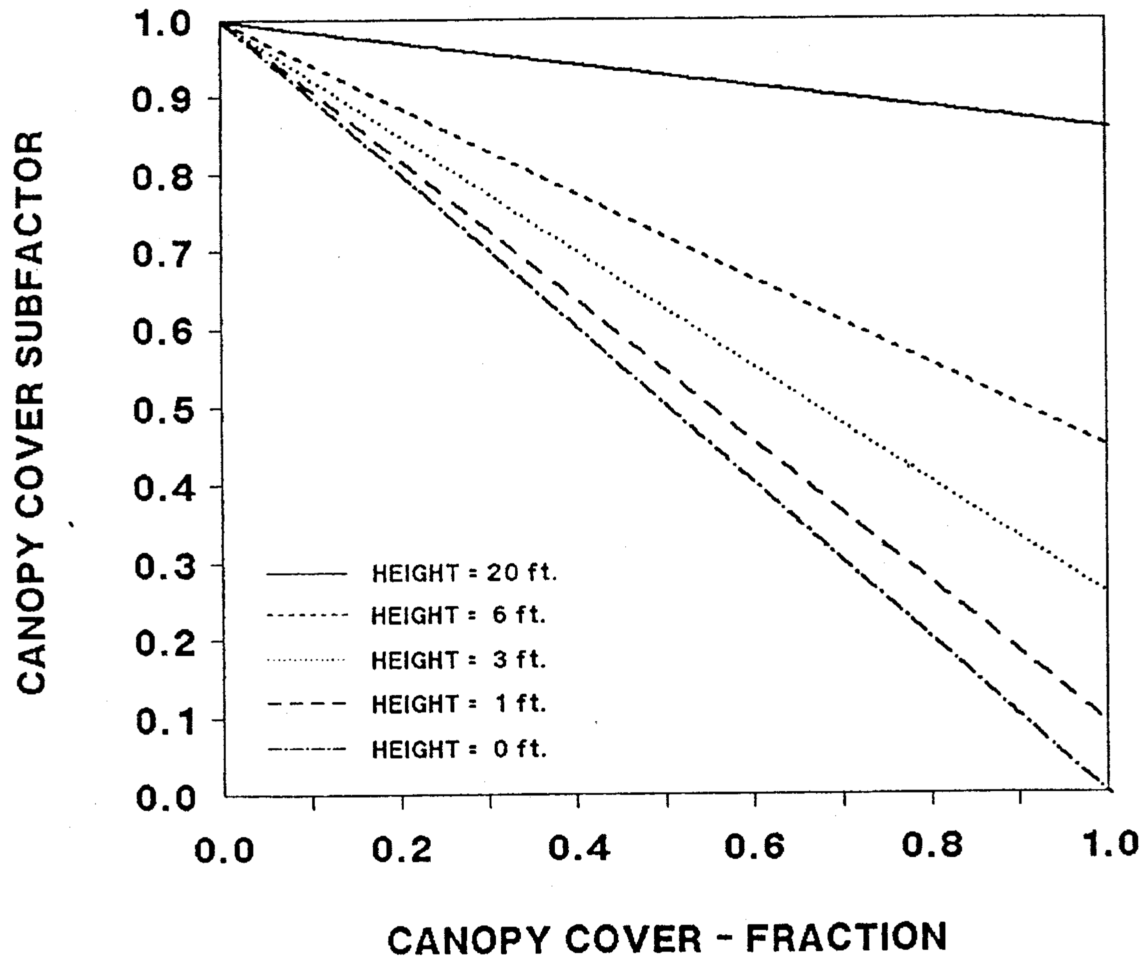

Figure 5-1.
Effect of canopy cover and canopy height on the canopy-cover subfactor

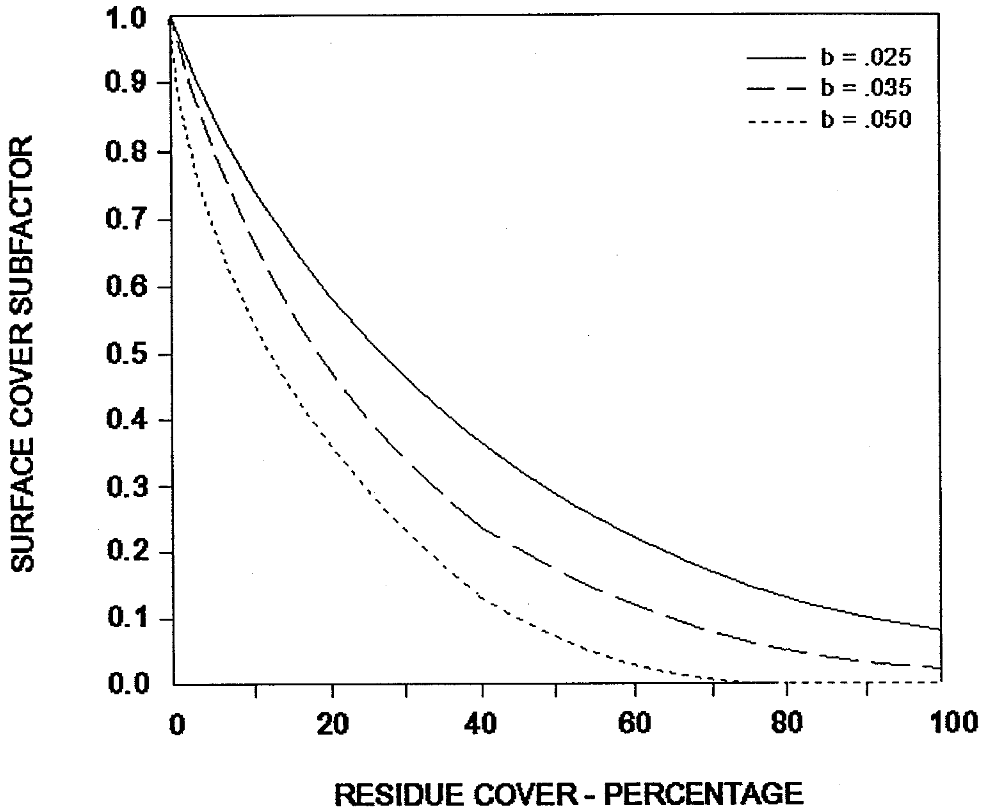

Figure 5-2.
Effect of residue cover and b values on the surface-cover subfactor for smooth field surfaces

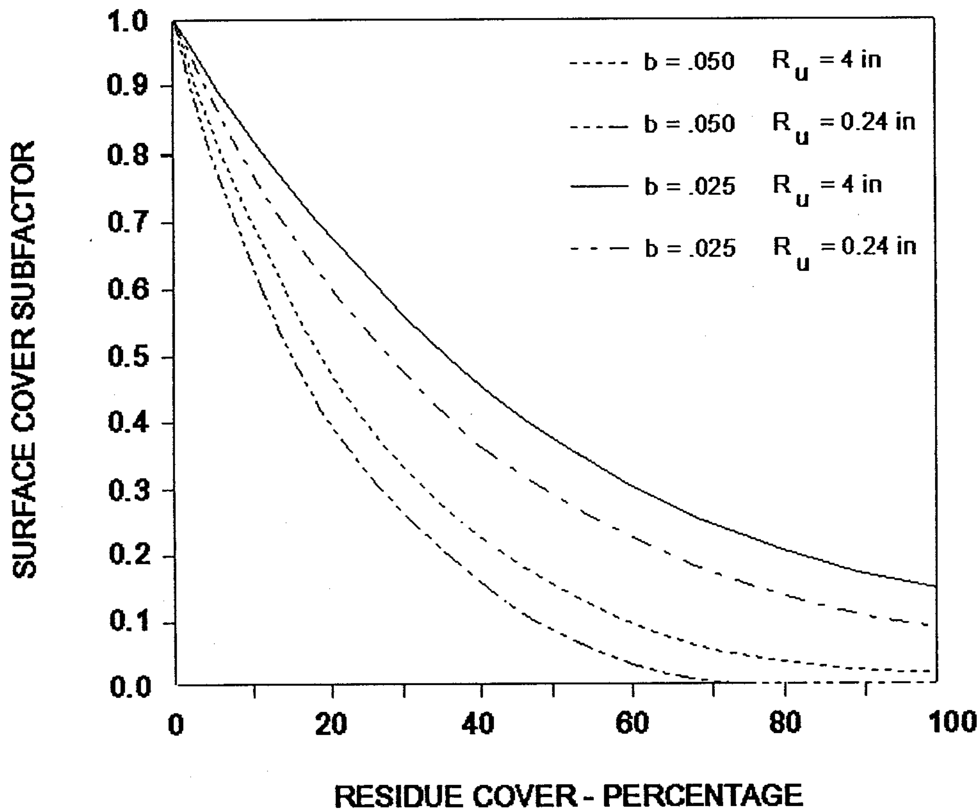

Figure 5-3.
Effect of residue cover, b values, and surface roughness on the surface-cover subfactor. An R_u value of 0.24 in is typical of a field in seedbed condition. An R_u value of 4 in indicates more roughness than from most primary tillage operations.

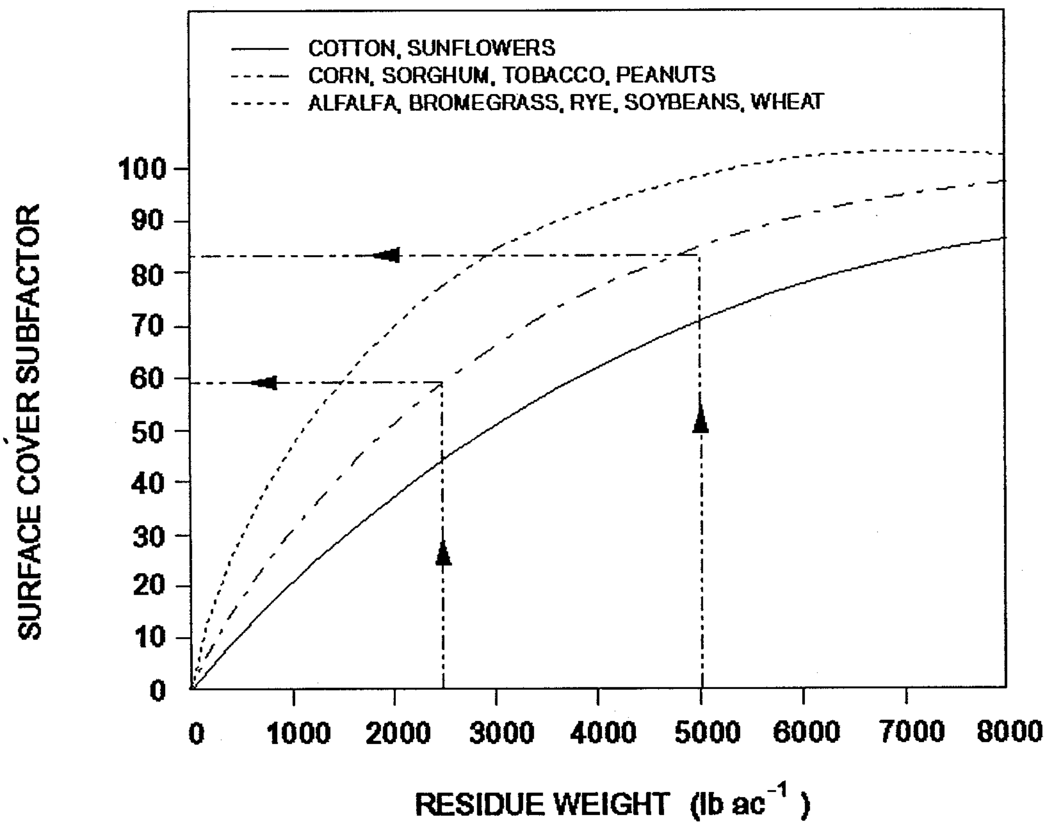

Figure 5-4.
Relationship of residue weight to percent residue cover for various crops.

Example: Dashed lines with arrows illustrate the procedure to convert weight to percent residue cover. Corn residue weighing 5,000 lb · acre^{-1} at harvest leaves 82% residue cover, and 2,500 lb · acre^{-1} leaves 57% cover. Note that, in this example, a 50% reduction in residue weight results in a 25% reduction in residue cover.

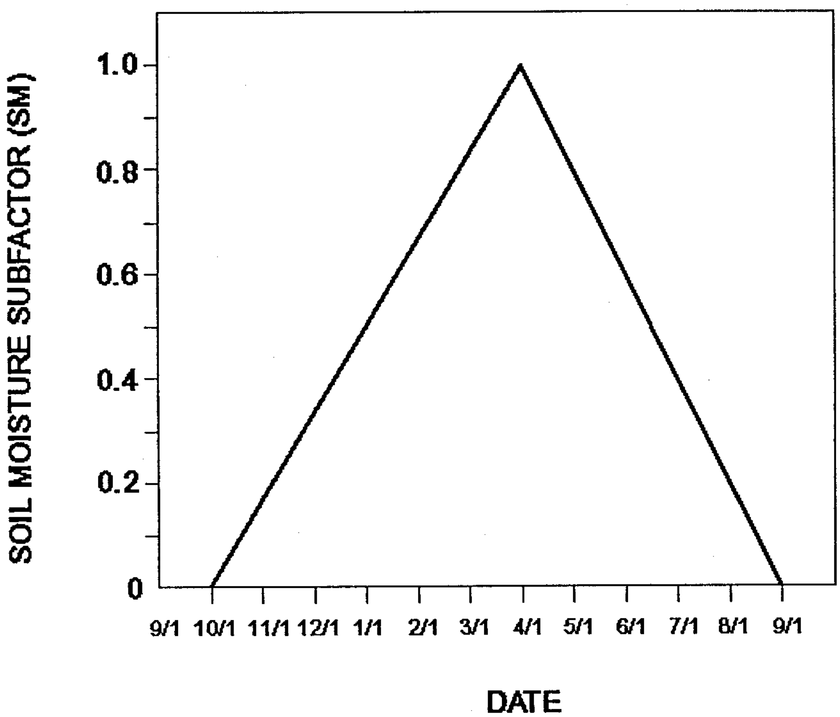

Figure 5-5.
Maximum range in soil-moisture subfactor as affected by profile replenishment and depletion for the Northwestern Wheat and Range Region

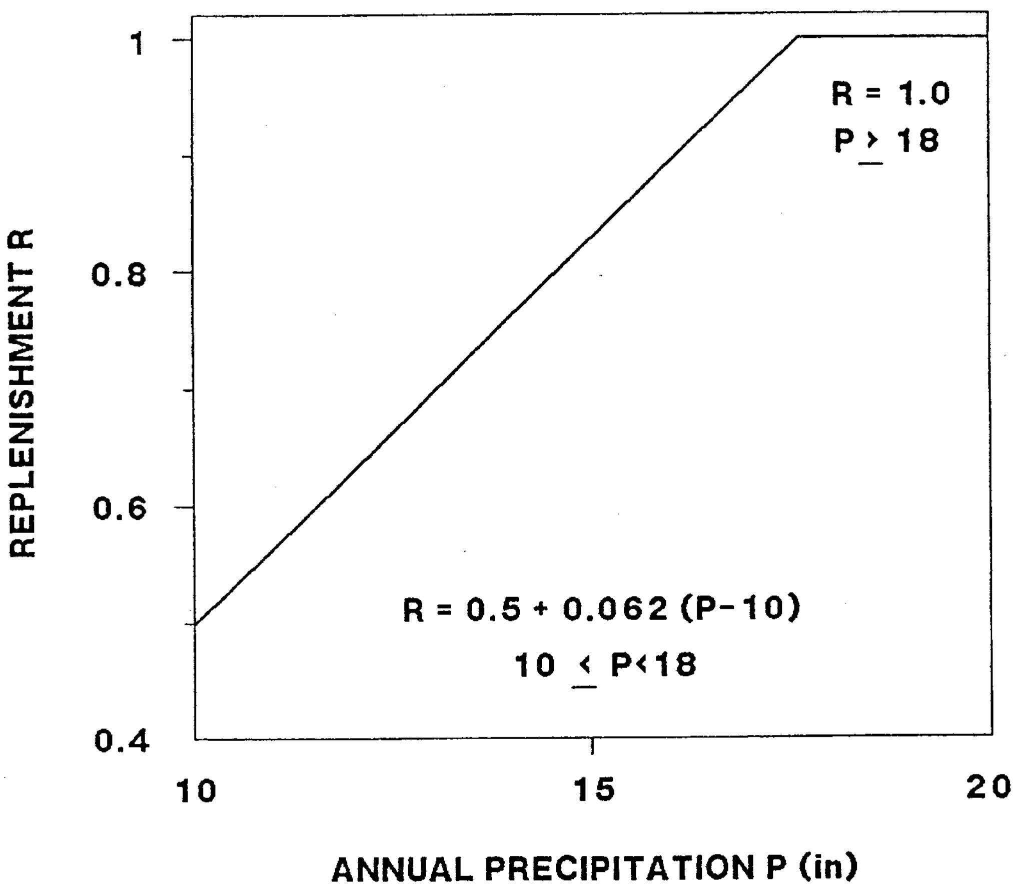

Figure 5-6.
Fraction of soil moisture replenished over winter versus annual precipitation for calculation of a soil-moisture subfactor for the Northwestern Wheat and Range Region

CHAPTER 6. SUPPORT PRACTICE FACTOR (P)

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By definition, the support practice factor (P) in RUSLE is the ratio of soil loss with a specific support practice to the corresponding loss with upslope and downslope tillage. These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by reducing the amount and rate of runoff (Renard and Foster 1983). For cultivated land, the support practices considered include contouring (tillage and planting on or near the contour), stripcropping, terracing, and subsurface drainage. On dryland or rangeland areas, soil-disturbing practices oriented on or near the contour that result in storage of moisture and reduction of runoff are also used as support practices.

P does not consider improved tillage practices such as no-till and other conservation tillage systems, sod-based crop rotations, fertility treatments, and crop-residue management. Such erosion-control practices are considered in the C factor.

Values for P factors contained in this chapter were obtained from experimental data, supplemented by analytical experiments involving scientific observations of known cause-and-effect relationships in physically based models such as CREAMS (Knisel 1980). Recommended factor values are generally rounded to the nearest five-hundredth.

An overall P-factor value is computed as a product of P subfactors for individual support practices, which are typically used in combination. For example, contouring almost always accompanies stripcropping and terraces.

SUPPORT PRACTICE FACTOR (P) FOR CONTOURING

The effect of contour tillage on soil erosion by water is described by the contour P factor in the Revised Universal Soil Loss Equation (RUSLE). If erosion by flow occurs, a network of small eroded channels or rills develops in the areas of deepest flow. On relatively smooth soil surfaces, the flow pattern is determined by random natural microtopography. When tillage is oriented along the contour, the ridges or oriented roughness will partially or completely redirect the runoff, thereby modifying the flow pattern. When tillage leaves high ridges, runoff stays within the furrows between the ridges, and the flow pattern is completely determined by the tillage marks. High ridges from tillage on the contour cause runoff to flow around the slope, significantly reducing the grade along the flow path and reducing the flow's detachment and transport capacity compared to runoff directly downslope.

When grade is sufficiently flat along the tillage marks, much of the sediment eroded from the ridges separating the furrows is deposited in the furrows (Meyer and Harmon 1985). However, tillage is seldom exactly on the contour. Runoff collects in the low areas on the landscape and if accumulated water overtops the ridges, then rill and concentrated flow erosion usually occur, especially in recently tilled fields (Hill et al. 1944). Runoff from contoured fields is often less than that from fields tilled upslope-downslope (Van Doren et al. 1950). Contour tillage reduces erosion by reducing both the runoff and the grade along the flow path.

Values currently used in USLE (Wischmeier and Smith 1978) for the contour P factor are almost identical to those developed by Smith and Whitt (1947, 1948). At a 0% slope, Smith and Whitt reasoned that the value for the contouring subfactor should be 1.0 because no flow direction is defined. For steep slopes, they reasoned that the contouring subfactor value should be 1.0 for slopes steeper than 25% because a typical ridge 6 in high would store no water. At intermediate slopes, they chose a value of 0.6 for a 2% slope from the plot study of Van Doren et al. (1950) and a value of 0.5 for a 7% slope from the study of Smith et al. (1945).

This handbook recommends values for the RUSLE contour P factor based on erosion theory and analyses of experimental data. Data were from three sources: plots, small watersheds, and solutions of equations derived from erosion theory.

Data Analyses

Plot Data

Data from plot studies on the effect of contouring were found for the 18 locations identified in table 6-1. Plot dimensions varied from study to study with widths as narrow as 6 ft to as wide as 150 ft and lengths of 70 to 400 ft. Six studies were conducted with simulated rainfall, and 12 studies were on natural-runoff plots. The duration of the natural-runoff-plot studies ranged from a few days to 10 yr. Cropping and ridge height varied among the studies.

Contouring affected both runoff and erosion, but erosion was affected more than runoff. The ratio of (1) runoff and soil loss from a treatment tilled on the contour to (2) the runoff and soil loss from the same treatment tilled uphill-downhill was calculated for the period of record at a location. The results for runoff are shown in figure 6-1. The results for soil loss, the RUSLE contour P factor, are shown in figure 6-2.

Watershed Data

Soil-loss data collected from watersheds of 0.15-5 acres at four locations (table 6-2) were analyzed and plotted in figure 6-2. Straightforward comparisons of soil loss from uphill-downhill tillage with soil loss from contour tillage were impossible for many of the watershed studies. For example, the crop rotation at Clarinda, Iowa (Browning et al. 1948), differed among the watersheds. Data from a plot were compared against data from a watershed at LaCrosse, Wisconsin (Hays et al. 1949), to estimate a value for the contouring subfactor. At Bethany, Missouri (Smith et al. 1945), extensive gully erosion in the noncontoured watershed produced sediment that was measured at the watershed outlet but is not estimated with RUSLE. Also, the contoured watershed at Bethany had an extensive network of grassed waterways on 20% of the watershed, resulting in an unusually low sediment yield for this watershed. Therefore, the ratio of sediment yield to erosion from these two watersheds at Bethany gave a value for the contouring subfactor that was probably too low, in general. At Temple, Texas (Hill et al. 1944), areas of the watersheds were not equal. For example, the area of the watershed in the up-and-down tillage was 0.15 acre whereas the area of the contoured watershed was 1.5 acres. Such watershed differences result in appreciable differences in runoff, erosion, and sediment yield, so the data must be appropriately considered.

Analysis With CREAMS

The erosion component of the CREAMS model (Foster et al. 1981a) was used to compute erosion and sediment yield on several hypothetical watersheds under two levels of soil susceptibility to rill and concentrated flow erosion. The configuration of these watersheds was two planes that formed a V with a concentrated flow channel in the middle. Runoff on the planes was analyzed as flow in a series of furrows between ridges spaced 2.5 ft apart. An overland flow channel-channel hydrologic sequence was used in CREAMS to represent the watersheds. The overland-flow element represented the row side slopes, the first channel represented flow in furrows, and the second represented concentrated flow in the V between the planes. The maximum length of the concentrated flow channel in the V was 500 ft. Widths of the planes from their upper edge to the concentrated flow channel were 40 ft and 120 ft for two steep watersheds and 40 ft and 200 ft for two flat watersheds. The steepness of the planes on the steep watersheds was 12%, and the grade along the channel in the V was 6%. The steepness of the planes for the flat watersheds was 6%, and the grade along the channel was 4%. A critical shear stress value of 0.10 lb $\cdot$ ft^{-2} represented a field immediately after secondary tillage—a condition of high susceptibility to erosion by flow (Foster et al. 1980a). A critical shear stress value of 0.20 lb $\cdot$ ft^{-2} represented a field about a month or two after the last secondary tillage—a condition of moderate susceptibility to erosion by flow (Foster et al. 1980a).

Storm characteristics assumed in the analysis were 2.5 in for rainfall amount, 1.6 in for runoff amount, 2.0 in $\cdot$ h^{-1} for peak runoff rate, and 50 ft$\cdot$ tonf$\cdot$ in(acre-h)$^{-1}$ EI units for rainfall erosivity, which represent typical simulated rainstorms used in plot studies (Meyer 1960). These runoff values were not varied by watershed condition even though contouring affects runoff as shown in figure 6-1. Therefore, the computer analysis with CREAMS underestimated the effect of contouring.

Furrow grades in the analysis were 0.5%, 1%, 2%, and 4% for the flat watershed and 6% for the steep watersheds. As the grade of the furrows was increased, the upslope drainage area at the head of the concentrated flow channel was increased and the channel length of the concentrated flow in the V was shortened. The results from furrows on a 0.5% grade were assumed to represent excellent contouring and were plotted in figure 6-2.

Results

Figure 6-2 presents the basic data available in the literature. However, the application of RUSLE to contouring problems requires consideration of the storm erosivity and grade along the tillage marks when RUSLE is used in its standard way of taking slope length and steepness directly downslope.

Effect of Ridge Height

Five curves, drawn by inspection through the data shown in figure 6-2, represent the effectiveness of contouring where ridge heights are very low, low, moderate, high, and very high and where the ridges follow the contour so closely that runoff spills over the ridges uniformly along their length. Data showing the greatest effectiveness of contouring were generally from plots having high ridges (Borst et al. 1945, Moldenhauer and Wischmeier 1960). Conversely, data showing the least effectiveness of contouring were from plots having low ridge heights (Van Doren et al. 1950). The end points of the curves at the steep slopes were based on the steepness where typical ridge heights and row spacings would store no runoff.

These curves were described by the following equations:

$$P_b = a(s_m - s_c)^b + P_{mb} \qquad s_c < s_m \qquad [6\text{-}1]$$

$$P_b = c(s_c - s_m)^d + P_{mb} \qquad s_c \geq s_m \qquad [6\text{-}2]$$

$$P_b = 1.0 \qquad s_c \geq s_e \qquad [6\text{-}3]$$

where P_b = base values of the P factor for contouring, s_m = slope (expressed as sine of the slope angle) at which contouring has its greatest effectiveness, s_c = slope (expressed as sine of the slope angle) for which a value of P_b is desired, s_e = slope steepness (expressed as sine of the slope angle) above which contouring is ineffective, and P_{mb} = the minimum P value for a given ridge height with base conditions. The coefficients a, b, c, and d also vary with ridge height.

The curves described by equations [6-1] and [6-2] pass through P_m at the slope s_m, which varies with ridge height shown in table 6-3, and have a zero slope at s_m. In addition, values for the coefficients a and b must be chosen so that equation [6-1] passes through 1 at $s_c = 0$ and equation [6-2] passes through 1 at $s_c = s_e$. To meet these boundary conditions, a is given by the equation

$$a = \frac{1 - P_m}{s_m^b} \qquad [6\text{-}5]$$

and c is given by the equation

$$c = \frac{1 - P_m}{(s_e - s_m)^d} \qquad [6\text{-}5]$$

Values for b, d, s_m, and s_e, chosen by inspection to give good fits to the data shown in figure 6-2, are listed along with values for a and c given in table 6-3.

The data in figure 6-2 are assumed to be for the base condition of a 10-yr-frequency storm EI of 100 ft · tonf · in(acre · hr)$^{-1}$ and for a row crop with clean tillage on a soil classified as being in the hydrologic soil group C.

Effect of Storm Severity

Data from field studies indicate that contouring is less effective for large storms than for small storms (Moldenhauer and Wischmeier 1960, Jasa et al. 1986). The reduced effectiveness depends on both amount of runoff and peak rate of runoff. These runoff variables are directly related to rainfall amount and intensity, which are the principal variables that determine EI (storm energy times maximum 30-min intensity), the erosivity factor in RUSLE. Therefore, values for the contouring subfactor should be near 1 (little effectiveness) when EI is high and infiltration into the soil is low, and should be small (greater effectiveness) when EI is low and infiltration is high (Moldenhauer and Wischmeier 1960). Loss of contouring effectiveness is likely to occur from a few major storms (Hill et al. 1944, Jamison et al. 1968). Therefore, erosivity of a single storm, such as the storm having a 10-yr return frequency, should be a better indicator of loss of contouring effectiveness than is average annual erosivity.

In figure 6-2, the highest 10-yr storm EI for the locations represented in figure 6-2 was 165 ft · tonf · in(acre · hr)$^{-1}$ at Temple, Texas (Wischmeier and Smith

1978), where contouring had little effectiveness. Conversely, the lowest 10-yr storm EI was 50 ft · tonf · in(acre · hr)$^{-1}$ at Arnot, New York (Lamb et al. 1944), where contouring was most effective. The contouring P-factor values were also low at Clarinda, Iowa (Moldenhauer and Wischmeier 1960), where the 10-yr storm EI was 76 ft · tonf · in(acre · hr)$^{-1}$. Erosivity was high—140 ft · tonf · in(acre · hr)$^{-1}$ at Batesville, Arkansas (Hood and Bartholomew 1956), where ridge breakovers occurred and the contouring P-factor value was high.

A linear regression analysis using the complete data set showed an increase in the contouring P factor with an increase in the 10-yr single-storm EI [$(EI)_{10}$]. The analysis also showed that effectiveness of contouring increased with increasing ridge height (Moldenhauer and Wischmeier 1960).

The effectiveness of contouring in RUSLE is assumed to vary with runoff, which is a function of both rainfall and infiltration. Runoff, computed using the Natural Resource Conservation Service (NRCS) runoff curve number method and the rainfall amount estimated from the 10-yr single-storm EI, is used as a guide in RUSLE to adjust P-factor values for changes in effectiveness of contouring that result from runoff differences among locations, soils, and cover-management conditions.

Values for the 10-yr storm EI are obtained from the Citycode files in the computer program of RUSLE. These EI values are converted to storm rainfall amounts using the equation (Foster et al. 1980b)

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

where V_r = rainfall amount in inches. Values for rainfall amount, V_r, are used in the NRCS runoff curve method to compute a runoff amount. Cover-management conditions for cropland are grouped in the seven categories described in table 6-4. The runoff index values, equivalent to curve numbers, used to compute runoff for each of these conditions are given in table 6-5. (For Northwestern Wheat and Range conditions and runoff index values, see tables 6-25 and 6-26.)

Runoff was assumed to affect P-factor values for contouring in two ways: the minimum value of the P factor was assumed to vary directly with computed runoff, and the slope steepness above which contouring loses its effectiveness was also assumed to vary directly with runoff. The basis for these assumptions is that the effectiveness of contouring is assumed to be directly proportional to the shear stress applied to the soil by the runoff. This shear stress is directly proportional to runoff rate and slope steepness to the 1.167 power (Foster et al. 1982). Runoff rate was assumed to be directly proportional to runoff amount. Thus the slope steepness (s_e) at which contouring loses its effectiveness was computed as

$$s_e = s_{eb}\left(\frac{3.72}{Q_k}\right)^{0.857} \qquad [6\text{-}7]$$

where s_{eb} = slope steepness for a given ridge height on base conditions at which contouring loses its effectiveness, Q = computed runoff amount (in) for the given soil and cover-management condition indicated by subscript k, and 3.72 = runoff amount (in) computed for cover-management condition 6, hydrologic soil group C, and a 10-yr storm EI of 100 ft · tonf · in(acre · hr)$^{-1}$. This storm EI is typical of much of the central part of the eastern United States, and the hydrologic soil group C is assumed to be typical of many of the soils in the contouring experiments that produce the data shown in figure 6-2. Similarly, the minimum P-factor value (P_m) is computed from

$$P_m = P_{mb}\left(\frac{Q_k}{3.72}\right) \qquad [6\text{-}8]$$

where P_{mb} = minimum P-factor value for a ridge height on base conditions.

Equations [6-1], [6-2], and [6-3] give P-factor values for base conditions. These curves shift as field conditions vary from the assumed base conditions. The following approach was used to take into account these differences:

The first step is to compute a scaled slope steepness. For a slope steepness of less than s_m, the actual slope steepness is used directly in equation [6-1] to compute a P_b value. For slopes steeper than s_m, the slope used in equation [6-2] is computed from

$$s_c = \frac{\left(s - s_m\right)\left(s_{eb} - s_m\right)}{\left(s_e - s_m\right)} + s_m \qquad [6\text{-}9]$$

The computed P_b value is then scaled as

$$P = 1 - \frac{\left(1 - P_b\right)\left(1 - P_m\right)}{1 - P_{mb}} \qquad [6\text{-}10]$$

If the steepness exceeds s_e computed from equation [6-7], then P = 1.0. If the value computed by equation [6-10] is less than an absolute minimum value (P_z) given in table 6-3, the absolute minimum P_b value for that ridge height is assigned to P.

Effect of Off-Grade Contouring

Contouring alone is often inadequate for effective erosion control (Hill et al. 1944, Smith et al. 1945, Jamison et al. 1968). Runoff frequently flows along the furrows to low areas on the landscape, where breakovers occur. Grassed waterways are needed in conjunction with contouring to safely dispose of the runoff that collects in natural waterways at the breakovers (Smith et al. 1945).

Erosion in the concentrated flow areas occurs even if contouring is not used, although eroded concentrated flow channels extend farther upslope with contouring. Our analysis with CREAMS showed that if row grade is slight, 0.5% or less, deposition in the furrows more than offsets the erosion in the concentrated flow areas.

As grade along the furrows increases from tillage being off contour, the effectiveness of contouring decreases. Results from CREAMS and experimental data (McGregor et al. 1969, Meyer and Harmon 1985) showed a rapid loss of effectiveness of contouring as grade along the furrows increased. The furrows in these situations were for clean-tilled row crops.

Soil loss estimated with RUSLE using the slope length measured downslope and the contouring factor in figure 6-2 includes the erosion in concentrated flow (ephemeral gully) areas for about 500 ft of a concentrated flow channel. The reason for the inclusion of ephemeral gully erosion by concentrated flow in the P factor is that the watershed data used in the derivation of figure 6-2 were collected on small watersheds that contained eroding ephemeral gully areas.

The equation used in RUSLE to compute P-factor values for off-grade contouring is

$$P_g = P_o + \left(1 - P_o\right)\left(\frac{s_f}{s_l}\right)^{1/2} \qquad [6\text{-}11]$$

where P_g = P factor for off-grade contouring, P_o = P factor for on-grade contouring (as computed by equation [6-10]), s_f = grade (expressed as sine of the slope angle) along the furrows, and s_l = steepness (expressed as sine of the slope angle) of the land. This equation is similar to the relationship assumed by Dissmeyer and Foster (1980) for application of USLE to disturbed forest lands. The data collected by McGregor et al. (1969) seem to be the only field data available that can be used to directly evaluate equation [6-11]. Grade along furrows in that study varied between 0.2% and 0.4%. The P-factor value in the McGregor et al. (1969) study was 0.39 for 150-ft wide plots on a 5% slope with off-contour tillage whereas the P-factor value was 0.10 when the furrows were perfectly on the contour. Given a value of P_o = 0.10, the value of P_g computed by equation [6-11] for a 0.3% furrow grade is 0.32, slightly less than the 0.39 measured value.

ESTIMATING SOIL LOSS WITH CONTOURING WHEN SLOPE LENGTH EXCEEDS CRITICAL SLOPE LENGTH

Critical Slope Limits

At long slope lengths, contouring loses its effectiveness. Wischmeier and Smith (1978) gave a table of values for critical slope lengths for USLE that represented slope lengths beyond which contouring was assumed to lose much of its effectiveness. These critical slope-length limits were given only as a function of slope steepness, but Wischmeier and Smith suggested that critical slope length increased if residue cover exceeded 50%.

Foster et al. (1982) investigated the hydraulic conditions under which surface residue failed and allowed serious erosion to occur. Their analysis considered the shear stress exerted by the runoff on the soil and the residue. When the shear stress exerted on the residue exceeded a critical value, the residue was assumed to move. Similarly, when the shear stress exerted on soil exceeded a critical shear stress, flow was assumed to erode the soil.

The equation derived by Foster et al. (1982) for movement of mulch used discharge as the principal hydraulic input variable. Critical slope-length limits in RUSLE are computed with a simplification of the Foster et al. (1982) equation for mulch stability. The equation is

$$\lambda_c = \frac{20182 n_t^{1.5}}{s^{1.1667} Q} \qquad [6\text{-}12]$$

where λ_c = critical slope length, n_t = Manning's n, s = slope (expressed as sine of the slope angle), and Q = runoff amount from the 10-yr storm EI. The value 20,182 was obtained by calibrating equation [6-12] to compute a critical slope length of 200 ft for a 7% slope, moderately high ridges, clean-tilled row crops, a soil classified in the hydrologic soil group C, and a 10-yr storm EI of 100 ft · tonf · in(acre · hr)$^{-1}$. This critical slope-length value agrees with Wischmeier and Smith (1978). Values for Manning's n_t are given in table 6-6 and were chosen from those suggested for the CREAMS model (Foster et al. 1980a) and from field research on the movement of mulch (Foster et al. 1982).

Existing recommended values for critical slope length (Wischmeier and Smith 1978) were based on judgment and field observations. The condition chosen for calibration seems to best represent the typical condition that would have been observed in the field. Values for a range of slopes were computed with equation [6-12] and are shown in table 6-7 along with values from Wischmeier and Smith (1978). The values computed by equation [6-12] are very close to those from Wischmeier and Smith (1978) except for slopes less than 4%. A value of 1,000 ft is set in RUSLE as a maximum critical slope length. Values for critical slope length for a range of conditions are given in tables 6-8, 6-9, and 6-10.

Derivation of RUSLE Equation for Effective P

The procedure for applying RUSLE to irregular slopes (Foster and Wischmeier 1974) was used to develop the equations to calculate effective P-factor values. The beginning point in the derivation is RUSLE applied to a point, as follows:

$$D = (m + 1)\ RKSCP \left(x_* \frac{\lambda}{72.6} \right)^m \qquad [6\text{-}13]$$

where D = erosion rate at a point, m = slope-length exponent, R = rainfall-runoff erosivity factor, K = soil erodibility factor, S = slope steepness factor, C = cover-management factor, and P = support-practice factor for contouring.

The normalized distance x_* is x/λ, where x is distance along the slope length λ and 72.6 is length (ft) of the RUSLE unit plot. All factor values apply to conditions at the point x. The derivation is for a uniform slope. If a more complex situation is being analyzed, the full irregular slope procedure should be used.

Equation [6-13] can be rearranged to give

$$D = (m + 1)\ RKSCP \left(\frac{\lambda}{72.6} \right)^m (x_*)^m \qquad [6\text{-}14]$$

where the term $(\lambda/72.6)^m$ is the slope length factor of RUSLE.

Soil loss, G, for the slope length is obtained by integrating equation [6-14] for the two parts of the slope: the upper part where contouring is assumed to be fully effective and the lower part where no effectiveness of contouring is assumed. The equations for this soil loss are

$$G = \int_0^{x_c} D dx + \int_{x_c}^{1} D dx \qquad [6\text{-}15]$$

Substitution of equation [6-14] into equation [6-15] gives:

$$G = (m+1)\,\lambda \left(\frac{\lambda}{72.6}\right)^{m} \left(P \int_0^{x_c} x_*^{m}\, dx_* + \int_{x_c}^{1} x_*^{m}\, dx_*\right) \qquad [6\text{-}16]$$

Soil loss expressed in units of mass per unit area is obtained by dividing sediment yield G from the slope by slope length λ. Completion of the integration and division by λ gives the equation for soil loss A of

$$A = RKLSC\left[P_{eff}\right] \qquad [6\text{-}17]$$

where

$$P_{eff} = \left[1 - x_c^{\,m+1}(1 - P)\right] \qquad [6\text{-}18]$$

is the effective P factor to compute average soil loss for the slope length λ. Values for P_{eff} were computed using equation [6-18]. Slope-length exponent values for a range of slopes and rill-to-interrill erosion classes are in table 4-5.

Discussion

Use of the effective P-factor values from table 6-10 gives an estimate of the average soil loss for the slope length λ. Soil loss on the lower part of the slope where contouring has been assumed to fail can be considerably greater than the average soil loss for the entire slope. When using this method in conservation planning, the conservationist must consider whether it is permissible to allow soil losses on the lower part of the slope in excess of the soil loss tolerance. Chapter 4 describes how to use RUSLE to compute soil loss on segments and how to adjust segment values to compare with soil-loss tolerances to provide for consistency in RUSLE applications.

SUPPORT PRACTICE FACTOR (P) FOR CROSS-SLOPE STRIPCROPPING, BUFFER STRIPS, AND FILTER STRIPS

Stripcropping is a support practice where strips of clean-tilled or nearly clean-tilled crops are alternated with strips of closely growing vegetation such as grasses and legumes. Another form of stripcropping used on cropland in the Northwestern Wheat and Range Region is very rough, tilled strips instead of strips of closely growing vegetation. The crops are generally rotated sequentially so that at some time in the rotation cycle, every crop will have been grown on every strip. To be compatible with the crop rotation, the width of all strips in the system is usually the same. Stripcropping performs best when the upper edge of each strip is perfectly on the contour.

Stripcropping for the control of water erosion is variously described as contour stripcropping, cross-slope stripcropping, and field stripcropping. Each of these practices has the common characteristic of crops in rotation forming strips of nearly equal width. The difference between the practices is the degree of deviation from the contour. All of them, including contour stripcropping, involve some degree of off-grade contouring. The effectiveness of all of them can be determined with the same equations in the RUSLE computer model. All are versions of the same technology with no sharp distinction despite the wide variation in effectiveness, depending on grade of the row. Therefore, the term "cross-slope stripcropping" is used to refer to the various conditions described above.

Buffer strips, located at intervals up the slope, are resident strips of perennial vegetation laid out across the slope. Like the strips in cross-slope stripcropping, they may or may not be on the contour. These strips, predominantly composed of grass species, are not in the crop rotation, are usually much narrower than the adjacent strips of clean-tilled crops, and may be left in place for several years or permanently. The effectiveness of buffer strips in trapping sediment and reducing erosion can also be evaluated by the RUSLE model.

Vegetated filter strips are bands of vegetation at the base of a slope. Riparian filter strips are located along stream channels or bodies of water. These conservation practices are designed to reduce the amount of sediment reaching offsite water bodies. Neither practice traps eroded sediment on the hillslope and therefore has minimal benefit as a P factor.

Densely vegetated strips or very rough strips that induce deposition of eroded sediment are assigned a P-factor value. Deposition must occur on the hillslope in areas where crops are routinely grown to deserve a low P factor indicative of greatest value to soil conservation. Therefore, P-factor values for maintenance of soil productivity are lowest for cross-slope stripcropping, moderate for buffer strips, and highest for filter strips. A P value of 1.0 is often assigned to filter strips because they provide little protection to the majority of the field where crops are grown.

A major advantage of stripcropping is the rotation of crops among the strips. By rotating crops among strips, each clean-tilled crop receives benefit from the sediment deposited in a previous year by the closely growing crop or the rough strip. Stripcropping significantly reduces the rate of sediment moving down the slope. Because filter strips are located at the base of slopes, the strips do not greatly affect this rate. In general, the benefit of deposition depends on the amount of deposition and its location. Sediment deposited far down the slope provides less benefit than does sediment deposited on the upper parts of the slope. With buffer strips, the sediment is trapped and remains on small areas of the slope, such as terraces; thus the entire slope does not benefit as much as it does in stripcropping.

A strip is effective in reducing soil loss when it significantly reduces the transport capacity of the runoff as it leaves one strip and enters the next strip. For deposition to occur, the transport capacity must be reduced to less than the sediment load being transported by the runoff. If no deposition occurs, the P value is 1.0. The following examples illustrate the basis for assigning P-factor values.

Examples

The first example is the situation of strips of a clean-tilled row crop separated by strips of grass hay. It is assumed that the uppermost strip is in corn and that erosion occurs at a high rate on this strip. Sediment load will be large in the runoff at the lower edge of the corn strip. The hay strip has a much greater hydraulic resistance to flow than does the clean-tilled area, and this resistance greatly reduces the transport capacity of the runoff as it enters the hay strip. If transport capacity is reduced at the upper edge of the hay strip to a level much less than the sediment load of the runoff entering the hay strip, much deposition occurs and gives a P-factor value of less than 1. As the runoff moves through a sufficiently wide hay strip, deposition reduces the sediment load to less than the transport capacity of the flow in the hay strip. The flow can be erosive as it exits the lower edge of the hay strip.

The relationship of erodibility of a clean-tilled strip to the transport capacity in the densely vegetated strip is illustrated by the extreme example of strips of concrete separated by dense grass strips. It is assumed that the uppermost strip is concrete. Flow over the concrete has great transport capacity, but its sediment load is very low (and approaches zero) because the concrete is not erodible. Even though the grass strip at the lower edge of the concrete greatly reduces the transport capacity of the flow, no deposition occurs because the transport capacity was not reduced to a level less than the sediment load in the flow. Therefore, the value of the P factor for this case is 1.0.

Another example more realistic than the above concrete-grass example illustrates the same principle. This example involves strips of no-till corn interspersed among strips of grass. It is assumed that the uppermost strip is no-till corn with a very heavy cover of residue. Very little erosion occurs on the strip of no-till corn. When the runoff reaches the grass strip, little reduction in the transport capacity of the runoff occurs because that of the grass is only slightly greater than the hydraulic resistance of the no-till corn. Therefore, since the sediment load in the runoff leaving the strip of no-till corn is very low because of little erosion on the no-till corn, no deposition will occur because the grass strip did not reduce the transport capacity of the runoff to a level less than the sediment load in the flow from the no-till strip. In this case, the P-factor value is 1.0.

In summary, the effectiveness of stripcropping, buffer strips, and filter strips as support practices depends on the sediment load generated from the erodible strips relative to the transport capacity of the strips that have greater hydraulic resistance.

Development of P-Factor Values for Strips

The first step in developing RUSLE P-factor values for strips was to review the literature. Unfortunately, most of the experimental research on stripcropping was conducted from 1930 to 1960 and did not include modern conservation tillage systems (Hill et al. 1944, Borst et al. 1945, Smith et al. 1945, Hays et al. 1949, Hood and Bartholomew 1956, Hays and Attoe 1957). Also, crop yields during that period were much less than modern yields, and canopy cover and residue amounts were less than those with modern practices.

Therefore, published experimental data alone are inadequate for developing the necessary P-factor values for the wide range of current practices. The approach taken was to develop a simple erosion-deposition model based on fundamental erosion concepts (Renard and Foster 1983, Flanagan et al. 1989) that could be used in RUSLE to estimate P-factor values for strips. Steps in addition to developing the model included developing parameter values based on theory and experimental data from fundamental erosion studies and adjusting parameter values to obtain an adequate fit of the model to the limited field data. The model is included in RUSLE to compute values for the P factor for stripcropping, buffer strips, and filter strips for a wide variety of situations.

A value for the P factor for strips is computed from

$$P_s = \frac{(g_p - B)}{g_p} \qquad [6\text{-}19]$$

where P_s = value for P factor for strips, g_p = sediment load at end of slope that would occur if the strips caused no deposition, and B = credit for deposition.

Table 6-11 shows values for sediment yield from experimental data for stripcropping found in the literature, along with values computed by the model.

The model computes erosion, sediment transport, and deposition on a strip-by-strip basis, routing the sediment from the top to the bottom of the slope. One of the four following conditions exists on each strip:

(1) Net erosion occurs everywhere along the strip.

(2) Net deposition occurs everywhere along the strip.

(3) Net deposition occurs on an upper area of the strip and net erosion occurs on a lower area of the strip.

(4) Runoff ends within a strip, and no runoff or sediment leaves the strip.

The objective in each case is to compute the amount of deposition (M_i) on each strip and the sediment load (g_i) leaving each strip.

Case 1. Net Erosion Occurs Everywhere Along the Slope

For this case to apply, one condition is that the rate of increase in transport capacity along the strip must be greater than the detachment rate along the strip. For this condition, net erosion is computed by

$$D_{ni} = \xi_i \left(x_i^n - x_{i-1}^n \right) \qquad [6\text{-}20]$$

where ξ = an erosion factor, x = relative distance from the top of the slope to the lower edge of a strip (absolute distance/slope length), n = an exponent set to 1, and I = subscript indicating a particular strip. Values of ξ are given in table 6-12. Sediment load at the lower edge of the strip is given by

$$g_i = g_{i-1} + D_{ni} \qquad [6\text{-}21]$$

where g = sediment load.

The exponent n is set to 1 for all conditions. The reasoning for this value is that contouring is an integral part of stripcropping. When contouring is completely effective, it eliminates rill erosion. Much of the effectiveness of contouring is because of deposition in the furrows left by tillage. Erosion on strips where cover is dense is minimal and is mostly interrill erosion rather than rill erosion. In both situations, the appropriate value of the exponent is 1 (Renard and Foster 1983). The value of the exponent should be about 1.5 where rill erosion is significant. A single value of 1 is used in RUSLE because the principal intent of equation [6-21] is to provide an index of net erosion.

Local deposition, such as in depressions left by tillage, can occur within a strip because the detachment rate exceeds the rate of increase in transport capacity along the strip. For this condition, the deposition equation developed by Renard and Foster (1983) is used to compute net erosion as

$$D_{ni} = \left[\frac{\left(\dfrac{\phi dT_i}{dx} + \xi_i \right)}{(1 + \phi)} \right] \left(x_i - x_{i-1} \right) \qquad [6\text{-}22]$$

where $\phi = V_f / \sigma$, V_f = fall velocity of the sediment, and σ = excess runoff rate (rainfall intensity - infiltration rate). A value of 15 was selected by calibration for ϕ. Although the value for ϕ varies with sediment size and density, the single value of 15 is used in RUSLE. Equation [6-23] is based on the following equation for deposition (Renard and Foster 1983):

$$D = \left(\frac{V_f}{q}\right)(T - g) \qquad [6\text{-}23]$$

where D = deposition rate, q = discharge rate, and T = transport capacity of the runoff.

Case 2. Deposition Occurs Everywhere Along Strip

Deposition occurs at the upper edge of a strip if the transport capacity at the upper edge of a strip is less than the sediment load reaching the upper edge. Deposition will occur over the entire strip if the strip is narrow or if runoff rate decreases with distance within the strip. This latter condition occurs where the infiltration rate in a particular strip is much greater than the infiltration rates on upslope areas.

The basic equation used for strips where deposition occurs is equation [6-23]. Discharge rate q is given by the equation

$$q = q_{i-1} + \sigma_i \left(x - x_{i-1}\right) \qquad [6\text{-}24]$$

In RUSLE, the excess runoff rate is computed as the ratio of runoff amount, expressed as a depth, for the given strip condition to the runoff amount from a clean-tilled row-crop strip, which is condition 6 in table 6-4. Runoff amounts are computed by use of the NRCS runoff curve number method and runoff index values given in table 6-5.

When the infiltration rate on a strip is greater than the rainfall intensity, discharge rate decreases within the strip; if the strip is wide, runoff ends within the strip. Because the NRCS runoff curve number method would ordinarily compute no runoff for this condition, the method was modified to compute the rainfall amount that would just produce runoff. This equation is

$$r = V_r - 0.2\left[\left(\frac{1000}{N}\right) - 10\right] \qquad [6\text{-}25]$$

where r = excess runoff depth (in), V_r = rainfall amount, and N = runoff index. The equation for transport capacity (T) is

$$T = \zeta q \tag{6-26}$$

where ζ = a sediment transport capacity factor. Values of ζ are relative and were chosen based on the Manning's n_t recommended for the CREAMS model (Foster et al. 1980a), the relation of runoff velocity to Manning's n_t, and the assumed relationship that transport capacity varies with the cube of runoff velocity (Foster and Meyer 1975). Values for ζ are given in table 6-12.

The equation derived from equations [6-24], [6-25], and [6-27] to compute sediment load where deposition occurs along the entire strip is

$$\begin{aligned} g_i = &\left(\frac{\phi dT_i}{dx} + \xi_i\right) q_i \left[\sigma_i(1 + \phi)\right]^{-1} \\ &+ \left(\frac{q_{i-1}}{q_i}\right)^{\phi} \left\{ g_{i-1} - \left(\frac{\phi dT_i}{dx} + \xi_i\right) q_{i-1} \left[\sigma_i \left(1 + \phi\right)\right]^{-1} \right\} \end{aligned} \tag{6-27}$$

The change of transport capacity with distance dT_i/dx is given by

$$\frac{dT_i}{dx} = \zeta_i \sigma_i \tag{6-28}$$

The amount (M) of deposition on the strip is computed from

$$M_i = g_i - g_{i-1} + D_{ni} \tag{6-29}$$

Case 3. Both Deposition and Erosion Within a Strip

If the sediment load at the upper edge of a strip is greater than the transport capacity at that location, deposition occurs over an upper area of the strip.

Deposition ends within a strip if the rate of increase in the transport capacity, dT/dx, exceeds the detachment rate ξ, and if the strip is wide. The location where deposition ends is the location where the sediment load equals the transport capacity. The discharge rate (q_{de}) for this condition is given by

$$q_{de} = \left(\frac{a_2 \phi \sigma_i}{a_1 \sigma_i + \xi_i} \right)^{\frac{1}{1+\phi}} \left[q_i \right]^{\frac{\phi}{1+\phi}} \qquad [6\text{-}30]$$

where coefficients a_1 and a_2 are given by

$$a_1 = \frac{\left(\frac{\phi dT_i}{dx} + \xi_i \right)}{\left[\sigma_i \, (1 + \phi) \right]} \qquad [6\text{-}31]$$

$$a_2 = g_{i-1} - a_1 q_{i-1} \qquad [6\text{-}32]$$

The location x_{de} where deposition ends is computed from

$$x_{de} = \frac{\left(q_{de} - q_{i-1} + \sigma_i \, x_{i-1} \right)}{\sigma_i} \qquad [6\text{-}33]$$

The sediment load at the location where deposition ends is given by

$$g_{de} = \zeta_i \, q_{de} \qquad [6\text{-}34]$$

If $dT_i / dx > \xi_i$, sediment load at the lower edge of the strip is given by

$$g_i = g_{de} + \xi_i \left(x_i^{\,n} - x_{de}^{\,n} \right) \qquad [6\text{-}35]$$

If $dT/dx < \xi_i$, sediment load at the lower edge of the strip is given by

$$g_i = g_{de} + \left[\frac{\left(\frac{\phi dT_i}{dx} + \xi_i \right)}{(1 + \phi)} \right] \left(x_i - x_{de} \right) \qquad [6\text{-}36]$$

The amount of deposition (M) is given by

$$M_i = g_i - g_{de} + \left[\frac{\left(\frac{\phi dT_i}{dx} + \xi_i \right)}{(1 + \phi)} \right] \left(x_{de} - x_{i-1} \right) \qquad [6\text{-}37]$$

Another possibility is for net erosion to occur on the upper area of a strip and local deposition to begin within the strip. This condition occurs when the sediment load is less than the transport capacity at the upper edge of a strip and the rate of increase in the transport capacity is less than the detachment rate, $dT_i /dx < \xi_i$. The location where local deposition begins is where sediment load (g_i) equals transport capacity (T). The sediment load at the lower edge of the strip is given by

$$g_i = g_{db} + \left[\frac{\left(\frac{\phi dT_i}{dx} + \xi_i \right)}{(1 + \phi)} \right] \left(x_i - x_{db} \right) \qquad [6\text{-}38]$$

where g_{db} = sediment load where local deposition begins and x_{db} = location where deposition begins. The amount of deposition (M) is zero for this condition if $g_i > g_{db}$. If $g_d < g_{db}$, then $M = g_{db} - g_i$.

Case 4. Runoff Ends Within a Strip

Sometimes the difference in infiltration can be so great between strips that all runoff from upslope is infiltrated within a strip having high infiltration rates. No runoff or sediment leaves these strips.

The location where runoff ends is calculated by use of equations [6-24] and [6-25]. The amount of deposition is the amount of sediment in the runoff entering the strip plus the amount of sediment detached within the strip between the upper edge of the strip and the location where runoff ends.

Application

Computation of P-Factor Value

The P-factor value for stripcropping is computed from

$$P_s = \frac{g_p - B}{g_p} \qquad [6\text{-}39]$$

where P_s = a P-factor value for conservation planning; g_p = potential sediment load if no deposition, other than local deposition, would have been caused by the strips; and B = amount of deposition considered to benefit the long-term maintenance of the soil resource. This benefit is computed by

$$B = \sum_{i=1}^{n} M_i \left(1 - x_{i-1}^{1.5}\right) \qquad [6\text{-}40]$$

where n = number of strips. The potential sediment load (g_p) is computed from

$$g_p = \sum_{i=1}^{n} D_{ni} \qquad [6\text{-}41]$$

where D_{ni} is computed for each strip according to equation [6-20] or [6-22].

The model also computes a sediment delivery ratio (P_y) for the slope by use of the equation

$$P_y = \frac{g_\lambda}{g_p} \qquad [6\text{-}42]$$

where g_λ = sediment load at the end of the slope.

Values for P computed for several stripcrop systems are shown in table 6-13.

The above equations and parameter values given in table 6-12 are used in RUSLE to compute a P-factor value and a sediment-delivery-factor value for any combination of strips, including buffer and filter strips. The parameter values in table 6-12 were developed to produce average annual P-factor values. The data used to determine the parameter values were heavily weighted by erosion in late spring and early summer, conditions when most erosion occurs with row crops in the eastern United States. Thus, the parameter values in table 6-12 most represent these conditions, but other conditions can be represented by choosing parameter values from table 6-12 based on surface conditions at a given time. The model can be applied several times during the year to compute an average P-factor value for the year, or the model can be applied over several years to compute a rotational P-factor value.

The equations used to compute deposition by strips do not take into account deposition in the ponded runoff on the upper side of the grass strip. The effect of the ponded runoff can be partially taken into account by adding the width of the ponded area to the width of the grass strip.

The effectiveness of strips as a soil conservation practice primarily results from the deposition induced at the upper edge of heavily vegetated or rough strips. In traditional applications of stripcropping, uniform-width strips are moved up the slope according to a crop rotation such as corn-wheat-1st yr hay-2d yr hay. In buffer strip applications, permanent vegetated strips that are much narrower than the cropped strips are installed. In rotational stripcropping, clean-tilled crops are grown on the strips where deposition occurred in prior years. In contrast, the benefit of narrow, permanent strips is that sediment is trapped and kept on the slope, but the immediate benefit is localized. The benefit to the entire slope is very little if a permanent strip is narrow and located at the end of the slope. If a single, narrow strip is placed high on the slope, none of the slope segment above the strip benefits from the deposition. This portion of the slope continues to erode at the same rate as if the strip were not present. The strip does, however, decrease the rate at which sediment moves off the slope over the long term; thus the slope segment below the strip benefits from the deposition induced at the upper edge of the strip.

The P-factor values and the resulting soil-loss values computed by RUSLE are intended to be used in conservation planning for maintenance of the soil resource base. Full credit is not taken for the total amount of deposition for conservation planning. The benefit assigned by equation [6-40] to the deposition depends on the location of deposition. The degree of benefit increases as the location of deposition moves up the slope; conversely, little benefit is assigned when the strip is near the end of the slope. This approach is conceptually consistent with the way that P-factor values are assigned to terraces (Foster and Highfill 1983).

RUSLE also computes a sediment delivery factor. Multiplication of this factor by the product RKLSC gives an estimate of sediment yield leaving the slope. Sediment-yield values are typically less than the soil loss computed with RUSLE because RUSLE does not give full credit to deposition as a benefit for maintenance of the soil resource over the entire slope.

The effectiveness of stripcropping is assumed to be independent of strip width up to the point that rilling begins. Results were varied in experimental studies on the effect of strip width. Once strips become so wide or slope lengths become so long that rilling occurs, stripcropping begins to lose its effectiveness. Because of the complexity of the problem, no approach is suggested to estimate a P-factor value representing the lost effectiveness of stripcropping due to excessively long slope lengths. Critical slope lengths for conservation planning for stripcropping are assumed to be 1.5 times the critical slope length for contouring. Critical slope lengths for stripcropping are related to the maximum slope lengths for contouring because contouring is an integral part of stripcropping. Computation of soil loss when slope lengths exceed critical slope lengths is the same as computation of soil loss for contouring.

For maximum effectiveness, stripcropping is installed with the upper edge of the strips on the contour. However, strips are sometimes installed off contour, resulting in a grade along the upper edge of the strips. The effectiveness of these strips is difficult to evaluate. Deposition occurring at the upper edge of the densely vegetated strips builds up a ridge of soil that can cause runoff to flow along the upper edge of the strip and not pass through the strips. On tilled strips, runoff can flow along the tillage marks and never reach the strip if tillage is on a grade. The net result is that the system behaves no differently than off-grade contouring with a weighted C factor based on the area occupied by the various strips. This approach produces a P-factor value that represents the minimum effectiveness of strips. The maximum effectiveness can be estimated by use of the stripcrop model by choosing a designation for the cropped strips having an erodibility greater than that for the contour tilled condition, to represent the reduced effectiveness of off-grade contouring. The overall P factor is a combination of two P factors: one for off-grade contouring, and one for stripcropping with an adjusted surface designation because of increased sediment (resulting from off-grade contouring) reaching the densely vegetated strips.

The stripcrop model in RUSLE estimates the amount of deposition induced by a strip by representing the main factors that affect sediment transport and deposition. However, even though the parameter $\phi = V_f/\sigma$ represents the effect of sediment characteristics, a single value is used for all conditions. Therefore, actual deposition will be greater and sediment delivery will be less than that computed with RUSLE for soils high in either clay or sand content compared to typical silt loam soils. The converse is true for soils whose silt content is higher than that in silt loam soils. Furthermore, upslope localized deposition in depressions left by tillage or deposition by upslope strips reduces the particle size and thus the amount of sediment deposited by downslope strips. In estimating sediment passing through strips that induce deposition, the CREAMS model (Foster et al. 1980a) or the SEDIMOT II model (Wilson et al. 1986) considers more factors over a wider range of conditions than does RUSLE.

SUPPORT PRACTICE FACTOR (P) FOR TERRACING

Terraces reduce sheet and rill erosion on the terrace interval by breaking the slope into shorter slope lengths. Also, deposition along the terraces may trap much of the sediment eroded from the interterrace interval, particularly if the terraces are level and include closed outlets, have underground outlets, or have a very low grade. Deposited sediment remains on the field and is redistributed over a significant portion of the field, thus reducing soil deterioration caused by erosion. In this way, terraces help to maintain the soil resource much as contour stripcropping does. Furthermore, properly designed terraces and outlet channels collect surface runoff and convey it off the field at nonerosive velocities. Without the terraces and outlet channels, runoff in natural waterways on unterraced fields can cause significant erosion.

Deposition Behind Terraces

The amount and location of sediment deposited on terraced fields are important in assigning P-factor values to calculate soil loss for conservation planning. If no soil is trapped, none is saved by deposition. Even if deposition traps all sediment eroded from the interterrace interval, the area benefiting directly is that near the terraces. Some of the interterrace interval is still degraded as if no deposition occurs. The P factor for computing soil loss for conservation planning to maintain the soil resource is computed as a function of spacing between terraces. The maximum benefit assigned to deposition is that half of the deposition directly benefits maintenance of the soil resource at spacings of less than 110 ft. At spacings of greater than 110 ft, the benefit is assumed to decrease to the point that no benefit is assigned for spacings of 300 ft and greater.

Erosion of the upslope and deposition on the downslope portion, within the terrace interval, cause a flatter slope that can be permanently maintained above storage-type terraces. On deep soils, a permanent bench can be formed, resulting in less erosive topography and easier farming (Jacobson 1981).

Measured elevations on gradient terraces (Borst et al. 1945, Copley et al. 1944, Daniel et al. 1943, Pope et al. 1946, Smith et al. 1945) showed that after 8 yr, deposited soil accumulated on terrace ridges, channel bottoms, and front and back slopes. The sediment accumulation on ridges and backslopes was produced by displacement during tillage and terrace maintenance. With closed outlet and underground outlet terraces, sediment accumulates where runoff enters standing water.

Effect of Grade

An analysis of terrace data from the 1930's and 1940's showed that deposition varies greatly with terrace grade (Foster and Ferreira 1981). Sediment yield from single-terrace watersheds with a range of grades was measured for about 8 yr at several locations. Results of this analysis show that the sediment yield from uniform-grade terraces increases according to the following exponential relationship:

$$P_y = 0.1e^{2.4s} \qquad s<0.9\% \tag{6-43}$$

$$P_y = 1.0 \qquad s\geq 0.9\% \tag{6-44}$$

where P_y = sediment delivery factor and s = terrace-slope grade (%). The P factor for conservation planning is computed as

$$P = 1 - B(1-P_y) \tag{6-45}$$

where B = the benefit assigned to deposition, and the quantity $1-P_y$ = that amount of deposition, comparable to M in the stripcropping computations. Values for B are given in table 6-14.

Terrace P Factor for Conservation Planning

The P factor for terraces for use in conservation planning considers both the benefit of deposition and the amount of sediment deposited. This net soil loss is the soil loss on the interterrace interval minus the amount of deposited soil that is credited for helping to maintain the soil resource. Table 6-15 gives terrace P-factor values for use in conservation planning (Foster and Highfill 1983). Table 6-16 gives values for use in estimating sediment yield from terraces.

To compute soil loss with RUSLE for conservation planning, values for the terrace P factor are multiplied by other factor values for contouring and stripcropping on the interterrace interval.

SUPPORT PRACTICE FACTOR (P) FOR SUBSURFACE DRAINED AREAS

Limited field data indicate that subsurface drainage is effective in reducing overland flow and erosion (Formanek et al. 1987, Bengtson and Sabbage 1988). Both the Formanek and the Bengtson and Sabbage studies reported P values with an average of about 0.6, although individual annual values and storm values varied appreciably.

Because of limited information and differences in procedures among studies, further research is needed to develop a range of P-factor values for subsurface drained areas that are applicable across many conditions of climate, soil, crop, and slope. The technique needing development may well include a procedure similar to that reported by Skaggs et al. (1982). This technique may involve estimating runoff volume, peak runoff rate, and storm EI by use of a physically based model like CREAMS (Knisel 1980) to estimate P-factor values for simulations with and without subsurface drainage situations over a wide range of field conditions.

SUPPORT PRACTICE FACTOR (P) FOR RANGELANDS

The support practice factor (P) in RUSLE reflects the effect on rangeland erosion of mechanical practices such as ripping, root plowing, contour furrowing, and chaining. Some common mechanical practices applied on rangelands are listed in tables 6-17, 6-18, and 6-19. These practices affect erosion in several ways, including the removal of surface cover, which is perhaps the most important single factor affecting erosion. However, that effect is considered by the cover-management factor C in RUSLE. Mechanical practices described by the P factor can affect runoff amount, runoff rate, flow direction of runoff, and hydraulic forces exerted by runoff on the soil.

Almost every mechanical practice that disturbs rangeland soils increases infiltration, which in turn reduces runoff and erosion. An exception is the compaction and smoothing used for water harvesting. The degree to which infiltration is increased depends on the soil. The increase in infiltration and the reduction in runoff can be very large on the coarse-textured soils of the southwestern United States, whereas the increase in infiltration and the reduction in runoff can be slight on fine-textured soils like those in South Dakota. In fact, the crusting of fine-textured soils after mechanical practices that expose the soil can cause decreased infiltration. The ratings for runoff reduction given in tables 6-16, 6-17, and 6-18 are general. More precise ratings are possible from knowledge of the hydrologic properties of local soils.

A practice like contour furrowing that produces ridges and furrows will redirect surface runoff from flowing directly downhill to a flow path around the hill on a reduced grade. The reduced grade can greatly decrease the erosivity of the runoff. A practice like ripping at right angles to the slope, which leaves a very rough surface, also slows the runoff and reduces its erosivity. Depressions formed by the roughness provide areas where sediment is deposited, thus reducing soil loss.

The effectiveness of mechanical practices decreases over time as the soil surface seals and the depressions and furrows are filled with sediment. The rate at which a practice loses its effectiveness depends on the climate, soil, slope, and cover. The estimated times of effectiveness for practices listed in table 6-19 are general and should be adjusted for local conditions. Values for P should be increased over time from the minimum value immediately after treatment, because the practices are estimated to lose their effectiveness.

Runoff Reduction and Surface Roughness

The effect of increased infiltration and surface roughness are considered together when selecting a value for P because the influence of runoff and surface roughness are interrelated with slope steepness. The effect of surface roughness on the reduction of soil loss will decrease as the slope steepness increases.

Values for the P factor for rangelands for the effect of roughness, infiltration, and slope are computed in RUSLE with the equation

$$P = \frac{D_y}{D_e} \qquad [6\text{-}46]$$

where D_y = sediment transported from the slope, and D_e = sediment produced on the slope by detachment.

The P factor considers that the roughness is assumed to cause some of the sediment produced by detachment to be deposited in the depressions left by the roughness. The amount of sediment leaving the slope (D_y) is computed by the deposition equation used to compute values for P with stripcropping (Renard and Foster 1983), as follows:

$$D_y = \left(\phi \; dT/dx + D_e\right) / \left(1 + \phi\right) \qquad [6\text{-}47]$$

where ϕ = a parameter that indicates how readily sediment is deposited, and dT/dx = change in transport capacity with distance.

A value of 15 was assigned to ϕ, the same as in the stripcropping computations. The equation for dT/dx is based on the transport capacity equation used in WEPP (Foster et al. 1989), as follows:

$$dT/dx = k_t \; s \; \sigma \; r_f \qquad [6\text{-}48]$$

where k_t = a transport coefficient, s = sine of the slope angle, σ = excess rainfall rate (rainfall rate minus infiltration rate), and r_f = a roughness factor.

The parameter k_t was assigned a value of 33.28, which was chosen so that the model would fit experimental data for deposition as a function of slope (Meyer and Harmon 1985). Excess runoff rate is computed from

$$\sigma = 1 - f_r \tag{6-49}$$

where f_r is a runoff reduction factor that varies between an initial value at the time of disturbance and zero after decaying over time as the soil consolidates after the disturbance according to

$$f_r = f_{ri}\ c_d \tag{6-50}$$

where f_{ri} = the initial runoff reduction, and c_d = the consolidation factor that is given by

$$c_d = \exp\left(-d_t\ t_d\right) \tag{6-51}$$

where d_t = a decay parameter, and t_d = time (yr) since the soil was disturbed.

Consolidation is assumed to begin immediately. The decay parameter is computed from

$$d_t = -\ln(0.05)\ /\ t_c \tag{6-52}$$

where t_c = time (yr) for 95% of effect of disturbance to have disappeared by consolidation.

Runoff reduction at the time of disturbance is computed by use of the 10-yr frequency single-storm erosivity, and the NRCS runoff index method. Values for runoff index as a function of cover roughness are described in table 6-20; cover roughness conditions are shown in table 6-21. The runoff index values are a function of the rainfall intensity pattern in a storm. Runoff index values are greater for thunderstorm-type rains than for long-duration, gentle, frontal-activity rains. The ratio of 10-yr storm erosivity, $(EI)_{10}$, to average annual precipitation (P) is used as an index to determine curve number values. For $(EI)_{10}/P > 3$, values for thunderstorm-dominated areas are used; for $(EI)_{10}/P < 1$, values for areas dominated by frontal activity are used. Linear interpolation is used for values of $(EI)_{10}/P$ between 1 and 3.

The roughness factor (r_f) is computed from

$$r_f = 0.23\ r_i^{-1.18} \qquad [6\text{-}53]$$

where r_i is a roughness index (in). The coefficient 0.23 and exponent -1.18 were selected to give values for the roughness factor (r_f), which are similar to the values used for ζ in the stripcropping computations.

The value used for r_i is the value that represents the current surface condition. That value is determined by interpolating between the roughness immediately after disturbance and the roughness after consolidation. Equations [6-50] and [6-51] are used in this interpolation. Roughness values for the RUSLE range condition classes are given in tables 6-21 through 6-24.

Detachment (D_e) is assumed to be the same for all conditions except for the effect of disturbance. Detachment is computed with the equation

$$D_e = D_b + \left(1 + D_b\right) c_d \qquad [6\text{-}54]$$

where D_b is the minimum value of detachment after it decreases over time after consolidation relative to the detachment immediately after disturbance. A value of 0.45 is assumed for D_b, the same as used in the C-factor computations.

Redirection of Runoff

When applied on rangelands, practices like contour furrowing are effective because they redirect surface runoff from a downslope path to a less erosive path around the hill. Any rangeland practice that leaves ridges sufficiently high to redirect runoff in this manner has an effect that is considered in the P factor.

Slope Length and Steepness Taken Downhill

Ideally, the grade along the furrows between the ridges should be flat or near flat so that runoff may spill uniformly over the length of the ridges. Ridges perfectly on the contour ensure maximum runoff storage and infiltration and also minimize runoff and erosion. P values for this condition are computed using equations [6-1] through [6-10] by use of the parameter values given in tables 6-21 through 6-24. Slope length is then taken directly down the hill perpendicular to the contour.

The effectiveness of contouring depends on the storm erosivity and the reduction in runoff caused by mechanical practices. Because a few major storms determine the overall effectiveness of contouring, the erosivity (EI_{10}) of the storm with a 10-yr return interval is recommended as the basis for adjusting contour factor values to account for the influence of storm erosivity.

The effectiveness of contouring depends on the ridge height, as indicated by the contour factor values in figure 6-2. A low-height ridge (2-3 in) is like that left by a typical rangeland drill or light disk. Moderately high ridges are those that are left by an agricultural chisel plow with twisted shanks. Very high ridges (>6 in) are like those left by typical contour furrowing on rangelands.

To get the ridges exactly on the contour is practically impossible. When the ridges are off-contour, runoff flows along the furrows to low places in the landscape. As water accumulates, breakovers in these depressed areas often occur and cause concentrated flow erosion. The effectiveness of contouring is rapidly lost as grade along the furrows increases.

The same relationships used in the cropland section and the parameter values given in tables 6-21 through 6-24 are used to compute the effect of storm erosivity, increased infiltration, ridge height, and grade along the ridges for contouring on rangeland.

Terraces, Diversions, and Windrows

Terrace and diversion channels on a slight grade across a slope will intercept surface runoff and direct it around the slope on a slight grade. As a part of chaining, brush and other debris are sometimes pushed into windrows that are on the approximate contour. If these windrows intercept surface runoff and direct it around the hill, they too should be treated as terraces.

Terraces and similar practices usually reduce the slope length. Therefore, when RUSLE is applied to terraced land, the slope length is taken from the origin of surface runoff on the upslope terrace ridge or other watershed divide to the edge of the flow in the terrace channel. Slope steepness used in the S factor is the slope of the interterrace area. This procedure for selecting slope length is used when the terraces are on a uniform grade. Sometimes the terraces may be on a nonuniform grade and may be so far apart that concentrated flow areas develop on the interterrace interval. When this situation exists, terraces may have little effect on slope length, and the slope is taken in the same way as if the terraces were not present.

Terrace, diversion, or windrow channels on a sufficiently flat grade cause considerable deposition, with the amount deposited being a function of erosion between terraces and channel grade. Sediment yield from the terrace outlets may be obtained by multiplying the RUSLE soil-loss estimate for the interterrace area by the sediment delivery ratio values in table 6-16.

Conservationists debate the value of deposition in terraces for maintaining soil productivity. It is usually given some credit on cropland because tillage is assumed to partially redistribute the deposited sediment. Because tillage is infrequent, if ever, on rangelands, no credit should be given for a benefit of deposition. However, if this credit is taken for conservation planning purposes, the suggested values in table 6-15 may be used.

Undisturbed Strips

Undisturbed strips of land adjacent to channels are sometimes left to minimize the sediment yield into a channel and the accelerated channel erosion. If the undisturbed strips have heavy ground cover, the deposition of sediment can occur when water flows through the strips from the disturbed areas. The effectiveness of these practices on rangeland are judged to be highly variable, and a procedure for applying RUSLE to these strips is not provided.

P-FACTOR VALUES FOR STRIPCROPPING ON CROPLAND IN THE NORTHWESTERN WHEAT AND RANGE REGION

Runoff and erosion processes occur very differently on cropland in the Northwestern Wheat and Range Region than on cropland in other parts of the United States. Much of the erosion occurs during the winter from rain or snowmelt on thawing soils. These soils remain wet and highly erodible over several weeks from repeated freezing and thawing. A transient frost layer near the surface allows little infiltration, producing high amounts and rates of runoff for given amounts and intensities of rainfall.

The definition of cover-management conditions and the values for the runoff indices used in RUSLE for cropland in the Northwestern Wheat and Range Region for these winter conditions differ from values used for other locations. These definitions and the adjusted values for winter are shown in table 6-25 and 6-26, respectively.

Strips with residue and stubble that are rough tilled with implements similar to chisel plows and moldboard plows that turn the soil uphill can have high infiltration rates—often so large that runoff from upslope completely infiltrates within the strip if the strip exceeds about 50 ft. No runoff or sediment leaves the rough-tilled strip. The soil must be left in a rough-tilled condition with residue from the previous crop for these high infiltration rates to occur. Infiltration on these rough strips seems to be greater than that for permanent grass strips.

The cover and roughness of this rough-tilled condition is represented by condition VR in table 6-25. The rough-tilled strip is assumed to behave the same during the winter as at other times during the year. Values for the runoff index for the remaining strips where frost affects infiltration are selected from table 6-26. Values for runoff indices for periods not influenced by frost are selected from table 6-5.

The choice of slope length must be considered where all upslope runoff infiltrates on a strip. Two approaches may be used. The preferred approach is to use the entire slope length as if infiltration did not differ among the strips. The effect of all sediment reaching a strip being deposited within the strip is considered by RUSLE in the computation of P.

The alternative approach is to assume that the effect of the stripcropping system is like that of terraces. A slope length equal to the width of the strip is selected and a P-factor value is computed for terraces assuming a closed-outlet terrace.

Table 6-1.
Summary of data from plot studies on the effect of contouring on runoff and soil loss

Study number	Location	Reference	Plot dimensions: Length (ft)	Width (ft)	Slope (%)	Type of study[1]
1	Auburn, Alabama	Diseker and Yoder (1936)	50	15.1	0, 5, 10, 15, 20	Both
2	Urbana, Illinois	Van Doren et al. (1950)	180	53	2	Nat
3	Temple, Texas	Hill et al. (1944)	[2]—	[2]—	3.5	Nat
4	McCredie, Missouri	Jamison et al. (1968)	420	104	3.5	Nat
5	Morris, Minnesota	Young et al. (1964)	75	13.5	4, 7.5, 10.5	Sim
6	Batesville, Arkansas	Hood and Bartholomew (1956)	90	30	4	Nat
7	Central, Illinois	McIsaac et al. (1987)	35	10	5	Sim
8	Lincoln, Nebraska	Jasa et al. (1986)	35	10	5	Sim
9	Bethany, Missouri	Smith et al. (1945)	270	45	7	Nat
10	Guthrie, Oklahoma	Daniel et al. (1943)	[3]—	[3]—	7	Nat
11	Clarinda, Iowa	Browning et al. (1948)	158	84	9	Nat
12	Auburn, Alabama	Nichols and Sexton (1932)	50	15	10, 15	Sim
13	Concord, Nebraska	Jasa et al. (1986)	35	10	10	Sim
14	Arnot, New York	Lamb et al. (1944)	310	21	11	Nat
15	Sioux City, Iowa	Moldenhauer and Wischmeier (1960)	726	10	12	Nat
16	Zanesville, Ohio	Borst et al. (1945)	726	6	13	Nat
17	Sussex, New Jersey	Knoblauch and Haynes (1940)	70	13.5	16	Nat
18	Holly Springs, Mississippi	McGregor et al. (1969)	70	150	4.2	Nat

[1]Nat = study with natural rainfall, Sim = study with simulated rainfall, Both = study involving both natural and simulated rainfall.
[2]These are 0.01-, 0.03-, and 0.084-acre plots; other plot dimensions not available.
[3]A 0.25-acre plot; other dimensions not available.

Table 6-2.
Summary of data from watershed studies on effect of contouring on runoff and soil loss

Study number	Location	Reference	Watershed dimensions: Area (acre)	Watershed dimensions: Average slope (%)
1	Temple, Texas	Hill et al. (1944)	0.15, 1.5, 2.2	3, 5
2	Bethany, Missouri	Smith et al. (1945)	4.5, 7.4	7
3	Clarinda, Iowa	Browning et al. (1948)	2, 3.2	8
4	LaCrosse, Wisconsin	Hays et al. (1949)	2.2	15

Table 6-3.
Values for coefficients in equations [6-1] and [6-2] used to fit the base data for the P factor for contouring

Ridge height	Coefficient							
	a	*b*	*c*	*d*	s_m (%)	s_{eb} (%)	P_{mb}	P_z
Very low[1]	24,120	4	10.36	1.5	5	11	0.85	0.50
Low	27,201	4	13.31	1.5	6	15	0.65	0.3
Moderate	23,132	4	12.26	1.5	7	20	0.45	0.15
High	18,051	4	10.24	1.5	8	26	0.27	0.08
Very high	22,255	4	6.83	1.5	8	36	0.1	0.05

[1]See fig. 6-2 for ridge height definitions.

Table 6-4.
Description of cropland cover-management conditions used in RUSLE for estimating P-factor values

Categories of conditions	Description of condition
C1. Established meadow (very dense cover)	Grass is dense and runoff is very slow, about the slowest under any vegetative condition. Becomes condition 2 when mowed and baled.
C2. 1st yr meadow, hay (moderately dense cover)	Hay is a mixture of grass and legume just before cutting. Meadow is a good stand of grass that is nearing the end of 1st yr. Becomes condition 4 when mowed and baled.
C3. Heavy (dense) cover or very rough or both	Ground cover for this condition is about 75-95%. Roughness is like that left by a high-clearance moldboard plow on a heavy-textured soil. Roughness depressions appear 7 in or more deep. Vegetative hydraulic roughness like that from a good legume crop (such as lespedeza) that has not been mowed.
C4. Moderate cover or rough or both	Ground cover for this condition is about 40-65%. Roughness is like that left by a moldboard plow in a medium-textured soil. Depressions appear 4-6 in deep. Vegetative hydraulic roughness is similar to that produced by winter small grain at full maturity.
C5. Light cover or moderate roughness or both	Ground surface cover is 10-30%. Surface roughness is like that left by first pass of tandem disk over a medium-textured soil that has been moldboard plowed. This roughness could also be similar to that left after a chisel plow through a medium-textured soil at optimum moisture conditions for tillage. Roughness depressions appear 2-3 in deep. In terms of hydraulic roughness produced by vegetation, this condition is similar to that produced by spring small grain at about 3/4 maturity.
C6. No cover or minimal roughness or both	This condition closely resembles the condition typically found in row cropped fields after the field has been planted and exposed to a moderately intense rainfall. Ground cover is less than about 5%. Roughness is like that of a good seedbed for corn or soybeans. Surface is rougher than that of a finely pulverized seedbed for seeding vegetables.
C7. Clean-tilled, smooth, fallow	Surface is essentially bare, 5% or less of cover. Soil has not had a crop grown on it in the last 6 mo or more, so much of the residual effects of previous cropping has disappeared. Surface is smooth, similar to the surface that develops on a very finely pulverized seedbed exposed to several intense rainfalls. This condition is most likely found in fallow and vegetable fields.

Table 6-5.
Values of runoff index used to compute runoff to estimate P-factor values for cropland

Cropland cover-management condition	Hydrologic soil group			
	A	B	C	D
C1	30	58	71	78
C2	46	66	78	83
C3	54	69	79	84
C4	55	72	81	85
C5	61	75	83	87
C6	64	78	85	88
C7	77	86	91	94

Table 6-6.
Values of Manning's n_t used in RUSLE cropland conditions

Cover-management condition[1]	Manning's n_t
C1	0.200
C2	0.110
C3	0.070
C4	0.040
C5	0.023
C6	0.014
C7	0.011

[1]Refer to table 6-4 for a description of cover-management conditions.

Table 6-7.
Critical slope length values computed by equation [6-12] and critical slope length values from AH 537

Slope (%)	From Equation [6-1][1] (ft)	From AH 537 (ft)
1.5	1000	400
4.0	384	300
7.0	200	200
10.5	125	120
14.5	80	86
18.5	60	64
23.0	50	50

[1]Moderate ridge height, hydrologic soil group C, C6 cover-management condition (defined in table 6-4), 100 ft·tonf·in (acre h)$^{-1}$ $(EI)_{10}$ storm

Source: Wischmeier and Smith (1978).

Table 6-8.
Computed critical slope length as a function of $(EI)_{10}$ storm erosivity and cover-management conditions[1]

	For cover-management condition[2]						
$(EI)_{10}$ Storm erosivity	C1 (ft)	C2 (ft)	C3 (ft)	C4 (ft)	C5 (ft)	C6 (ft)	C7 (ft)
10	1,000	1,000	1,000	1,000	1,000	1,000	933
25	1,000	1,000	1,000	1,000	1,000	824	348
50	1,000	1,000	1,000	1,000	885	387	184
100	1,000	1,000	1,000	1,000	446	201	104
200	1,000	1,000	1,000	579	243	111	61

[1] 7% slope, hydrologic soil group C
[2] Cover-management conditions are defined in table 6-4.

Table 6-9.
Critical slope length computed as a function of hydrologic soil group and $(EI)_{10}$ storm erosivity[1]

	For hydrologic soil group			
$(EI)_{10}$ storm	A (ft)	B (ft)	C (ft)	D (ft)
10	1,000	1,000	1,000	1,000
25	1,000	1,000	1,000	1,000
50	1,000	1,000	1,000	1,000
100	1,000	1,000	1,000	969
200	1,000	700	579	537

[1]7% slope, cover-management condition C4

Table 6-10.
Critical slope length computed as a function of hydrologic soil group and $(EI)_{10}$ storm erosivity[1]

	For hydrologic soil group			
$(EI)_{10}$ storm	A (ft)	B (ft)	C (ft)	D (ft)
10	1,000	1,000	1,000	1,000
25	1,000	1,000	824	687
50	1,000	525	387	343
100	407	246	201	185
200	178	127	111	106

[1] 7% slope, cover-management condition C6

Table 6-11.
Values for sediment delivery for stripcropping as determined from experimental data

Location	Rotation	Sediment delivery	
		Observed	Model
Bethany, Missouri (Smith et al. 1945)	C-W-M	0.44	0.53
Zanesville, Ohio (Borst et al. 1945)	C-W-M	0.36	0.53
Owen, Wisconsin (Hays and Attoe 1957)	C-W-M-M	0.42	0.48
LaCrosse, Wisconsin (Hays et al. 1949)	C-W-M-M	0.55	0.48
Batesville, Arkansas (Hood and Bartholomew 1956)	C-Ct-O/L	0.80	0.68
Temple, Texas (Watershed 1) (Hill et al. 1944)	C-Ct-O	0.52	0.51
Temple, Texas (Watershed 2) (Hill et al. 1944)	C-Ct-O	0.30	0.51

C = corn, Ct = cotton, W = wheat, O = oats, O/L = oats/lespedeza mixture, M = meadow.

Table 6-12.
Erosion and sediment transport factor values for P factor model for strips

	Cover-management condition[1]	Factor values: Erosion (ξ)	Factor values: Transport (ζ)	Length exponent (n)
C1	Very dense cover	0.005	0.02	1.0
C2	Dense cover or extreme roughness or both	0.02	0.05	1.0
C3	Moderately dense cover	0.03	0.10	1.0
C4	Moderate cover or roughness or both	0.12	0.14	1.0
C5	Light cover or moderate roughness or both	0.25	0.25	1.0
C6	Clean row crop tillage, no cover or minimal roughness or both	0.50	0.50	1.0
C7	Clean-tilled, smooth, fallow	1.00	1.50	1.5

[1]Cover-management conditions defined in table 6-4.

Table 6-13.
Values for P factor for sediment delivery and conservation planning computed with model for selected stripcropping, buffer, and filter strip systems[1]

System[2]	Sediment delivery (P_y)	Conservation planning (P_s)
RC-WSG-M1-M2[3]	0.53	0.78
RC-RC-WSG-M1[4]	0.54	0.80
RC-RC-WSG-M1-M2	0.47	0.77
RC-SSG-RC-SSG	0.75	0.91
RC-SSG[5]	0.83	0.93
RC-WSG[6]	0.71	0.86
RC-M1	0.58	0.78
RC-M1-RC-M1 (year 1)[7]	0.39	0.69
SSG-M2-SSG-M2 (year 2)		
M1-RC-M1-RC (year 3)		
M2-SSG-M2-SSG (year 4)		
RC-RCrt-RCrt-M1	0.65	0.84
Cnt-SBrt-SBnt	1.00	1.00
Crt-SBrt-Crt-WSGrt	0.89	0.96
0.5 filter[8]	0.06	0.51
0.1 filter[9]	0.24	0.91
Buffer strips[10]	0.15	0.67
Buffer strips[11]		0.71
Buffer strips[12]		0.75

[1]Values for filter strip systems are primarily for illustration as filter strips are usually not used to protect upslope areas from productivity loss.

[2]RC = row crop, WSG = winter small grain, SSG = spring small grain, M1 = 1st yr meadow, M2 = 2d yr meadow, C = corn, SB = soybeans, rt = reduced tillage, nt = no till.

[3]Wischmeier and Smith (1978) P = 0.50.

[4]Wischmeier and Smith (1978) P = 0.75.

[5]Wischmeier and Smith (1978) P = 1.00.

[6]Wischmeier and Smith (1978) P = 1.00, but they note that winter small grain can be effective in some cases.

[7]Location of strips by year in rotation; that is, Y1 is year of rotation.

[8]Permanent meadow filter strip that covers 0.5 of slope below row crop.

[9]Permanent meadow filter strip that covers 0.1 of slope below row crop.

[10]Permanent meadow buffer strips located at 0.4-0.5 and 0.9-1.0, separated by row crop strips.

[11]Permanent meadow buffer strips located at 0.35-0.40 and 0.65-0.70, separated by row crop strips.

[12]Permanent meadow buffer strip at 0.4-0.5, separating two row crop strips.

Table 6-14. Benefit assigned to deposition behind terraces

Terrace spacing (ft)	Benefit (B)
≤110	0.5
125	.6
160	.7
200	.8
260	.9
≥300	1.0

Table 6-15.
Terrace P-factor values for conservation planning[1]

Horizontal terrace interval (ft)	Terrace P-factor values			
	Closed outlets[2]	Open outlets, with percent grade of[3]		
		0.1-0.3	0.4-0.7	>0.8
Less than 110	0.5	0.6	0.7	1.0
110-140	.6	.7	.8	1
140-180	.7	.8	.9	1
180-225	.8	.8	.9	1
225-300	.9	.9	1	1
More than 300	1	1	1	1

[1]Multiply these values by other P-subfactor values for contouring, stripcropping, or other support practices on interterrace interval to obtain composite P-factor value.

[2]Values for closed-outlet terraces also apply to terraces with underground outlets and to level terraces with open outlets.

[3]Channel grade is measured on the 300 ft of terrace closest to outlet or 1/3 of total length, whichever distance is less.

Table 6-16.
Sediment delivery subfactor (P_y) for terraces[1]

Terrace grade	Sediment delivery subfactor
%	
Closed outlet	[2]0.05
0 (level)	.10
.1	.13
.2	.17
.4	.29
.6	.49
.8	.83
.9	1
[3]>1	1

[1]Includes terraces with underground outlet.
[2]From Foster and Highfill 1983. All other values from $P_y = 0.1e^{2.64g}$, where e = natural logarithm and g = terrace grade (%).
[3]Potential for net erosion in terrace channels, depending on flow hydraulics and soil erodibility in the channels. If net erosion occurs, $P_y > 1$.

Source: Foster and Highfill (1983).

Table 6-17.
Runoff and erosion effects from mechanical practices on rangelands

Rangeland treatment	Data source	Runoff and erosion changes after treatment for indicated years[1]		
		Runoff (%)	Erosion (%)	Years
Pitting	Hickey and Dortignac (1963)	-18 -10	-16 0	1 3
Ripping	Hickey and Dortignac (1963)	-96 -85	-85 -31	1 3
Moldboard plowing	Gifford and Skau (1967), Blackburn and Skau (1974)	+U 0	0 0	1 5
Contour furrowing (model B)	Branson et al. (1966), Wein and West (1973)	-U -U	-U -U	1 10
Root plowing	Simanton et al. (1977)	+50 -80	-54 -45	1 4
Land imprinting	Unpublished, Walnut Gulch Experimental Watershed (1978)	0	-90	1

[1]Relative to pretreatment level; (-) = decrease, (+) = increase, and U = unknown.

Source: Simanton (1988, personal communication).

Table 6-18.
Ratings[1] of possible effects of rangeland treatment and implement use

Possible effect	LP	PT	CH	BP	RP	RI	CF	BR	RD	TR	FL	BU
	Treatment or implement[2]											
Incr. infiltration	3	3	1	2	3	1	3	2	1	3	1	0
Incr. percolation	2	2	1	1	3	3	3	1	0	3	0	0
Incr. pore space	2	2	1	2	2	3	3	1	0	1	0	0
Incr. water holding cap.	3	3	1	2	2	3	3	2	1	3	1	0
Incr. surface porosity	1	2	0	2	3	1	2	2	1	1	0	0
Incr. surface stability	3	2	1	2	2	1	1	3	1	1	1	0
Incr. roughness	3	3	1	2	2	1	2	3	1	1	0	0
Incr. seedling establish.	3	2	0	1	2	0	2	1	2	1	0	1
Decr. surface compaction	0	2	0	3	3	1	2	0	2	1	0	0
Decr. soil water evap.	2	1	1	1	1	0	1	2	0	0	3	0
Decr. surface runoff	2	2	1	1	2	1	3	1	1	2	1	0
Decr. erosion	2	2	1	1	3	2	2	1	1	2	1	0
Decr. canopy cover	3	2	2	2	2	1	1	3	0	0	3	3
Decr. competition	1	1	2	2	3	0	1	1	0	0	1	2
Treatment or implement used on:	**LP**	**PT**	**CH**	**BP**	**RP**	**RI**	**CF**	**BR**	**RD**	**TR**	**FL**	**BU**
Steep slopes	3	1	3	1	2	3	1	3	2	3	3	3
Rocky soils	3	1	3	1	2	1	2	3	2	3	3	3
Clay soils	2	2	3	1	3	3	2	2	3	3	3	3
Shallow soils	3	3	3	3	3	2	3	3	3	3	3	3
Woody shrubs	3	2	3	2	3	3	2	3	1	3	3	3
Herbaceous plants	3	3	0	3	0	0	3	0	1	3	0	3
Treatment longevity	3	1	3	2	3	3	2	1	1	3	0	2
Return/cost	3	1	3	1	2	1	2	1	3	3	1	2
Treatment or implement totals:	53	43	34	38	51	34	46	39	27	43	28	28

[1]LP = Land imprinter, broadcast seeding
PT = Pitting, broadcast seeding
CH = Chaining, cabling
BP = Brushland plow
RP = Rootplow, rangeland drill seeding
RI = Ripping
CF = Contour furrow, broadcast seeding
BR = Brush roller
RD = Rangeland drill (seeding)
TR = Terrace, broadcast seeding
FL = Flail
BU = Burning
[2] Ratings range from 0 = no effect, to 3 = greatest effect.

Source: Simanton (1988, personal communication).

Table 6-19.
Common mechanical practices applied to rangelands

Practice	Degree of disturbance	Surface configuration	Estimated duration of effectiveness (yr)	Runoff reduction
Rangeland drill	Minimal tillage except in furrow	Low ridges (<2 in) and slight roughness	1–2	None to slight
Contour furrow/pitting	Major tillage 8-12 in deep	High ridges, about 6 in	5–10	Slight to major
Chaining	Severe surface but shallow	Slight to moderate random roughness	3–5	Slight to moderate
Land imprinting	Moderate-sized shallow depressions	Short channels (40 in) and small to moderate	2–3	Slight to moderate
Disk plows, offset disks	Major tillage, about 4-8 in deep	Moderate ridges 2-4 in	3–4	Slight to moderate
Ripping, grubbing, root plowing	Minimal but often deep, 8+ in	Slight to very rough, especially when done at right angles	4–7	Moderate to major

Table 6-20.
Definition of cover-roughness conditions for rangeland

Condition identification	Description
R1	Very rough; plant plus rock cover greater than 50%
R2	Very rough; plant plus rock cover less than 50%
R3	Rough; plant plus rock cover greater than 50%
R4	Rough; plant plus rock cover less than 50%
R5	Moderately rough; plant plus rock cover less than 50%
R6	Moderately rough; established vegetation; plant plus rock cover less than 40%
R7	Slightly rough; plant plus rock cover less than 25%
R8	Slightly rough; established vegetation; plant plus rock cover less than 35%
R9	Smooth; established vegetation; plant plus rock cover less than 25%

Table 6-21.
Runoff indices for cover-roughness conditions at disturbance in areas dominated by thunderstorms

Cover-roughness condition[1]	Hydrologic soil group				Manning's n_t	Roughness index (in)
	A	B	C	D		
R1	47	50	53	56	0.10	2.0
R2	52	55	58	61	0.08	2.0
R3	57	60	63	66	0.07	1.4
R5	62	65	68	71	0.04	0.9
R7	67	70	73	76	0.023	0.5

[1]Defined in table 6-20

Table 6-22.
Runoff indices for cover-roughness conditions at disturbance in areas dominated by frontal activity

Cover-roughness condition[1]	Hydrologic soil group				Manning's n_t	Roughness index (in)
	A	B	C	D		
R1	32	35	38	41	0.20	2.0
R2	37	40	43	46	0.10	2.0
R3	42	45	48	51	0.07	1.4
R5	47	50	53	56	0.04	0.9
R7	52	55	58	61	0.023	0.5

[1]Defined in table 6-20

Table 6-23.
Runoff indices after consolidation for cover-roughness conditions at disturbance in areas dominated by thunderstorms

Cover-roughness condition[1]	Hydrologic soil group A	B	C	D	Manning's n_t	Roughness index (*in*)
R3	67	70	73	76	0.10	1.4
R4	72	75	78	81	0.08	1.4
R6	77	80	83	86	0.07	0.9
R8	82	85	88	90	0.04	0.5
R9	87	90	92	94	0.023	0.2

[1]Defined in table 6-20

Table 6-24.
Values for runoff index after consolidation for cover-roughness conditions in areas dominated by frontal activity

Cover-roughness condition[1]	Hydrologic soil group A	B	C	D	Manning's n_t	Roughness index (in)
R3	47	50	53	56	0.10	1.4
R4	52	55	58	61	0.08	1.4
R6	57	60	63	66	0.07	0.9
R8	62	65	68	71	0.04	0.5
R9	67	70	73	76	0.023	0.2

[1]Defined in table 6-20

Table 6-25.
Description of cropland cover-management conditions used in RUSLE for estimating P-factor values in the Northwestern Wheat and Range Region.

Categories of conditions	Description of condition
C1. Established sod-forming grass (very dense cover)	The grass is dense and runoff is very slow; about the slowest under any vegetative condition. When moved and baled, this changes to condition 2.
C2. Standing stubble, 1st year grass, or meadow to be cut for hay (moderately dense cover)	The stubble is from a good stand with few rills or flow concentrations. The hay is a mixture of grass and legumes just before cutting. When mowed and baled, this becomes condition 4.
C3. Heavy (dense) cover or very rough or both	Ground cover is about 75 to 95%. Roughness depressions appear to be 5 or more inches deep (Random Roughness >2 ½ inches). Vegetative hydraulic roughness is like that of a good legume crop that has not been mowed.
C4. Moderate cover or roughness or both	Ground cover is about 40 to 65%. Roughness depressions appear to be about 3 to 5 inches deep (Random Roughness 1 ½ to 2 ½ inches), and vegetative hydraulic roughness is like that of a good stand of winter small grain at full maturity.
C5. Light cover or moderate roughness or both	Ground cover is from 10 to 30%. Roughness depressions appear to be 1 to 3 inches deep (Random Roughness ½ to 1 ½ inches), and the vegetative hydraulic roughness is like that of a typical stand of spring small grain at 3/4 maturity.
C6. Minimal cover or minimal roughness or both	Ground cover is 5 to 10% and the roughness is that of a moderately tilled seedbed. The surface is rougher than that of a finely pulverized seedbed for seeding vegetables. Roughness depressions appear to be ½ to 1 inch deep (Random Roughness 1/4 to ½ inch).
C7. Clean, tilled, smooth, fallow	The surface is essentially bare, with less than 5% cover. A crop has not been grown for some time so that the residual effects of previous cropping have disappeared. The surface is smooth, similar to that of a finely pulverized seedbed exposed to one or more intense rainfalls. Roughness depressions appear to be less than ½ inch deep (Random Roughness < 1/4 inch). This condition is most likely found in a fallowed field, but could exist in a vegetable field as well.
VR. Very rough primary tillage	Very rough primary tillage across slope that leaves the soil fractured below normal frost depth. The fractures are expected to last through the winter erosion season, preventing surface sealing and formation of impermeable frost, thus allowing a high rate of infiltration. Roughness depressions are greater than 7 inches deep (Random Roughness > 3 inches).

Table 6-26.
Values for runoff index used to compute runoff to estimate P-factor values for cropland in the Northwestern Wheat and Range Region for conditions where frost in soil significantly reduces infiltration

Cropland cover-management condition	Hydrologic soil group			
	A	B	C	D
C1	40	67	78	86
C2	65	76	84	88
C3	69	82	85	89
C4	75	92	92	92
C5	81	93	93	93
C6	85	94	94	94
C7	89	95	95	95
VR	30	58	71	78

[1]Defined in table 6-25

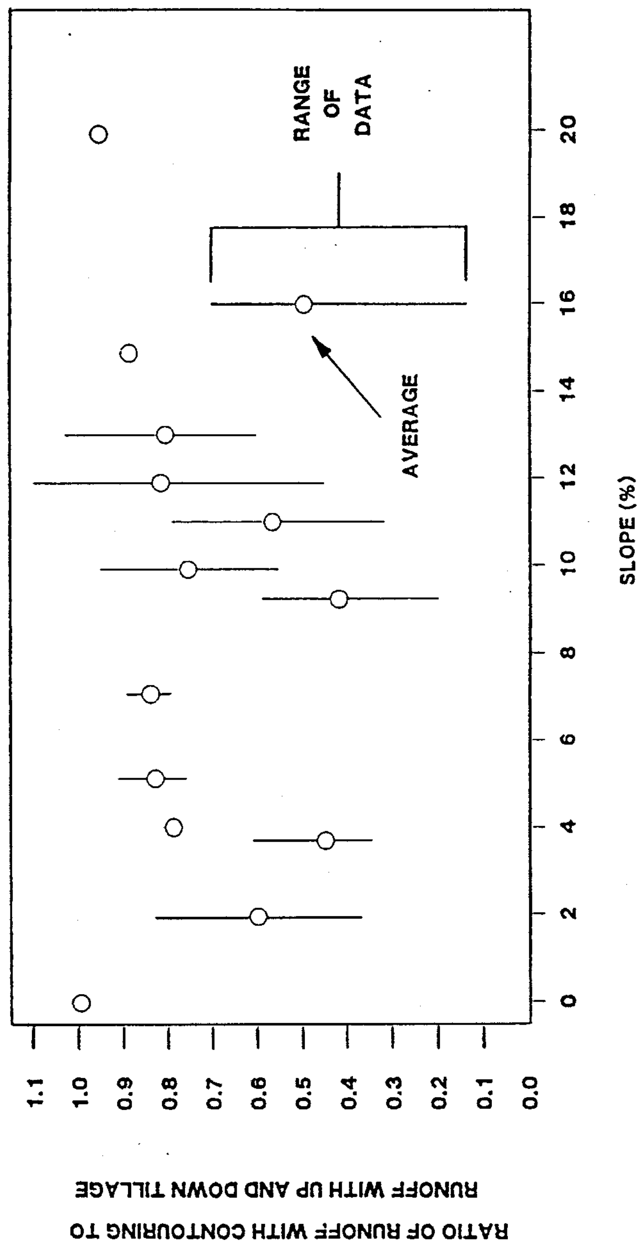

Figure 6-1. Effect of contouring on runoff.

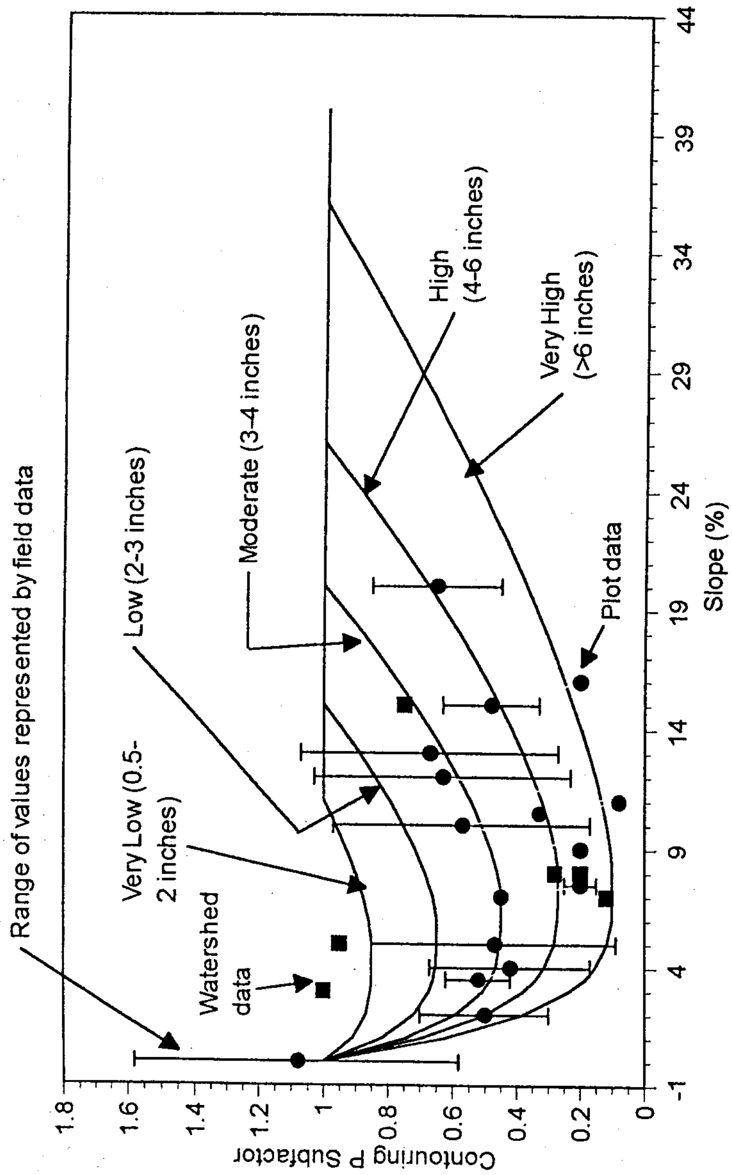

Figure 6-2. Effect of contouring on soil loss.

CHAPTER 7. RUSLE USER GUIDE

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CHAPTER 7. CONTENTS

WELCOME TO THE RUSLE COMPUTER PROGRAM

Purpose of the User Guide

This User Guide is designed to teach the first-time user how to run the RUSLE computer program, and to answer the questions most frequently asked by more experienced users. Because the program itself provides online help screens that describe the expected user responses, this Guide focuses instead on the reasoning and mechanics behind the responses. The background theory and equations used in soil-loss calculations are described in chapters 1 through 6 of this handbook.

Introduction to the User Guide

The first portion of this User Guide is meant for first-time users. It explains in general terms how RUSLE works and introduces the terminology that will be used in the following sections. This introductory section is not long, and we strongly recommend that novice users read it to familiarize themselves with the program.

The remainder of the User Guide gives specific information on the different parts of the program, including answers to frequently asked questions. This reference section of the User Guide assumes familiarity with the terminology of the program, and may be confusing if you have not read the introductory section.

Within the User Guide, a command or entry that you type in is shown in brackets, [ ], and the name given that command or entry is placed in braces, { }.

INFORMATION FOR FIRST-TIME USERS

Getting RUSLE To Work on Your Machine

Background

The RUSLE computer code was written in the C programming language. Since C is portable, the program can be run on a variety of machines. RUSLE has been tested on IBM-compatible machines with 640 kilobytes of RAM memory using the MS-DOS operating system (version 2.0 or later). It has also been used on large systems under the UNIX operating system, and on the ATT 6386 under both DOS and UNIX. The executable program will run only on the type of machine on which it was compiled; if this is something other than DOS, the machine type will be specifically noted on the diskette labels.

The RUSLE executable program is large and does not have the capability of using expanded memory. It therefore may cause problems if used at the same time as other programs that reside in lower memory, possibly including some shell programs or peripheral drivers. This problem most often shows up as an "out of memory" error message. This can be minimized by not using these memory-resident packages when running RUSLE. Consult your DOS or program manuals or your site consultant for more details.

Loading RUSLE From Supplied Diskette(s) Onto Computer

The RUSLE program can be run directly from the supplied diskette in the floppy drive. As with most other programs, however, RUSLE can be run much faster and more efficiently by loading it onto the hard disk drive.

For DOS systems, RUSLE can be loaded by copying all the files from the diskette(s) onto the hard disk. These files include the RUSLE executable program, the Database files, the files used to create the Help screens, and some miscellaneous system files. These files should be copied into a directory created specifically to run RUSLE, as this will speed execution and make the program easier to use. Consult your DOS system manual for instructions on creating a directory and on copying files from the diskette drive to that directory.

Copying all the files onto the hard disk should also be done when using the RUSLE computer program from within a DOS window environment. The files should still be copied from the supplied diskette(s) into a directory, although this will be done through use of a file manager. If desired, the windowing package can then be used to link the execution of the RUSLE code to an icon through use of a command line containing one of the commands specified below.

For UNIX systems, the technique for loading the program from the diskette(s) onto the hard disk depends greatly on the system. Consult your system manuals or specialist for instructions.

Running RUSLE

Once the RUSLE files have been loaded into a directory on the hard drive, begin operation by moving into that directory and typing one of the commands listed below. The command [rusle] puts you into the main program and brings up a menu that lists the options for the program. If you want to run only one of the factors or options, simply enter its command. For example, to have access to the CROP Database, the command is [rusle crop]; to run the C-factor subprogram, the command is [rusle c]. The options for the command string are as follows:

[rusle]	to get the RUSLE Main Menu, giving access to all the options
[util]	the three Database Utility programs
[city]	the CITY Database Utility program
[crop]	the CROP Database Utility program
[op]	the OPERATIONS Database Utility program
[r]	R-factor routine only
[k]	K-factor routine only
[ls]	LS-factor routine only
[c]	C-factor routine only
[p]	P-factor routine only

If you choose any option other than [rusle], you will not be able to reach all the other options.

How RUSLE Works

Background

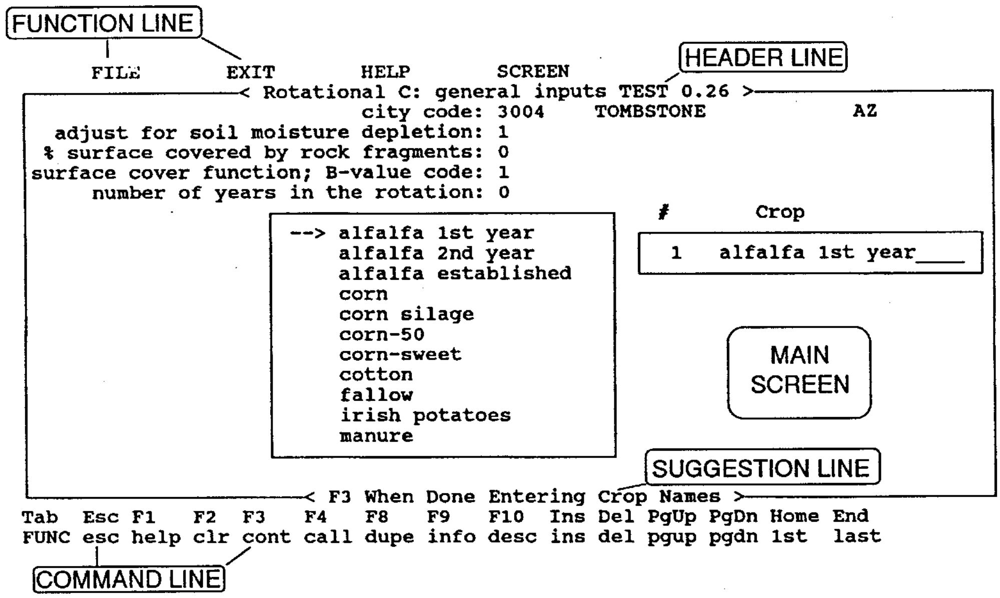
The computer code within RUSLE is responsible only for calculations based on information that you give it; you are responsible for the quality of that information, and most of your time using the program will be spent describing your situation in terms that the program understands.

RUSLE is based on a routine that waits for your response. There are two basic types of responses. The first is to answer the question that the program is asking–a fill-in-the-blank answer. We call this response an "input." The second type of response is a "command," which tells the program what to do next. For example, commands are used to direct the program to carry out the calculations or to move to the next screen. Inputs and commands are often used together. For instance, if the program prompts you for the name of a CROP, you might type in [cotton] as the input, and then give a command by pressing the [ENTER] key.

In most cases, you can respond with either an input or a command, but there are a few cases when only a command is appropriate. For instance, in looking at results, all the program needs to know is when and how you want to move on; the input type of response is not available.

Description of RUSLE Screen

All your interaction with RUSLE will be through screens that have the same general pattern as shown



The screen can be divided into five parts, as follows:

(1) Main Screen

The main portion of the screen is the area in the center, which contains the list of questions and comments. It is here that inputs are entered and results displayed.

(2) Command Line

The bottom two lines of the screen make up the Command Line. Whenever the program is awaiting your response, commands will tell it what to do next. The available commands are listed here on the screen. The upper of these two lines shows which key to press to execute each command; on the lower line below each key is listed a three- or four-letter command description. The section "Giving Program Commands" later in this chapter lists all possible commands and what they do.

(3) Function Line

The top line on the screen is called the Function Line; it defines RUSLE Functions. These are subroutines that perform the housekeeping chores for the program. The FILE Function provides all the options for manipulating Input Files and the Current Input List (see "Input Lists And Files"). The EXIT Function provides options for leaving the program. The HELP Function provides several options for general help on running RUSLE. The SCREEN Function gives the user control over how the screen looks. "The Functions: Program Housekeeping" explains the use of the Function Line.

(4) Header Line

The second line down from the top of the screen is the Header Line, which tells the user the version of RUSLE that is running and the name of the current screen.

(5) Suggestion Line

The third line up from the bottom of the screen is the Suggestion Line, which lists the most likely command or course of action. This displays the suggested response or course of action as you go through the logical sequence of the program.

Input Field

An Input Field is a place where the cursor sits as the program waits for you to answer a question. As mentioned above, your response can be either an answer to the question (input), or a command telling the program what to do next. An input can take any of three forms:

(1) *Filling in a blank.* For example, when the program asks for a CROP name, the appropriate response may be to type [cotton].

(2) *Selecting an option.* The program shows a numbered list of options and asks you to select one. If you have not already chosen one of the options, the entire list will be shown. There are two ways to select an option: Type in the number shown next to the desired option and then press [ENTER] to select it, or use the [ARROW] keys to move through the list and then press [ENTER] to choose the marked option. If one of the options was chosen earlier, the list may not be shown, but the {list} command will display the options again. See "Giving Program Commands" for more information on this command. In some cases the list is always shown, but the marking arrow may not appear within it. In this instance, use of the {list} command will move the arrow into the list.

(3) *Selecting an item from a list.* This works in the same way as the option selection described above, but is based on a list of named items rather than on a numbered list of options. The box in the center of the example screen shown previously contains such a list.

Giving a Command

The second way to respond to an input field is to give the program a command, which tells it what to do next. There are several commands to which the program will always respond, so they are not displayed on the screen. These are the [ARROW] keys and [ENTER]. A list of all possible commands and what they do can be found in the section titled "Program Commands and Controls." Not all of the commands can be used at every place in the program, so the list of commands that are available for use from the current Input Field is shown on the Command Line at the bottom of the screen. A command is given by pressing the key listed on the Command Line.

Calling a Function

One command that is usually available is {FUNC}, which moves the cursor onto the Function Line (the top line of the screen). This allows you to perform the general housekeeping chores shown on that line. These include the FILE routines (see "How RUSLE Gets, Uses, and Saves Information" for an overview or "Input Lists and Files" for complete information), the EXIT routines that allow the user to leave the program, the HELP routines for assistance in using the program (see "Help"), and the SCREEN routine for changing screen colors.

When {FUNC} has been used to move the cursor to the Function Line, use the [RIGHT ARROW] or [LEFT ARROW] keys to move it through the functions. As the cursor moves to a function, the list of associated routines is displayed. [ARROW] up or down through the list until the routine you want is marked, or type in the number of the desired function. Press [ENTER] to select that routine and begin its execution. With the cursor on the Function Line, use the {esc}ape command to return to the Main Screen.

"The Functions: Program Housekeeping" gives more information on calling and using the Function routines.

Getting Help

RUSLE provides two general types of help. The first is additional information on the current input field, describing what sort of input is expected and why. This is always available through the {help} command. The second is made up of general descriptions of RUSLE and its operation, available through the HELP routines of the Function Line.

How RUSLE Gets, Uses, and Saves Information

Background

RUSLE requires a lot of information telling it which calculations to make and what values to use for the variables in each equation. It can get that information from one of three sources: values you enter directly, data that you have stored in Databases, or information that you entered earlier and then stored.

Current Input List

RUSLE maintains a record of all responses to the program questions in a list called the Current Input List. This is updated every time you respond to a question by either entering an input or selecting an option or item. The list does not include the commands given to the program. When the program begins, this list is cleared (everything is set to 0).

The section titled "Input Lists and Files" provides more information on the Current Input List and its manipulation.

Input Files

Entering information by hand is tedious and inefficient. In order to make it easier to enter information and also to provide a record of the values used, you can save the Current Input List into an Input File. Each Input File thus contains a copy of the Current Input List at the time it was saved, along with a unique name and identifying comments. "Input Lists and Files" explains how to save the Current Input List into an Input File, and how to load one of these files back in as the new Current Input List.

Databases

The RUSLE Databases provide another way of entering data more efficiently by associating a large amount of information with a single Identifier. For example, all the weather information for a specific city can be associated with a city code, which from then on serves as the Identifier for all that information. You need to enter the weather information for that city only once; from then on, you can retrieve any part of that information by just giving the Citycode Identifier.

RUSLE contains three Databases. The CITY Database includes all necessary climatic data identified with a specific city or region. The CROP Database provides information on the growth and residue characteristics of specific crops or other vegetation. The OPERATIONS Database defines how field operations affect the soil, crop, and residue and, through those, the erosion rates. General information on using the Databases can be found in the section titled "Databases," and information unique to an individual Database can be found in the sections "CITY Database," "CROP Database," and "OPERATIONS Database."

You should change the information in the Databases to meet your specific situation and needs. Remember that the Databases exist to make it easier to enter the required information but that the users are still responsible for the validity of the information used in their computations. Appendix D provides valuable advice on how to modify the existing core database information to match your specific situation.

PROGRAM COMMANDS AND CONTROL

From any input field within RUSLE, you have the option of either answering the question or giving the program a command. In general, these commands control the flow of the program by telling it when to move on to the next step or screen, telling it that you want to get back out of the current section, telling it to leave the program altogether, and so on.

Giving Program Commands

There are several commands to which the program will always respond, so these are not shown on the screen. One such command is {ENTER}, given using the [ENTER] key ([RETURN] or [NEW LINE] on some machines). This command tells the program to accept the current value as the answer to the question being asked and to move on to the next question. The other commands not displayed are the [ARROW] commands, which are used to move the cursor. When a [RIGHT ARROW] or [LEFT ARROW] doesn't make sense (as in a vertical list of questions), using either [ARROW] will have the same effect as using [ENTER].

The [ARROW] commands have one additional peculiarity. As described in "Input Field," some questions ask you to choose from a list of options. When no choice has been made, moving the cursor onto that question will automatically display the list and put the cursor in the list. Using [ARROW]'s at this point will move the cursor within the list rather than between questions on the main screen. Once you have answered the question, the list will not be displayed unless you ask for it with the {list} command, so the [ARROW]'s will move the cursor on the Main Screen without interruption.

In addition to [ENTER] and [ARROW], there are usually several other commands to which the program will respond. These vary from screen to screen and question to question, but the available commands will always be listed on the Command Line. The Command Line actually comprises the bottom two lines of the screen. The upper line shows which key to use, and the lower line gives a three- or four-letter description of the command. "Description of RUSLE Screen" shows an example of how this appears on the screen.

List of Commands

A complete list of all possible commands and a brief description of what each does is given below. The command description or name is given within braces, { }, and the associated DOS key for each command is shown within brackets, [ ]. The keys may differ on some machines, but the command description is always as shown here.

{FUNC} [TAB]	places the cursor onto the Function Line to let you do the required housekeeping chores (see "Calling a Function" or "The Functions: Program Housekeeping"). When the cursor is on the Function Line, use {esc}ape to bring it back to the Main Screen.
{esc} [ESC]	allows you to {esc}ape from the current screen or question without giving an answer. This is most commonly used in three places: (1) if you have gotten into a screen or series of screens and want to get back out; (2) after an error or warning message has been displayed, and you want to continue; (3) to continue the program after a result has been displayed.
{help} [F1]	shows one or more screens of additional information to help answer the current question (see "Help"). This usually includes a brief description of how the variable is used in the calculations and also suggestions for possible answers.
{clear} [F2]	{clear}s (sets to 0) all variables associated with the current screen. This is most useful when you want to get a fresh start on a screen containing several mistakes.
{cont} [F3]	{cont}inues program movement to the next logical screen in the sequence. For example, when you have answered all the questions on one screen, this command moves you to the next screen or initiates the calculations. For screens that require only one input or command, the {cont}inue command acts just like an [ENTER], telling the program to accept the current value and to move on.
{call} [F4]	{call}s a subroutine on which the answer might depend. Use of this command will automatically put you into the

required subroutine; when you exit from that, you will return to the current question.

The {call} command is used in three different instances.

(1) When an answer is calculated from the results of several different factors. An example is in estimation of soil loss from the factor values. Each factor is {call}ed individually by use of this command.

(2) When the question asks for the Identifier of a Database Set, as when entering a city code, a crop name, or an operation name. Use of the {call} from one of these locations allows you to examine or modify the information within the associated Database. "Databases" gives more detail.

(3) When the calculation requires information entered in another portion of the program. An example of this is the value of average field slope, which is used in several places but is calculated within the LS factor. If this value has already been calculated, it will be shown; if not, the {call} command must be used to move to that calculation.

{list} [F6] displays a list from which you can select an option or item, as explained in "Input Field." If you have previously selected one of the choices, the list may not be shown but this command will appear as an option. Use of this command displays the list and allows you to move through it using the [ARROW] keys.

There are places in the program where the list is also shown but the marker arrow is not visible. In these cases, a {list} command will move the marker arrow into the list, where the marker can be controlled with the [ARROW] keys.

{save} [F7] {save}s the data shown on the screen into a Database Set named by the Identifier at the top of the screen. Changes made within the CITY, CROP, or OPERATIONS Database routines will not be saved into those Databases unless this command is used before exiting those routines. If changes have been made, you will be asked whether or not you want to save them before you are allowed to exit.

{dupe} [F8]	used only in the crop listing on the initial C factor input screen, this duplicates an entire operation listing screen into another location within the list. For example, if I {dupe} "corn" from the first place on the list into the fifth, the program will duplicate all operations associated with that first corn onto the fifth screen. It will not change the dates, so this must be done by moving to that screen and modifying them individually.
{info} [F9]	gives information on the Current Input List. When you {save} a Current Input List into an Input File, you are also saving a series of comments describing that List. Use of this command allows you to look at (and change) the descriptive information for the Current Input List.
{desc} [F10]	gives information on the current CROP or OPERATIONS Database Set. These sets also contain a series of descriptive comments, which can be viewed and/or changed from almost anywhere this command is available.
{ins} [INS]	used to insert a line of information just above the line on which the cursor is resting.
{del} [DEL]	used to delete the line of information on which the cursor is resting.
{1st} [HOME]	used to jump to the first in a series of screens or to the beginning of a list.
{last} [END]	used to jump to the last in a series of screens or to the end of a list.
{pgup} [PGUP]	used to move forward one screen in a series of screens or up one screen in a long list of information.

{pgdn} [PGDN]	used to move back one screen in a series of screens or down one screen in a long list of information.

Giving a Command

A command is given by pressing the key listed above the desired command. This directs the program to immediately execute that command.

THE FUNCTIONS: PROGRAM HOUSEKEEPING

Several components of the RUSLE program are not part of the actual program workings but are needed to make the program easier to use. These are called Functions and are used to manipulate Input Files, to exit the program, to manipulate the screen coloring, or to get additional help. They are displayed on the Function Line, which is the top line on the screen. See "How RUSLE Works" for explanation of a sample screen.

Calling a Function

Functions are called by use of the {FUNC} command to move the cursor to the Function Line. Then use the [RIGHT ARROW] or [LEFT ARROW] key to move the cursor to the desired Function. The list of routines associated with that Function will be shown automatically. Either use the [UP ARROW] or [DOWN ARROW] key to select a routine or type in the option number. Press [ENTER] to execute the routine.

Once the cursor has been moved to the Function Line, you can return it to the Main Screen by using {esc}.

The FILE Function

The most commonly used Function in RUSLE is the FILE Function. From here, the Current Input List (see "How RUSLE Gets, Uses, and Saves Information" or "Input Lists and Files") can be cleared (all values set to zero), it can be SAVEd into an Input File, or it can be replaced by values LOADed from an Input File. As described in "Input Lists and Files," the purposes of this function are to allow you to save information so that you don't have to reenter it later, and to keep a record of the inputs used to reach a specific answer.

The EXIT Function

The EXIT Function provides a quick and easy way to get out of RUSLE from anywhere in the program. This Function is not the only way out (a series of {esc} commands will give the same result), but it is the fastest.

The HELP Function

The HELP Function provides general help in operating RUSLE, including such options as introductory information for the novice user and definitions of the various commands. This Function does not give information about the current question, because that role is filled by the {help} command. "Help" gives more detail on the HELP Function and the {help} command.

The SCREEN Function

The SCREEN Function gives the user some control over the appearance of the screen, including a color option for computers with color screens and a black-and-white option for monochrome screens.

HELP

Two types of help are available within the RUSLE program. The first is help for a specific question, available by using the {help} command. This is meant to provide you with information on how the variable fits into the general scheme of RUSLE calculations and with an idea of the expected type and size of answer. The second type of help available is more general information on the workings of RUSLE, available through the HELP Function.

Help for a Specific Question

It is often difficult to know what sort of response is expected when faced with a specific question. The {help} command provides that information. Help information is available for almost every response within the program, such as a blank to fill in, a list to select from, or even a warning message. If you don't know how to respond, try the {help} command.

Information on giving commands is found in "Program Commands and Control."

General Help

If you need more general information on running RUSLE, you can almost always call in the HELP Function. This provides information on the following:

- guide to RUSLE
  - how RUSLE works
  - principal contributors
- how to use help
- Command keys
  - ENTER
  - ARROW keys
  - Command keys
- guide for first-time user

Information on using the Functions is found in "The Functions: Program Housekeeping."

INPUT LISTS AND FILES

As explained briefly in "How RUSLE Gets, Uses, and Saves Information," RUSLE maintains a set of the current values of all important variables used by the program, and this is called the Current Input List. This List is updated every time one of these variables is changed.

The calculated values of the R, K, LS, C, and P factors and of the average annual soil loss are also saved in the Current Input List. This can cause a situation in which some of the inputs have been changed but new results have not been calculated. The results in the Current Input List may thus be meaningless, because they no longer correspond to the inputs in that List. RUSLE keeps track of such potential errors and gives warnings in the Soil Loss Prediction Table when they occur.

To facilitate the use of RUSLE, the FILE Function has been included to store the Current Input List for later use. When the Current Input List is stored (SAVEd), it becomes an Input File. This File contains all the values from the Current Input List at the time of SAVEing, plus any descriptive comments that you added through use of the {info} command. This File can later be LOADed back into the program, replacing all values in the Current Input List with the values in the File. This capability allows you to use that Current Input List later as a template, changing only the necessary input values before calculating another answer. It also gives you a record of the inputs associated with a particular result.

SAVEing the Input List to an Input File

The Current Input List is SAVEd to an Input File through the FILE Function of the Function Line. Refer to "Calling a Function" or "The FILE Function" for detailed information on the Function Line and on how to call a Function. Briefly, you move the cursor to the Function Line with the {FUNC} command. Because the FILE Function is the first one listed on the Function Line, its options will be shown automatically. Select the SAVE option either by marking it with the arrow (using the [UP ARROW] and [DOWN ARROW] keys) or by typing in the number of the SAVE option. [ENTER] to begin the SAVE routine.

This routine will bring up a list of the existing Input Files. To SAVE the Current Input List to an existing Input File, type in its name or move the marker with the [UP ARROW] and [DOWN ARROW] keys, and then press [ENTER]. *If you SAVE to an existing file, the information previously in it will be lost.*

You can SAVE the Current Input List to a new Input File by typing in a new name, using a maximum of eight characters. All alphanumeric characters (including the underscore, "_") may be used in the name. The program will not allow you to use blank spaces or a period within the name.

It is important that you choose an Input File name that will give you enough information so that you can pick it out of a list, because you may create many of these Files. This is difficult to do within the eight-character limit, but most users have found it helpful to include single-letter descriptions of each crop (for instance, *c* for corn, *b* for soybeans, *a* for alfalfa) followed by a single letter describing the tillage system. As an example of this sort of scheme, we describe a rotation of 4 yr of alfalfa followed by 1 yr of conventionally tilled corn and then 2 yr of no-till corn. One possible name is "4accc2cn," where the *4a* indicates 4 yr of alfalfa, the first *c* indicates that the alfalfa is planted after conventional tillage, the *cc* stands for conventional corn, followed by *2cn*, which describes the 2 yr of corn under no-till. The name you choose depends on which information that you are saving is most important to you. If you are most concerned with location, then the file name should include that. If you are comparing rotations, the location is probably not as important.

Finally, you will be allowed to enter up to five lines of file description, or to modify the comments entered previously through the {info} command. This may include such information as location, rotation, tillage practices–anything that might help you later to identify the file. Once you have entered all the information you want, use the {cont} command to force the actual SAVE to occur.

LOADing an Input File Into the Input List

A new Current Input List can be LOADed from an existing Input File. This allows you to take a File with values close to the ones you want and to change just the variables that differ. This is especially useful when you are making multiple runs under fairly similar conditions.

An Input File is LOADed into the Current Input List by use of the same procedure as for SAVEing, but by choosing the LOAD rather than the SAVE option of the FILE Function. Refer to "Calling a Function" or "The FILE Function" for detailed information on the Function Line and how to call a Function, or to the section immediately preceding this one for a brief description of the procedure.

LOADing an Input File into the Current Input List will replace all values in the List. These values will be lost unless they were SAVEd earlier.

Deleting Unnecessary Input Files

When Input Files are no longer needed, they can be removed using the Delete routine of the FILE Function. Either type in the file name or [ARROW] to the file you want; then [ENTER] to remove it. You can also use the {del}ete command from inside this routine or the LOAD and SAVE routines to erase files.

Using an Input File Created Earlier or Elsewhere

Input Files can be stored and shared with other users. When it is SAVEd, an Input File is stored in the directory in which the program is being run, and the Input File's name is the one you gave it when SAVEing plus a ".rus" suffix. If, for example, you gave the Input File the name "c-b-conv" when SAVEing, it would show up in the directory as the file "c-b-conv.rus."

The File can then be shared by copying it onto a diskette from which other users can copy it into their RUSLE directory. If your Input File has the same name as one already in their directory, they should change the name before copying it. After it is copied into the RUSLE directory, the new Input File will be treated like any of their other Input Files. Refer to your system manuals if you need help in copying or renaming files.

Files created on an older version of RUSLE can usually be used with newer versions of the program. Changes between versions may alter the number, names, and types of variables used by the program, but the program routines can adapt. If the program is looking for a variable that is not found within the old Input File, the variable will be set to zero or left blank. Extra values within the old Input File are ignored. If you are using an Input File created under an earlier program version, go through the program carefully the first time to make sure that all variables are set correctly.

DATABASES

Much of the information needed by the RUSLE calculations comes from a group of three Databases. The CITY Database contains information on climate, the CROP Database holds the parameters defining the characteristics of vegetative growth and residue, and the OPERATIONS Database defines the effects of field operations on the soil, crop, and residues.

Databases provide a way of associating a large amount of data with a single name or number, called the "Identifier." For instance, the CITY Database takes all the information necessary to describe for RUSLE the weather of a specific city or area, and associates that information with a single code number. One Identifier (city code, crop name, or operation name) is assigned to each Database Set, which includes all associated information.

In most cases, the data in each Database are independent of other available information. For example, the CITY Database's weather information is not likely to be affected by which crop is grown or which field operations are used. This independence holds to a lesser degree for the OPERATIONS Database and CROP Database. For example, a crop's growth characteristics will change with weather but likely will not vary as much from location to location as does weather. A corn Database Set may well apply to a fairly large part of the midwestern United States, although the weather within that area may vary considerably.

One key to using the Databases is to decide how many different Sets are required. For example, for how large an area of the Midwest are a set of corn-growth characteristics appropriate, and when will you have to add another CROP Database Set to show differences? How many CITY Database Sets are required to describe an area, given its particular weather patterns? How significant do crop varietal differences have to be to justify another CROP Set? You must answer these questions, and your responses will likely be based on the available data and the difference these changes seem to make in the final results.

Validity of Default Database Information

The values given in the default CROP and OPERATIONS Databases supplied with the program are supported by published literature cited in chapter 5. These values generally apply to the specific combination of location, crop variety, expected yield, row spacing, planting density, tillage practices, equipment speed, soil conditions, and so forth, used in the studies. The values should therefore be thought of as typical base values designed to give general guidance.

You, the user, are ultimately responsible for ensuring that the information within the Databases fits your local conditions. In general, you should modify the values in the Databases so that the results match your conditions. For instance, if you have seen in field observations and measurements that your soybean residue decays more quickly (or more slowly) than that predicted by RUSLE, you should change the residue decay parameter in the CROP Database until the model matches the information you have. The default Databases provide a strong basis in actual measured values, but these default values should be modified to reflect measured values under your specific conditions. Appendix D describes how to carry out these modifications.

The CITY Database is somewhat different, because the default Database values are based on the same information you are likely to find. You may, however, need to create additional Sets to describe your local conditions.

Calling the Database Utility Routines

The Database Utility routines are used to manipulate the information stored in the Databases. One way to reach these routines is by selecting the Database Utility from the RUSLE Main Menu. More commonly, you can get into the Utility routines for a specific Database from anywhere the Database is used. You can {call} the CITY Database routines from wherever you are asked for a city, the CROP Database routines from wherever you enter a crop name, and the OPERATIONS Database routines from wherever you give a field operation name. Practically speaking, you can {call} the CITY routines from the R, K, C, and P factors, whereas the CROP and OPERATIONS routines can be {call}ed from the input screens of the C factor. "Program Commands and Control" gives details on using commands such as {call}.

When you return from the Utility routines, the program should put you back at the same Input Field from which you {call}ed the routines.

Using the Database Utility Routines

The CITY, CROP, and OPERATIONS Databases are created and maintained by four major subroutines known as Utility routines. There are routines to edit the Database Sets or to create new ones, to print Database Sets, to delete unnecessary Sets from a Database, and to bring in (merge) new Database Sets.

Editing Existing Sets or Creating New Ones

The Edit routine is the most commonly used of the Database routines, and serves to review or revise an existing Database Set or to create a new one. After you choose this option, the program will respond with a list of available Sets, listed by Identifier. Select the desired Database Set by either typing in the Identifier or by [ARROW]ing to the one you want. Then press [ENTER]. The program will respond with a screen of information associated with that Identifier. Use {esc} to return from this option.

To edit an existing Database Set, move the cursor around on the screen to make the changes and then save the changed Set into the Database with the {save} command. See "Program Commands and Control" for how to give commands. Note that the new values will not be kept unless the modified Database Set is specifically {save}d into the Database.

The most efficient way to create a new Database Set is to begin with an existing Set that is similar to the one you want. Type in the new Identifier and then change only the values that need to be changed. To keep the new Database Set, {save} it before you {esc}ape from this Utility routine.

This routine can also be used to rename Database Sets. Call up the Set to be changed, then create a new Database Set by changing the Identifier and {save}ing. This gives you two Sets that are identical except for the Identifiers. You can then bring up the list and {del}ete the original Database Set as described below.

To delete an unnecessary Database Set, type in the name of the Set or use the [UP ARROW] and [DOWN ARROW] keys to move the marker to the Set Identifier; then give the {del}ete command. You will be asked to confirm this request.

Printing Database Sets

The second Utility routine is used to print information in the Database. This gives two options: The first option prints a list of available Sets within the Database, and the second option provides a complete printout of all information associated with a chosen Identifier. If, for some reason, the program cannot find an attached printer or cannot send the information to the printer, a warning will be displayed on the screen.

Background on Database Files

The RUSLE program uses three different computer files for each Database. The Original File contains only those Database Sets supplied with the program. The program will read from this file but cannot write to it, so it remains unchanged. The Working File is the one that you actually use. When you {save} a Set, it is copied here, and the list of Identifiers you usually see is made up from the Sets in this file. Finally, the Delete File contains all sets you didn't need and removed from the Working File. This serves as a file of last resort, allowing you an opportunity to bring back files that you wrongly deleted.

Every time the program is run, it checks to see if a Working File exists. If not, it creates one that is a clone of the Original File. If a Working File does exist, the program leaves it alone; this allows you to put new program versions in the same directory without destroying your Working File.

Deleting Unnecessary Database Sets

The speed and efficiency of the RUSLE program is improved by deleting extraneous information. Since Database Sets are designed to fit local conditions, it is likely that you will want to remove Sets that cannot possibly apply to your conditions. When one of the lists of Database Sets is shown, or when you are within the Create/Edit option of the Database Utility routines, you can do one of the following: Use the [ARROW] keys to mark the correct Set in the list, or type in the name of the Database Set, or move into that Set as if you are going to Edit. Giving the {del}ete command will then bring up a confirmation message, to prevent accidental removals. If you confirm your intentions, the Database Set will be removed from the list. As mentioned in the section below, it is still possible to recover that information.

You may also {del}ete Sets more quickly by using the Delete Database Utility routine. This option is faster because the program does not prompt you to confirm your decision to remove Sets.

Because of the large number of CITY Database Sets and because they are divided by state, the CITY Database Utility contains a special routine that allows you to remove large numbers of Sets from the CITY Database by indicating the names (abbreviations) of the states whose cities you wish to keep. It is then possible to {del}ete specific cities within those states by the procedure described above.

Sets {del}eted from the Working File are simply moved into the Delete File, but Sets removed from the Delete File are permanently deleted.

Restoring Information Deleted From a Database

You can use the "bring new Sets" routine of the Database Utilities to recover Database Sets that were mistakenly {del}eted. Simply specify that you want to bring the Sets in from the list of deleted Database Sets.

Information will be lost if you {save} to an existing Database Set. For example, if you make changes to the "corn" CROP Database Set and then {save} it, the information previously there will be lost, and will be replaced by the new information that will now be stored in the Working File. If there is any chance that you may want to keep this old information, either give the new Set a slightly different name or first {save} the old Set under a different name.

Using Database Sets Created Earlier or Elsewhere

The "bring new Sets" routine of the Database Utilities can also be used to copy Sets created on another computer or by another user. The procedure to do this is as follows:

(1) Before entering RUSLE (from the operating system):

- (a) You need to know that the names of the Working, Original, and Delete Files end with the ".dat," ".org," and ".del" suffixes, respectively. The prefixes are "croplist," "oplist," and "citylist" for the CROP, OPERATIONS, and CITY Database Sets, respectively. If you want to copy a CROP Database Set, for example, you are looking for the "croplist.dat" file.
- (b) Copy that file into another with a different name and with no suffix.
- (c) You need to make this available to your machine. In most cases, this means having a copy of the file on a diskette, but it can also mean having access to it over a network.
- (d) Copy that new file into your RUSLE directory. Do NOT copy "croplist.dat" into your RUSLE directory under that name, because doing so will erase your "croplist.dat" file.

(e) Refer to your system manuals for assistance if you have questions about copying files.

(2) After entering RUSLE:

(a) Enter the Utility routines for the Database you want to merge.

(b) Begin the "bring new Sets" routine.

(c) Enter the name of the file from which to merge; this is the name you gave it in step 1.b above. The routine will bring in the Sets within that new file. If a Set in the new file has the same Identifier as one already contained in your Database, you will be asked which to keep.

USING THE RUSLE SOIL LOSS PREDICTION TABLE

Although the individual factors and routines of RUSLE can be run separately, the heart of the erosion prediction package is the RUSLE Soil Loss Prediction Table. This table shows the R, K, LS, C, and P values calculated from the Current Input List as well as the annual soil-loss estimate (A) in tons · $acre^{-1}$.

Each line of the table corresponds to a single set of inputs. For instance, the top line may contain the results of a conventional tillage rotation on a specific field, the next line may be for the same rotation but using reduced tillage, and the third and fourth lines may examine what happens with different rotations on the same field. As this example shows, one main purpose of the table is to show the effects of alternative management systems, although the table may also be used to make other comparisons.

Relationship of Input Lists and Files to Lines of the RUSLE Table

NOTE: See "How RUSLE Gets, Uses, and Saves Information" and "Input Lists and Files" for a description of the Current Input List and of Input Files.

Each line of the RUSLE table corresponds to a set of inputs. When you enter the table, RUSLE creates a temporary Input File for each table line. This permits you to move freely between lines. The values from the Current Input List will be automatically SAVEd into the temporary Input File for the line you are leaving, and the values from the temporary Input File for the new line are automatically LOADed into the Current Input List.

You can also SAVE the Current Input List into an Input File. This replaces the temporary Input File assigned to that table line with the permanent Input File given whatever name you have assigned.

If you have made changes to the temporary Input Files but have not SAVEd these, the program will warn you of this before allowing you to exit.

You can move the cursor between factors on a single line without changing any values. To compute a factor, move the cursor to that column and use the {call} command. When the computations are complete, the new factor value will be shown on the table.

Entering Values Directly Into the RUSLE Table

You can also enter values into the RUSLE Soil Loss Prediction Table directly. For example, if you know that the R Factor associated with your location is 120, you can type that number in the R Factor column in the table. The program will use any combination of typed and computed results to calculate an estimated annual erosion rate.

Warning Footnotes on the RUSLE Table

Because of the complicated relationships between the RUSLE Soil Loss Prediction Table, the Current Input List, and the Input Files, RUSLE keeps track of potential problems and gives warning messages. These show up as flags placed near the values in the RUSLE table and as warnings in footnotes to the table.

In general, these warnings indicate that the factor values in the table may no longer correspond to the numbers in the Current Input List, which can happen in three instances: (1) if you go into one of the factor routines and make some changes but do not carry through with the calculations, (2) if you enter a factor value directly from the keyboard, and (3) if information used several places in the program is changed in one location without being changed everywhere. For example, the city of interest can be specified within the C factor, but the information is used in the C, R, K, and P factors. If the citycode is changed only in the C factor, the results shown in the other factors may no longer correspond to the Current Input List (with its new citycode). To resolve this, move to each of the other factors and use the {call} command to perform the calculations. A similar difficulty arises when the field slope is changed, because the R, LS, and P factors all use this value.

SPECIFIC GUIDELINES AND ANSWERS TO COMMON QUESTIONS

CITY Database

The CITY Database contains all the climate information used in RUSLE. This information is divided into Database Sets, each of which represents a specific location. You, as the user, must determine the size of area to which that information applies. Areas where climatic patterns change quickly with distance will require more Sets (for instance, in the mountainous regions of the western United States).

Each Set has a unique name called the Citycode Identifier. This is an integer number unique to that Set and may range from 1 to 99,999. Citycode Identifiers may be assigned in any arbitrary order, although a specific ordering scheme is used within the default Database. Each CITY Database Set also has a Block Identifier of two upper-case letters. This is used to group the cities into blocks. In the default Database, the state abbreviation is used.

"How RUSLE Gets, Uses, and Saves Information" gives some background, and "Databases" gives specific details on changing and manipulating this information.

Answers to Common Questions About the CITY Database

How do I name/number a new city?

(1) Select a Citycode Identifier. Although any numbering or naming scheme may be used, the one for the default CITY Database is recommended because changes in the numbering scheme may make it more difficult to share your Database Sets with others, or to incorporate their Sets into your program (see "Using Database Sets Created Earlier or Elsewhere"). The default Database uses a five-digit Citycode Identifier for each Set.

(a) An alphabetical list of states is numbered from 1 (Alabama) to 50 (Wyoming), and the District of Columbia is assigned number 51. The first two digits of the five-digit number indicate the number of the state within that list. Under this scheme, cities in Arizona (the third state in the list) have Citycodes of the form 3XXX (same as 03XXX), and cities in number 14 (Indiana) look like 14XXX.

(b) The three rightmost digits refer to the cities within that state. The default scheme places cities within a state in the order in which they were created, with the first city given the description 001, the next 002, and so on.

(2) Type in the name of the city or area. The name associated with a CITY Database Set is by no means limited to the name of an actual city. In fact, the Set is likely to be applied to a larger area, so the name can be that of a county or anything that identifies the Set. In the default Database, this is the city by which the original weather information was identified.

Note: The default scheme uses the two-letter state abbreviation as the Block Identifier.

When is the Equivalent R value used? Much of the erosion in portions of the Pacific Northwestern Wheat and Range Region is the result of rainfall and runoff on frozen or thawing soils, and erosion rates in that area far exceed those predicted using the standard R values. Also, the distribution of this erosion over the year does not match that expected from the standard EI distribution. These considerations make it necessary to use Equivalent R values to describe the erosivity, rather than the standard values of R.

Within RUSLE, the EI distribution you select for a city determines whether the equivalent R can be used. Figure 2-7 of chapter 2 shows all the distribution areas. The program currently recognizes EI distribution areas 6-10, 14-18, 20-22, 29-41, 45, 58-60, and 63 as those for which the Equivalent R value can be used. If you select one of these areas, you are given the choice of using either the standard EI distribution for that area, a "frozen soil 95-5" default distribution that researchers have found works well for the area, or your own distribution. If you choose one of the options containing a "frozen soil" distribution, an equivalent R value will need to be chosen from figures 2-13 through 2-16 of chapter 2.

How do I select and enter an EI distribution? The EI distribution defines how the precipitation energy-intensity varies over the course of the year. Every area within the continental United States has been assigned a standard distribution, numbered as shown in figure 2-7.

In general, two options are available in the selection of an EI distribution: (1) use of one of the standard distributions, with the number selected from figure 2-7; or (2) creation of a new distribution to meet specific local conditions. If the latter is done, the distribution will not be given a number, as it no longer corresponds to the numbering in the figure. Instead, it will be given the label "NEW." You then need to enter the EI values for the new distribution.

The exception to the rule is for the cities of the Northwestern Wheat and Range Region, where it is possible to include the effect of rainfall and runoff on frozen or thawing soils. In this case, four options are presented: (1), (2) the options mentioned above; (3) use of the standard 95-5 frozen soil distribution, which will be given the label "REQ"; and (4) manually entering a new frozen soil distribution, given the label "NEW REQ." The use of either of these last two options requires selection of an Equivalent R value.

For what is the city elevation used? The CITY Database Set includes an entry for the city elevation. The elevation is for information only and is not currently used within the RUSLE program.

CROP Database

The CROP Database contains all the information on growth and residue for the vegetation of interest. The information is divided up into Database Sets, each representing a specific crop or plant community. You must decide how many Sets are required to adequately reflect the differences caused by region, variety, or crop stress. This decision can be made only by noting the sensitivity of the outputs to differing inputs.

The information in each Set is associated with a Crop Identifier, which may be any name up to 20 characters long. This may be anything that makes the crop unique and describes it in a way that is meaningful to you. You cannot use some special characters reserved by the program or the operating system, but the program will warn you of these or will not allow you to enter them.

"How RUSLE Gets, Uses, and Saves Information" gives some background, and "Databases" gives specific details on changing and manipulating this information.

Answers to Common Questions About the CROP Database

How do I choose a vegetation/land use category? The crop category is critical in deciding how RUSLE gets and treats the crop information. The possible categories and what they mean to the program are:

(1) *time-varying vegetation:* This category is used for all vegetation where seasonal or cultivation effects cause significant changes in root mass,

canopy cover, or canopy height. This should be used for all cases except where the changes are so small or gradual that they can be ignored.

(2) *time-invariant vegetation:* If there are few seasonal changes in cover, residue, or root mass at the site, choosing this category greatly simplifies calculations. In this case, you need to enter only the average annual values. The use of this information is described in more detail in "C factor."

RUSLE uses these categories in displaying lists of crops. For example, in the calculation of an average annual C-factor value, RUSLE will show the list containing only the crops designated as "permanent"; when asking for a time-varying vegetation, RUSLE will show a list containing only those.

How does the database information control residue levels? Vegetative residue is a basic component of erosion control, and the information in the CROP Database Set determines the amount of residue and how it behaves. Each Set contains residue-decay rate parameters, which are used along with weather data to estimate the decay rates of the surface and subsurface residue.

RUSLE keeps track of the amount of residue by weight, although its effectiveness in controlling erosion is computed as a function of the percentage of cover. To convert between the two, each CROP Database Set contains as many as three values defining the relationship between cover and weight. You must supply at least one of these values, but giving two or three values will yield better results. Each supplied value is used to define a relationship between cover and weight; if you give more than one value, the relationships are averaged.

RUSLE contains routines that make it easier for you to decide how much residue has been added to the surface by a harvest operation. Within the CROP Database you enter the harvest yield and a few other constants, from which RUSLE will calculate a residue weight.

Surface residue is added to the field only by field operations (see "OPERATIONS Database") or by senescence, which is described in the next section. Surface residue is removed only through decay or by a field operation. Subsurface residue, on the other hand, can be added in one of two ways: (1) by the burial of surface residue during a tillage operation, or (2) by the death of the root biomass of vegetation.

The RUSLE program looks for two possible scenarios in adding root biomass to the subsurface residue. The first of these occurs when the vegetation is completely killed, as might occur with tillage or application of a knock-down herbicide. The second scenario occurs whenever the CROP Database Set indicates a drop in live root biomass, which the program takes as an indication of the conversion of that much root biomass from live roots to subsurface residue.

What is the crop senescence option? In RUSLE, senescence is defined as leaf loss after the plant has reached maturity. The senescence option in the C-factor calculations calls on the CROP Database Set to provide information that may not be readily apparent. If this option is chosen, the crop is assumed to add residue to the surface when the leaves fall. RUSLE handles this by treating a decrease in canopy cover as a similar increase in surface cover. For example, if the canopy cover decreases from 90% to 75%, the total weight of surface residue is presumed to increase by an amount equal to the weight that would give 15% surface cover as defined by the cover-weight relationship.

Do I have to enter all those values for root mass, canopy cover, and canopy fall height? You do not have to enter values for root mass, canopy cover, and canopy height for the entire year. The program searches for the last value of root mass greater than zero and then assigns all remaining root mass, canopy cover, and fall height to the values they have at that point.

How do I handle crops with growth cycles lasting longer than a year? There are two ways of handling a crop whose growth cycle lasts longer than 1 yr: (1) Leave it as a single crop. When the crop goes beyond 1 yr, the program will continue to use the last values of root mass, canopy cover, and canopy height for the rest of the time. (2) Call in a regrowth file, either under an operation within the original crop or as a completely separate crop.

OPERATIONS Database

Field operations are important to the RUSLE program in how they affect the soil, vegetation, and residue. Operations disturb the soil, begin vegetative growth, kill the vegetation, add residue to the surface, or incorporate residue. They may also affect the way the vegetation grows.

This information is divided into Database Sets, with each Set representing a specific operation. You must decide how many Database Sets are required to adequately reflect the differences in the type, speed, and method of use of implements. This decision can be made only by noting the sensitivity of the outputs to differing inputs.

The information in each Set is associated with an Operation Identifier, which may be any name up to 20 characters long. You cannot use some special characters reserved by the program or the operating system, but the program will warn you of these or will not allow you to enter them. The Operation Identifier may be anything that makes the name of the operation unique and that describes it in a way that is meaningful to you.

The OPERATIONS Database is currently used only in the C-factor calculations.

Answers to Common Questions About the OPERATIONS Database

What are the "effects"? The information in an OPERATIONS Database Set consists of a list of effects of the operation on the soil/vegetation/residue system and any additional information required to define them. The program goes through the effects in the order in which they are given (first #1, then #2, and so on) and calculates the impact of the effect on the soil, vegetation, and residue.

RUSLE allows up to five effects for any field operation, and these are chosen from a list of nine possible effects. If a field operation has more than five effects, these may be split between two operations scheduled to occur on the same day.

The program does not allow you to have more than one residue addition or removal in an operation. For instance, you may not add both residue from the current crop and some other residue within a single operation. This limitation exists because you can enter only a single number to tell the program how much residue you are adding. This also means that you cannot add and remove residue within the same operation.

The nine possible effects are listed below, along with a brief description of their place in the program and the calculations.

(1) *no effect:* The program requires five effects. Actual operation effects are listed first, and any remaining spaces are filled with this null value.

(2) *soil surface disturbed:* A field operation disturbs the soil surface in ways that affect erosion rates: (a) disturbing the soil is the only way to incorporate some of the surface residue; (b) the surface of the soil is loosened, which changes the degree of soil consolidation seen in the prior-land-use subfactor of the soil-loss-ratio (see ch. 5); (c) the surface roughness is altered, changing its impact on erosion rates. Including this effect in the list for an operation automatically brings forward questions that are used to define these changes.

(3) *current crop residue added to surface:* This effect specifies residue from the current crop, which means that the residue and decomposition parameters are taken from the current CROP Database Set. If a regrowth crop has been called in, the parameters are taken from there. If there is no current crop, the program adds residue from the most recent current crop.

The program will ask you to define in one of two ways how much residue is added to the surface. If the operation is a harvest operation (see below), the program will automatically pull in from the CROP Database Set the amount of residue added at harvest. If the operation is not defined as a harvest, you must enter the amount of residue added when you fill in the list of operations within the C-factor inputs.

(4) *other residue added to field:* This effect is used to model the impact of material coming from other sources, such as straw mulch used on a vegetable crop or manure spread on a field. This effect brings up questions asking you to define the cover and decomposition parameters for that residue, as well as what percentage of the applied material is left on the surface.

Because the only way to apply a material to the subsurface region (as with a manure injection) is to disturb the surface, this effect must be followed by a (2) within the same operation. When this is done, the percentage of residue buried by the (2) will be for the residue on the surface before the operation. The (2) effect will not bury any of the residue added to the surface by this operation.

(5) *residue removed/added to field:* This is the only effect that considers the removal of residue from the field. You need to specify whether it is from only the current or most recent crop (for instance, baling of corn stover) or from all previous crops (such as burning of residue). Within the list of operations in the C-factor inputs, you will need to specify how much residue is removed.

(6) *current crop harvested:* Information in the CROP Database Set for each crop indicates how much residue is added to the surface when the crop is harvested. Use of this effect automatically brings in that value as residue added to the surface. Refer to the earlier description of effect (3) for more information.

(7) *crop growth begins:* This effect tells RUSLE to begin the growth cycle found in the CROP Database Set for the vegetation listed at the top of the C-factor input screen, and to set "day 0" in that vegetation's cycle as the date of this operation.

(8) *current crop is killed:* This effect does two things: (a) the canopy cover and fall height are automatically set to 0 because the crop is no longer growing, and (b) the root mass is converted into a subsurface residue and begins to decay. The crop can be killed without adding residue to the surface, but from that point on there is no canopy effect.

(9) *call in a new crop growth set:* This effect begins growth of a regrowth crop whose name you are asked to specify when you define the cropping sequence and field operations. This effect should be used when growth patterns change because of an operation or weather, or simply to bring in a new crop as the current crop. The growth, decomposition, and weight-cover values are all replaced by those of the new growth Set, as are the root mass and canopy values.

In what order should I enter the effects? The effects of an operation must be entered in the order in which they occur. For example, operations that add residue either before or after disturbing the soil will give different results. Adding the residue before the soil disturbance will incorporate some of the residue, whereas adding it afterward will not.

How are residues buried or uncovered? The "% left" variable is defined as the percentage of original residue left on the surface following the operation. This can be defined as a "% wt", which is the percentage of the original surface-residue weight. If defined instead as a "% cov", it is the percentage of surface cover left after the operation. For example, if the residue covered 50% of the surface before the operation and the operation leaves 90% cover, the cover after the operation is 50% · 90% = 45%.

If there is more than one residue type on the surface, it is assumed that the specified "% cov" refers to each residue type individually and not to the overall cover. For example, if before the operation there was on the surface a weight of wheat residue equivalent to 60% cover plus a weight of soybean residue equivalent to 40% cover, then after an operation leaving 30% cover there would remain on the surface weights of residue equivalent to 18% and 12% cover for the wheat and soybeans, respectively. Depending on the specified residue characteristics, this might well yield an overall percent cover not equal to 30% of the original cover.

You can also use this term to uncover buried residue by specifying that more than 100% of the residue be left on the surface. For example, if before the operation the surface has 50% cover and the operation leaves 120%, the surface cover after the operation is 50% · 120% = 60%. The program is set to limit the total amount of residue cover to 99.99%, and will not bring up more residue than actually exists. The option of uncovering residue can be used with either the percent weight or percent cover options.

R Factor

The RUSLE R factor defines the total annual erosive potential that is due to climatic effects. This factor reflects the impact of geographical location on erosion, including such factors as localized impacts of lakes or mountain ranges and the dominance of frontal or cyclonic activity.

Options

Initial R-factor value. The first option in selecting an R value is to take it directly from the isoerodent maps of figures 2-1 through 2-5 of chapter 2. The R values in the default CITY Database Sets are taken from these. This information is currently available for all locations in the contiguous United States and Hawaii.

Adjusted R value. For fields with very low slopes and in areas with high rainfall, the R value will be modified to reflect the absorption of raindrop impact energy by ponded water. Note that this changes the R factor to a value that applies to only a specific field rather than to a general geographical region, and does not change the R value in the CITY Database Set.

You are asked to indicate whether or not you want this correction. If your field has a very rough surface or has moderate-to-high ridges, more of the surface will be exposed to raindrop impact, thereby increasing detachment. Under these circumstances, do not use the adjustment.

Equivalent R value. As explained in "Answers to Common Questions About the CITY Database" and chapter 2, erosion in parts of the Northwestern Wheat and Range Region far exceeds the amount predicted by the simple R value because much of the erosion occurs on frozen or thawing soils subjected to gentle rains but erosive runoff. If the CITY Database Set you specify was defined as being for such an area, the Equivalent R value can be entered. You are not required to enter this value, because you are not forced to have this effect for cities in this area. "Answers to Common Questions About the CITY Database" explains how to use this effect.

K Factor

The K factor of RUSLE defines the soil erodibility under a set of standard conditions.

Options

Seasonal K value. The seasonal K value attempts to include the effects of freeze-thaw cycles and other factors affecting the temporal variation of soil erodibility. This option requires an original estimate of K, which may be either entered directly or calculated through use of the soil-erodibility nomograph.

Volcanic K value. Data collected in Hawaii for volcanic soils have shown a somewhat different relationship between soil properties and erodibility. If this option is used, K is calculated for the entered data. No seasonal variation of K is needed for these soils, because they are in general not subject to freeze-thaw cycles. These data have not been tested for soils outside Hawaii.

Answers to Common Questions About the K factor

What are the dates of maximum and minimum K for the seasonal K option? The time-varying K calculations yield a K value for each half-month period through the year, with the calculations made at the middle of each period. The date shown for the maximum or minimum K may not correspond to the period with the highest or lowest value if that date is very early or very late in the period.

Why can't I use the time-varying K for the western United States? As described in chapter 3, the algorithms used to calculate the time-varying K work well for the eastern United States, but not for the area west of approximately longitude 105°W. The RUSLE program determines your location by use of the EI distribution zone number, and will not allow the calculations for any areas west of that line.

How is the K nomograph used? The calculation of seasonal K variability uses an original estimate of K. If a Soil Interpretation Record exists, you may enter the K value from it as your estimate. The other option is to develop an initial estimate of K using the K-nomograph method. You get access to the K-nomograph method by {call}ing the subroutine from the Input Field for the original estimate.

What is the soil hydrologic group? Because the soil hydrologic group is a soil property, it is entered within the inputs for the K factor even though it is not used in the K-factor calculations. It is used solely within the P factor to indicate the effect of runoff on support practices.

How is the # years to consolidate used? The C factor also requires the length of time it takes for the soil to fully reconsolidate in the calculation of the PLU subfactor. Since this is primarily a soil property, it is entered here in the K factor.

How is the % surface covered by rocks used? RUSLE treats rocks on the surface as surface cover rather than through their impact on the K factor. This value is therefore not used in the K-factor calculation, but rather is called in from here for the C-factor routines. However, since surface rock cover is generally a soil characteristic, this input is included here with the other soil inputs.

LS Factor

The RUSLE LS factor accounts for the effects of slope length and slope steepness on soil loss.

Answers to Common Questions About the LS factor

Which LS table should I use? The selection of an LS table depends on the condition of the soil and its susceptibility to rill erosion, presented as a ratio of rill to interrill erosion rates. This susceptibility can be a function of either the innate soil properties (such as texture, aggregation, and structure) or the degree to which the soil is modified by mechanical disturbance. In general, a disturbed soil shows a higher rill-interrill erosion ratio than does an undisturbed soil.

Table 4-1 is used for soils with low rill-interrill erosion ratios, usually including those not disturbed for some time. Table 4-2 applies to soils with a moderate percentage of erosion coming from the formation of rills, including soils that are disturbed relatively frequently. Most agricultural soils fall into this category.

Table 4-3 is used for soils that undergo high degrees of rill erosion, including highly disturbed soils such as those on construction sites. This category also contains agricultural soils that by their nature are susceptible to large amounts of rilling.

Finally, table 4-4 contains LS values for soils subject to thawing, runoff from snowmelt, and rain on frozen soil or snow. This changes the importance of the LS factor in relation to overall erosion rates. In general, these values will be used only for slopes in the Northwestern Wheat and Range Region.

What is the equivalent slope? Several routines within RUSLE require an estimate of the average steepness of the downhill slope, called the "equivalent slope." This estimation is easy for a uniform slope because uniform slope = average slope = equivalent slope. For a complex slope, RUSLE defines the equivalent slope steepness as the uniform slope steepness that gives the same LS value as that calculated for the complex slope. For example, if the complex slope has an overall length of 200 ft and an overall LS = 2.34, the equivalent slope steepness is that for which a uniform slope of 200 ft has an LS = 2.34.

The equivalent slope is calculated automatically in the LS routines. When needed by other parts of the program, these calculations may be {call}ed from there.

How do I get LS printouts? The Print option of the LS factor gives a printout of the tables showing LS values corresponding to a broad range of uniform slope lengths and steepnesses. The output tables are 132 characters wide and do not fit on most printers (which use 8½" x 11" paper), unless the printers can be specially configured to do this. Check your printer manuals.

C Factor

The RUSLE C factor describes the effects of cover and management on average annual soil loss.

Options

Time-varying vs. continuous. The C-factor calculations are used to determine the soil-loss ratio (SLR) subfactors for half-month time periods over which conditions are assumed to remain constant. The exception to this is cases of continuous pasture, meadow, or rangeland, for which conditions are likely to change very little over the course of an entire year. For these cases it would be of little value to make the calculations every half month, because the numbers would change only slightly.

The time-varying option must be used whenever the cropping or plant community changes significantly over a year, or when field operations disturb the soil or plant residues.

Single disturbance vs. rotation. Within the time-varying C option there are also two very different options. The first assumes that there is a single disturbance of the system, with subsequent long-term restabilization. You therefore need to define for the program the condition of the soil, vegetation, and residue immediately after the disturbance, and how the site changes over the years as the soil reconsolidates and vegetation regrows. This alternative fits best for construction sites, mine spoils, or many of the mechanical rangeland improvement techniques.

The single-disturbance option is selected by placing a zero (0) in the field for the number of years in the rotation. This brings up additional questions concerning the final surface roughness expected for the site, since this number will be a function of the expected long-term vegetation. For the rotation option, it is assumed that there is repeated soil disturbance, which keeps this natural long-term roughness from ever having a significant influence.

The other alternative is to assume a rotation, where the operations are repeated in a cycle through many years. For example, the list of operations for a corn-soybean rotation would be only 2 yr long, but this list would be expected to repeat itself every 2 yr. If the rotation option best fits the system you are describing, the RUSLE program runs through the calculations three times. The program uses the results from the first two times as the initial conditions for the third run. The rotation option is chosen by specifying the number of calendar years in the rotation.

Concepts of the Time-Varying C Factor, With Examples

At first glance it may appear complex, but the time-varying option for calculating a C factor is simple if several basic concepts are understood. Since these concepts are crucial to an understanding of the power and flexibility of the C-factor calculations, they are illustrated through the use of examples. *Values and Database Sets included in the examples are meant solely as illustrations.*

Important parameters in the time-varying C option. The time-varying C option is based on a listing of the field operations, which in turn call in information from the CITY, CROP, and OPERATIONS Databases. The combination of information from these sources defines the changes in crop root mass and canopy cover, in soil roughness and consolidation, and especially in surface and subsurface residue.

Defining the current crop in the time-varying C option. The RUSLE program keeps track of only one set of CROP Database parameters at a time: root mass, canopy cover and height, and residue amount and decay variables. These values are taken from a single CROP Database Set, and the Set in use at a specific time is referred to as the current crop. When a CROP Database Set becomes the current crop, the program automatically pulls in all the information associated with that crop name, replacing the root mass, canopy, and residue values that had been linked to the previous current crop.

There are two ways to identify the current crop, and both of these require the use of a field operation. The first option is to have a planting operation, which instructs the program to install as the current crop the Set named at the top of the operations list screen. The second option is to have a field operation that asks for a regrowth crop. The program will prompt you for the name of that new Set, which it then pulls in as the current crop.

Note that the crop listed at the top of the screen never becomes the current crop unless an operation tells the program to begin its growth. In spite of this, when the results are shown, they will be displayed under this crop name. This means that the crops you list on the initial C-factor screen and that are shown atop each operations list screen serve two purposes: (1) they are used in accounting, defining over what time period the SLR values are summed; and (2) if called on by a planting operation, they can become the current crop.

It is essential that you keep track of which is the current crop, as this defines all the crop and residue parameters. For instance, unless you specifically direct the program otherwise, any residue added to the surface will have the decay and cover characteristics associated with the CROP Database Set for the current crop.

Defining a Set as the current crop causes one additional hidden impact. The date of the operation defining a new current crop (either a planting operation or one requesting a new Set) automatically becomes day zero in the growth cycle in that Set.

Use of regrowth crops within the time-varying C option. Some events drastically alter the growth patterns of the vegetation without killing it completely, such as mowing hay or cutting rangeland brush. In RUSLE, these changes in growth patterns are handled through CROP Database Sets called in as regrowth crops. The regrowth Set is meant to reflect the crop growth and residue patterns as the crop rebounds from the effects of some operation or event that drastically changes those patterns. The date when an operation calls in a regrowth crop becomes day zero in the crop growth cycle, and that Set becomes the current crop.

When you use regrowth crops, you must make sure that proper transition is made between crops. For example, if there is a sudden drop between the last root mass value for the first Set and the first root mass for the second, the program will assume that you meant for this drop to occur, and will add that difference to the subsurface residue. Changes in residue cover and decay parameters as you move from one crop to the next indicate that subsequent residue additions will have those new characteristics.

How the time-varying option handles root mass. The root mass for the current crop begins growing at either the time of planting or when the crop is called in as a regrowth file. When an operation is defined as killing the current crop, the root mass becomes part of the subsurface residue and begins to decompose at a rate controlled by the decay parameter from the CROP Database Set in which the root mass was defined.

The program will also recognize a drop in root mass either within a CROP Database Set or between crops, as in the transition to a regrowth crop. Any drop in root mass is taken as a similar increase to the subsurface residue pool. If the drop in root mass occurs between Sets, the decay parameter for this residue will be that from the first Set.

Definition of canopy cover in the time-varying option. For the most part, the handling of canopy cover is very straightforward; the program simply takes the values from the current crop Set and uses them to make the calculations. The single possible complication occurs when you choose the senescence option for a crop. This indicates that a drop in canopy cover should cause an increase in residue on the soil surface. The program calculates this effect by looking at the percentage drop in residue cover, and then adding to the surface cover a mass of residue equal to that which would give the same percentage of cover to a bare surface. This amount is defined by the residue cover parameters from the CROP Database Set.

The program does not keep track of drops in canopy cover when you switch to a regrowth crop, because this type of change is usually caused by an operation, which often involves removing canopy material from the field.

How RUSLE handles surface residues. RUSLE keeps track individually of every residue you add to the field, and calculates its cover and decay relationships based on the specific parameters assigned to that residue when it was still associated with a current crop or when it was added as a "foreign" residue. Most residue additions are for the current crop, so you must be aware of which crop that is and whether its residue parameters are the ones you want.

Residue additions to the soil surface are specified on the screen where you list the operations. In general, you are responsible for telling the program how much residue is being added to the surface, but there is one exception. If you specify that the operation harvests the current crop, this tells the program to look in the CROP Database Set associated with that crop to find the residue added at harvest. The program then automatically enters that value into the correct place in the list of operations.

Example 1: Five years of Eastern alfalfa cut for hay followed by 3 yr of corn. Many of these concepts become more clear when dealing with specific examples. The first example is for an alfalfa-corn rotation in eastern Pennsylvania, with 5 yr of alfalfa followed by 3 yr of corn.

The first screen describes the location and gives general information about the rotation. The number of years in the rotation is set at 8 since, as we will see later, the first operation in the rotation will not be repeated for 8 yr. The crops indicated in the list were selected from the CROP Database File, and for each crop in the list the program will display a screen on which you will be asked to enter the field operations associated with that crop. The crops in this list need not correspond to calendar years; there can be either more or fewer crops in the list than years in the rotation. This list also does not need to include all CROP Database Sets used in the rotation.

```
     FILE        EXIT        HELP        SCREEN
 ───────────────< Rotational C: general inputs TEST 0.26 >──────────────────
                        city code: 38001   PHILADELPHIA            PA
   adjust for soil moisture depletion: 1
  % surface covered by rock fragments: 0
 surface cover function; B-value code: 1
      number of years in the rotation: 8
                                               #        Crop
                                              ┌───────────────────────────┐
                                              │ 1   alfalfa 1st year      │
                                              │ 2   alfalfa 2nd year      │
                                              │ 3   alfalfa established   │
                                              │ 4   corn                  │
                                              └───────────────────────────┘

 ───────────────────────< F3 When Questions Answered >───────────────────────
 Tab  Esc F1   F2  F3   F4   F6   F9   PgUp PgDn Home End
 FUNC esc help clr cont call list info pgup pgdn 1st  last
```

Below is the first screen of information describing the field operations associated with the rotation. All operations that we want included in the calculation for "alfalfa 1st year" are listed here.

```
    FILE       EXIT       HELP       SCREEN
┌─────────────< Rotational C: field operations TEST 0.26 >─────────────┐
│ 1/4   crop: alfalfa 1st year       senescence code: 2                 │
│─Date────────Field Operation────Res. Add. (#/A)──────────New Growth Set──│
│ 3/30/1      chisel (3 in. twist)                                       │
│ 4/5/1       disk; tandem                                               │
│ 4/6/1       harrow (tine)                                              │
│ 4/10/1      drill; conventional                                        │
│ 6/30/1      hay harvest              600              alf. 1st yr regrowth │
│ 8/15/1      hay harvest              450              alf. 1st yr regrowth │
│ 9/30/1      hay harvest              450              alf-1st yr.sen clrso │
│                                                                        │
└────────────────────────< F3 When Questions Answered >─────────────────┘
Tab  Esc F1   F2  F3   F4   F6   F9   F10  Ins Del PgUp PgDn Home End
FUNC esc help clr cont call list info desc ins del pgup pgdn 1st  last
```

The first three operations in this list are tillage operations, which disturb the soil surface and incorporate some of the surface residue. Since the corn crop came just before these operations in the rotation, the operations will be burying corn residue. The tillage operations will also affect the soil surface random roughness.

The drill operation on April 10 includes an effect entitled "crop growth begins." This takes the CROP Database Set listed at the top of the screen (alfalfa 1st year), installs it as the current crop, and begins its growth cycle.

The hay harvests scheduled in this first year do two things: (1) they completely change the alfalfa growth characteristics, requiring a regrowth Database Set to show how the crop responds after being cut, and (2) they add some alfalfa residue to the field through wastage in the harvest process. There are two ways of handling this residue addition. The first way is as shown above, which uses the OPERATIONS Database Set below.

```
      FILE      EXIT      HELP      SCREEN
┌─────────< Create/Edit Field Operation Database Set TEST 0.26 >──────────┐
         field operation: hay harvest________
 Effect #1: 6
 Effect #2: 3
 Effect #3: 9
 Effect #4: 1
 Effect #5: 1
                              ┌──────────────────────────────────────────┐
                              │ 1. no effect                             │
                              │ 2. soil surface disturbed                │
                              │ 3. current crop residue added to surface │
                              │ 4. other residue added to surface        │
                              │ 5. residue removed from field            │
                              │ 6. current crop harvested                │
                              │ 7. crop growth begins                    │
                              │ 8. current crop is killed                │
                              │ 9. call in a new crop growth set         │
                              └──────────────────────────────────────────┘
└──────────────────< F7 Saves, Esc Returns to OP Main Menu >──────────────┘
Tab  Esc F1   F2  F4   F6   F7   F9   F10  Ins Del
FUNC esc help clr call list save info desc ins del
```

This Set specifies that the operation harvests the current crop, which causes the program to automatically go into the CROP Database Set for the current crop (in this case, "alfalfa 1st year") and to extract the information required to calculate residue added at harvest. The OPERATIONS Set also specifies that the operation adds residue from the current crop to the field: this is redundant because this is assumed by the program when it sees the harvest effect, but this may be included for the sake of completeness. Finally, the Set states that the operation will significantly affect the crop growth characteristics, requiring a new CROP Database Set to model that regrowth.

The operations list is repeated below for convenience. In it we see the regrowth CROP Database Sets listed in the far right column. Note that from 6/30/1 to 8/15/1, the current crop is "alf. 1st yr regrowth," which once again becomes the current crop with the hay harvest of 8/15/1. This means that on 8/15, the program brings this Set in to replace itself, and once again sets the days of growth to zero and restarts the growth cycle all over again.

```
     FILE        EXIT        HELP        SCREEN
┌─────────────────< Rotational C: field operations TEST 0.26 >──────────────────┐
│ 1/4   crop: alfalfa 1st year      senescence code: 2                          │
│─Date──────────Field Operation────Res. Add. (#/A)──────────New Growth Set──────│
│ 3/30/1      chisel (3 in. twist)                                              │
│ 4/5/1       disk; tandem                                                      │
│ 4/6/1       harrow (tine)                                                     │
│ 4/10/1      drill; conventional                                               │
│ 6/30/1      hay harvest            600               alf. 1st yr regrowth     │
│ 8/15/1      hay harvest            450               alf. 1st yr regrowth     │
│ 9/30/1      hay harvest            450               alf-1st yr.sen clrso     │
│                                                                               │
└──────────────────────────< F3 When Questions Answered >───────────────────────┘
Tab  Esc F1   F2  F3   F4   F6   F9   F10  Ins Del PgUp PgDn Home End
FUNC esc help clr cont call list info desc ins del pgup pgdn 1st  last
```

The values in the third column, Res. Add., indicate the amount of residue added to the surface by each operation. Since the "hay harvest" Set listed the operation as a harvest, these values are calculated automatically from information in the CROP Database Set for the current crop. The 600 is calculated from the Set for "alfalfa 1st year" since it is the current crop to that point, and the 450 comes from the "alf. 1st yr regrowth" Set.

The second way of handling the residue additions is to specify the hay harvest simply as adding residue to the surface but not harvesting the crop. The program would then ask you to enter a value in the Res. Add. column rather than automatically calculating a value.

The senescence code for this crop is set at 2, which indicates that the program should consider a drop in canopy cover as an increase in surface cover. The CROP Database Set "alf-1st yr.sen clrso" includes such an effect to model the impact of winter on alfalfa growth, as shown below.

```
     FILE        EXIT        HELP        SCREEN
 ----------------< Create/Edit Crop Database Set TEST 0.26 >----------------
          crop: alf-1st yr.sen clrso              category: 1
res. @ harv. (lb/A): 200      row spacing (in): 6___  plant pop. (#/A): 900000
surf. res. decomp. cons.: 0.01500        sub. res. decomp. cons.: 0.01500
res. at 30% cover (#/A): 640      at 60% cover: 1650     at 90% cover: 4100
  days   root mass  canopy     fall   |  days   root mass  canopy     fall
   of    #/Ac (in   cover      height |   of    #/Ac (in   cover      height
 growth   top 4")    (%)       (ft)   | growth   top 4")    (%)       (ft)
 0       2600       0          0      | 180      0          0          0
 15      2650       65         0.1    | 195      0          0          0
 30      2700       80         0.1    | 210      0          0          0
 45      2700       70         0.1    | 225      0          0          0
 60      2700       60         0.1    | 240      0          0          0
 75      2700       10         0.1    | 255      0          0          0
 90      0          0          0      | 270      0          0          0
 105     0          0          0      | 285      0          0          0
 120     0          0          0      | 300      0          0          0
 135     0          0          0      | 315      0          0          0
 150     0          0          0      | 330      0          0          0
 165     0          0          0      | 345      0          0          0
 ------------------< F7 Saves, Esc Escapes to CROP Main Menu >--------------
Tab  Esc F1    F2  F7    F9    F10  Del
FUNC esc help clr save info desc del
```

The drop in canopy cover from 70% to 60% from day 45 to day 60 demonstrates the use of the senescence option. The program will use the residue weight/cover relationship from this Set to determine the weight of residue equivalent to 70 - 60 = 10% cover. This weight will then be added to the surface, with the addition distributed evenly over the 15 d in the period.

This completes the information required for the first crop listed on the first general information screen. The second crop listed is "alfalfa 2nd year," which requires the operations listing shown below.

```
     FILE        EXIT        HELP        SCREEN
 ----------------< Rotational C: field operations TEST 0.26 >--------------

 2/4   crop: alfalfa 2nd year      senescence code: 2
 -Date---------Field Operation----Res. Add. (#/A)----------New Growth Set------
 3/15/2        begin alfalfa growth
 5/15/2        hay harvest            525                alfalfa 2nd year
 6/29/2        hay harvest            525                alfalfa 2nd year
 8/13/2        hay harvest            525                alfalfa 2nd year
 9/27/2        hay harvest            525                alf-2nd y senescence










 --------------------------< F3 When Questions Answered >------------------
Tab  Esc F1   F2  F3   F4   F6   F9   F10  Ins Del PgUp PgDn Home End
FUNC esc help clr cont call list info desc ins del pgup pgdn 1st  last
```

The "begin alfalfa growth" in this listing calls in "alfalfa 2nd year" as the current crop and begins its growth. The hay harvest operations are the same as in the first screen, adding residue to the surface and calling in regrowth crops. As before, the hay harvest operation calculates the amount of residue added based on information in the CROP Database Set of the current crop.

Up to this point we have had a single year's worth of operations on each screen, but this is not a requirement. The screen below shows 3 yr of crops and operations intended to model the alfalfa crop once it has reached fairly stable growth.

```
     FILE       EXIT       HELP       SCREEN
 ─────────────< Rotational C: field operations TEST 0.26 >──────────────
  3/4   crop: alfalfa established   senescence code: 2
 ─Date────────Field Operation────Res. Add. (#/A)──────────New Growth Set──────
  3/15/3      begin alfalfa growth
  5/15/3      hay harvest              1800              alfalfa established
  6/29/3      hay harvest              1800              alfalfa established
  8/13/3      hay harvest              1800              alfalfa established
  9/27/3      hay harvest              1800              alf. est. senescence
  3/15/4      begin alfalfa growth
  5/15/4      hay harvest              1800              alfalfa established
  6/29/4      hay harvest              1800              alfalfa established
  8/13/4      hay harvest              1800              alfalfa established
  9/27/4      hay harvest              1800              alf. est. senescence
  3/15/5      begin alfalfa growth
  5/15/5      hay harvest              1800              alfalfa established
  6/29/5      hay harvest              1800              alfalfa established
  8/13/5      hay harvest              1800              alfalfa established
  9/27/5      hay harvest              1800              alf. est. senescence
  3/15/6      begin alfalfa growth
 ──────────────────────────< F3 When Questions Answered >─────────────────
 Tab  Esc F1   F2  F3   F9   Ins Del PgUp PgDn Home End
 FUNC esc help clr cont info ins del pgup pgdn 1st  last
```

A single screen can contain any number of years' worth of operations, as long as the total number of operations on the screen does not exceed 16. Similarly, a screen may contain operations representing a fraction of a year. The only difference comes in the final accounting. The program calculates an overall rotation C factor and a C factor for the time associated with each screen. For this rotation, the program would calculate separate C factors for each of the first 2 yr, but would lump these 3 yr together into a single C factor.

Note also that the program is not limited to working with calendar years; but it will allow you to divide the time up in any convenient fashion simply by which screen contains which operations.

The screens shown above take care of the 5 yr of alfalfa in the rotation, but we must still handle the 3 yr of corn. In the initial crop listing there was only one corn, so all operations associated with these 3 yr will also have to be lumped together on a single screen, as shown below.

The first operation in this listing is used to kill the alfalfa and also to prepare the soil for the corn-planting operation. The information for this operation is listed below.

```
     FILE        EXIT       HELP       SCREEN
              < Rotational C: field operations TEST 0.26 >
 4/4    crop: corn_______________  senescence code: 1
 Date         Field Operation    Res. Add. (#/A)          New Growth Set
 4/15/6       chisel alfalfa          2500
 4/20/6       disk; tandem
 4/25/6       planter; no-till
 6/10/6       fert. applicator
 10/10/6      harvest                 7280
 4/15/7       chisel (3 in. twist)
 4/20/7       disk; tandem
 4/25/7       planter; no-till
 6/10/7       fert. applicator
 10/10/7      harvest                 7280
 4/15/8       chisel (3 in. twist)
 4/20/8       disk; tandem
 4/25/8       planter; no-till
 6/10/8       fert. applicator
 10/10/8      harvest                 7280
                          < F3 When Questions Answered >
Tab  Esc F1   F2  F3   F4   F6   F9   F10  PgUp PgDn Home End
FUNC esc help clr cont call list info desc pgup pgdn 1st  last
```

```
     FILE        EXIT       HELP       SCREEN
         < Create/Edit Field Operation Database Set TEST 0.26 >
         field operation: chisel alfalfa______
Effect #1: 3
Effect #2: 2  % disturb.:100   roughness:1.5   % cov. left:50    depth:8
Effect #3: 8
Effect #4: 1
Effect #5: 1
                                  1. no effect
                                  2. soil surface disturbed
                                  3. current crop residue added to surface
                                  4. other residue added to surface
                                  5. residue removed from field
                                  6. current crop harvested
                                  7. crop growth begins
                                  8. current crop is killed
                                  9. call in a new crop growth set
                 < F7 Saves, Esc Returns to OP Main Menu >
Tab  Esc F1   F2  F4   F6   F7   F9   F10  Ins Del
FUNC esc help clr call list save info desc ins del
```

This case is one where the order of the operation's effects is critical. This operation first adds residue to the soil surface. Since the operation is not specified as a harvest, the amount added will not be calculated from information in the CROP Database Set, but will instead have to be entered manually in the Res. Add. column of the operations listing.

After the residue is added, the soil surface is disturbed, thereby incorporating some of that newly added residue. If these effects had been entered in the opposite order, none of this new residue would have been buried by the operation, because the soil disturbance would have occurred before the residue was added.

Finally, the current crop is killed, immediately removing the effects of crop canopy and turning the root mass into subsurface residue.

The remainder of the operations in the "corn" listing are relatively straight-forward, and are shown below. The "harvest" operation behaves like the "hay harvest" we saw earlier, in that it calculates the amount of residue added to the surface from the CROP Database Set. It does not call in a regrowth Set because harvesting corn also kills it.

The information needed by the rotation is now complete, because the next operation in the series would be the primary tillage before planting alfalfa, which is a repeat of the first operation in the sequence. Note that this would occur on 3/30 of year 9, which is 8 yr after its first occurrence. This is what determined the rotation length of 8 yr. If the rotation length had been entered as 9 yr, the program would assume a fallow period from 10/10/8 to 3/30/10.

Example 2: Continuously cropped conventional soybeans in Indiana with an aerially seeded rye winter cover crop. This example demonstrates how to handle two crops grown simultaneously. The example is based on a continuous conventionally tilled soybean crop, into which rye is aerially seeded when the soybeans are mature. The rye grows as an understory to the soybeans until they are harvested, at which time the rye begins vigorous growth until the onset of winter. The rye is tilled under in the spring before the planting of the next crop of soybeans. Because every operation is repeated every year, the rotation is 1 yr long.

The critical concept is that RUSLE can handle only one current crop, so the CROP Database Set associated with that crop must reflect everything that is growing in the field.

The general information screen for this rotation is shown below.

```
     FILE       EXIT       HELP       SCREEN
┌──────────────< Rotational C: general inputs TEST 0.26 >──────────────┐
                       city code: 14003   INDIANAPOLIS          IN
  adjust for soil moisture depletion: 1
 % surface covered by rock fragments: 0
surface cover function; B-value code: 1
     number of years in the rotation: 1
                                            #       Crop
                                          ┌────────────────────────┐
                                          │ 1   soybeans           │
                                          │ 2   rye cover after sb_│
                                          └────────────────────────┘

└──────────────────< F3 When Done Entering Crop Names >──────────────┘
Tab  Esc F1   F2  F3   F4   F6   F8   F9   F10  Ins Del
FUNC esc help clr cont call list dupe info desc ins del
```

We could vary the list of crops, depending on how we want the accounting to be done. For instance, if we want only a total rotation value, we could list just soybeans. Another option is as shown above, where we separate the time that the soybeans are growing from the rest of the time.

The operations listing associated with the soybean accounting time is shown below. This includes the planting of the standard soybean file and its growth up to the time of the aerial seeding of the rye. From this point on, the current crop must reflect the root mass and canopy characteristics of not only the soybeans but the combined soybean/rye mixture. These characteristics will be shown in the CROP Database Set "sb and aerial rye" as an increase in root mass and canopy cover and a decrease in canopy height to show the effect of the low-growing rye. The residue characteristics of this Set will still be those of the soybeans, as this is the type of residue that will be added.

At the time of harvest we must not kill the crop, because the rye will continue to grow. Instead, we add the soybean residue to the surface and then call in a regrowth crop to simulate the vigorous rye growth after soybean harvest. The root mass value in this Set will be much lower than that in the combined soybean/rye Set, which the program will recognize as an addition of the soybean roots to the subsurface soybean residue pool. This new Set will have the residue characteristics of the rye, because any residue added to the surface now will be rye residue.

```
        File          Exit          Help          Screen
                 < Rotational C: field operations >
 1/2    crop: soybeans              senescence code: 2
 —Date————Field Operation——Res. Add. (#/A)————New Growth Set————
 4/25/1      chisel (3 in. twist)
 4/27/1      disk; tandem
 4/30/1      harrow (spike)
 5/15/1      planter; row
 6/1/1       cult.; row
 6/15/1      cult.; row
 8/30/1      aerial rye seeding                      sb and aerial rye
 10/15/1     harv. intercrop        2625             rye cover after sb__

                      < F3 When Questions Answered >
Tab  Esc F1   F2  F3   F4   F6   F9   F10  Ins Del PgUp PgDn Home End
FUNC esc help clr cont call list info desc ins del pgup pgdn 1st  last
```

The rye crop is called in as the current crop with the last operation of the soybean listing, but recall that we wanted to account for the time from the soybean harvest to the next planting of soybeans under the rye cover crop. We do this with the first operation shown on the screen above. This "no operation" has no effects on the soil, crop, or residue, but is used to tell the program to begin the accounting under this crop name on this date. (See next figure.)

There are two ways of modeling the impact of a natural phenomenon like winter or drought conditions. First, if the impact is very sudden (as perhaps the first frost that kills tomatoes), you will want to model the impact as an operation. On the other hand, if the effect is more gradual (as it would be for the rye example), it is probably better to develop a CROP Database Set that shows the reduction in canopy cover and live root mass that can be caused by winter damage. Note in the listing below that nowhere within this screen is there an operation that begins the growth of the "rye cover after sb" crop. A current crop is still growing based on information in the previous screen, so there is no need to plant this crop.

```
     FILE        EXIT        HELP        SCREEN
┌──────────────< Rotational C: field operations TEST 0.26 >──────────────┐
│                                                                         │
│ 2/2   crop: rye cover after sb    senescence code: 2                    │
├─Date────────Field Operation────Res. Add. (#/A)──────────New Growth Set──┤
│ 10/15/1     no operation                                                │
│ 11/15/1     begin winter impact                    rye cover overwinter │
│ 3/1/2       begin spring growth                    rye cover spring ___ │
│                                                                         │
│                                                                         │
└───────────────────────< F3 When Questions Answered >───────────────────┘
Tab  Esc F1   F2  F3   F4   F6   F9   F10  Ins Del PgUp PgDn Home End
FUNC esc help clr cont call list info desc ins del pgup pgdn 1st  last
```

Example 3: Grazing of rangeland or pasture. The grazing of rangeland or pasture can be handled as the impact of winter on crops was handled. If the grazing is high intensity and can be thought of as occurring at a specific time, it can be treated as an operation, as with the hay harvests shown above. The vegetation would be harvested by the cattle, leaving a rough surface and trampling some residue onto the soil. The grazed area would then begin to regrow, so the high-intensity grazing operation would call in a regrowth crop Set.

On the other hand, if the grazing is long term and low intensity, it is probably best to treat it as a change in the crop growth patterns and to develop a CROP Database Set to reflect these conditions.

Answers to Common Questions About the C Factor

For a single disturbance, how do I define the initial conditions? Remember the factors that you must define: (1) amount of residue on the surface; (2) amount of buried residue; (3) surface roughness; and (4) any vegetative regrowth. This is done by beginning the growth of vegetation whose CROP Database Set reflects that found at the site before its disturbance. This should be grown for several years to reflect the soil consolidation found before the disturbance. The operations used in the disturbance are then listed, making sure that the effects of each operation reflect all of its impacts on the factors listed above.

How do I specify that the operations sequence is a rotation? You command the program to assume a rotation by specifying on the initial C-factor screen the number of years in the rotation. You calculate this by determining how many years it takes before the first operation will occur again. For example, if the first operation in the rotation takes place on May 1 of the first year and will not occur again until May 1 of the fourth year, then there will be 4 - 1 = 3 yr in the rotation. If you want a single disturbance rather than a rotation, simply place a zero in the input field for number of years in the rotation.

For the time-invariant C option, should I use the CROP Database or enter values directly? The C calculations for RUSLE require values from the CROP Database for canopy cover, fall height, and root mass. For continuous crops, these values are assumed to remain relatively constant through the year, so the only entries needed are average annual values. To specify these values, you can either enter them directly within the C factor or use the CROP Database Utility routines (see "Databases" and "CROP Database") to create a Set with these values. Do this with the "permanent" option for the crop/land use category, and then {save} the set under some unique Identifier name.

If you decide to use the CROP Database, the list of all {save}d "continuous" crops will be shown. Select an Identifier to automatically bring in the values from that Set for root mass, canopy cover, and fall height.

Within this time-invariant C option, the values of surface cover and roughness must be typed in directly.

What inputs are required for the time-invariant C option? The variables of surface cover, canopy cover, and fall height are relatively easy to deduce from experience. It is much harder to estimate the mass of roots in the top 4 in of soil. If you choose to not put the required data into a CROP Database Set (see section above), RUSLE will go through a series of questions to help you define the root-mass variable. You will be asked to define the type of plant community and the annual site production potential. The program will use these to calculate a root-mass value directly and, in that case, the program will calculate a corresponding site potential.

What general information is required for the time-varying C option? The first screen within the time-varying C-factor option defines all the general information for the rotation. Soil-moisture depletion should be taken into account only for those areas in which the rainfall is of low amounts and intensities and the soil surface characteristics do not limit infiltration. Thus far, this is supported only by data from the Northwestern Wheat and Range Region, although there may be other areas to which this option can be applied. The "rock cover" variable should reflect the presence of all rocks and similar "permanent" surface cover, and is changed by {call}ing the K factor. Choose the b-value option that best describes your conditions. For well-consolidated soils dominated by interrill erosion, a low b value should be used; for highly disturbed or thawing soils dominated by rilling, a high b value is more appropriate. All other cases should use the moderate b value.

The crop list on the first screen of this option makes it easy to change an existing Input File. Crops can be {dupe}licated to new spots in the rotation, old crops can be {del}eted from the list, and new crops can be {Ins}erted. When you move a crop within the list, its operations will tag along, but the dates of the operations may need to be changed to show their new place within the rotation.

What information is needed on the operations screens of the time-varying C option? The rotation information screen contains general information about the crop and a list of all associated field operations. Also included is a question on whether a decrease in canopy cover should be seen as a contribution to surface cover. If you specified in the general information that you wanted to account for soil moisture depletion, the depletion rate value associated with the crops on this screen is entered here.

You must enter the dates (using xx/xx/xx to represent month/day/year) and names of all field operations, as well as any additional information required by the effects listed in the OPERATIONS Database Sets for those operations. You have great flexibility in entering the year. You can enter it as a calendar year (1995), as an abbreviated calendar year (95), or as the number of the year in the crop sequence. The program calculates the relative time elapsed, so all of these will be treated the same.

There are some limitations on the operations that you can enter, as follows:

(1) You can have only one current crop. Since there will be interactions between interplanted crops, RUSLE does not allow you to use two separate CROP Database Sets and to have them both growing at once. You must instead combine the Sets into one that reflects the total values of the combined crops. The residue parameters should be for the crop whose residue is added to the surface by a harvest operation; you can call in a regrowth CROP Database Set containing the parameters of the second crop before harvesting it.

(2) If an operation has a "harvest" effect, the program will automatically enter the weight of residue added. For other effects, you will be asked to specify the amount of residue added.

(3) The operation can also ask for the name of a regrowth crop. In this case, a list of the crops is shown, and you must either pick from this list or go into the CROP Database Utility routines to create a new crop.

(4) There are few restrictions on the order in which the operations may be listed, but one restriction is that the current crop must exist in order to be able to do anything with it. The program will issue a warning if you try to do anything with the current crop without having specified something to tell the program just what that crop is.

How are all the different roughness values set and used? The time-varying C-factor calculations use three different random roughness values. The first is the roughness immediately after a soil disturbance operation; this value is defined within the OPERATIONS Database Set for that operation, and is a function of soil condition and of the implement that is used.

The second roughness value is that to which the tillage roughness decays as it is acted upon by raindrop impact and surface flow. The default setting for this roughness is 0.24 in, which is the roughness found on experimental fallow plots exposed to natural rainfall. If desired, this value can be set to reflect continuous re-roughening of the surface, as can happen with cattle grazing. In this case, the initial and final roughness values can be set equal to indicate a constant roughness, or can be adjusted as desired to indicate increasing or decreasing roughness. The final decay roughness value is set in the OPERATIONS Database Set.

The third random roughness value used in this part of RUSLE reflects the impact of the vegetation on soil surface roughness; this will be a function of protruding roots, basal mounding, and so on. This variable represents the site roughness several years in the future (as defined by the number of years to soil consolidation), under the assumption that the site will not be disturbed during that time. The value, therefore, also reflects the assumption of some vegetative community that will come to dominate the undisturbed site over this time period. The program uses this value only for runs with a single disturbance, and uses a sigmoidal growth curve to increase the natural roughness to this value from the minimum value defined in the previous paragraph. The long-term site roughness is set in the general information screen of the time-varying C-factor option if the length of the rotation is set to zero.

What outputs are available for the time-varying C option? The options for showing the results of the rotational C-factor calculations vary primarily in the degree of detail shown. The "Rotation C" option divides the results into the SLR · %EI associated with each crop, whereas the "Operation C" option breaks this down further into the SLR · %EI associated with each operation. The "Half-Month Subfactor" option shows the finest division, displaying each of the SLR subfactors for each calculation period.

There is one difference between the "Operation C" results and the "Half-Month" results that might cause confusion. In Operation C, the values shown for percent surface cover are calculated immediately after the operation, whereas the Half-Month surface cover values are calculated in the middle of the time period.

P Factor

The RUSLE P factor reflects the impact of support practices on the average annual erosion rate.

Options

As with the other factors, the P factor differentiates between cropland and rangeland or permanent pasture. Both options allow for terracing or contouring, but the cropland option contains a stripcropping routine whereas the rangeland/permanent-pasture option contains an "other mechanical disturbance" routine. For the purposes of this factor, the rangeland/permanent-pasture option is based on the support operation being performed infrequently, whereas in the cropland option, the support operation is part of the annual management practice.

One variable seen in the contouring, mechanical-disturbance, and stripcropping routines is a site description. RUSLE asks you to choose from a list of descriptions the one that best fits your conditions. This information is used in several ways, as follows:

(1) The site description is used to assign a runoff index and roughness value to the situation. The runoff index is a measure of the percentage of available precipitation that will be seen as runoff, and is a function of soil type, soil structure, soil surface condition, and surface vegetative cover. The runoff index value is similar to the curve number used in the NRCS Direct Runoff method of calculating runoff volume, and is used here for roughly the same purpose. Runoff index values associated with specific soil hydrologic groups and site descriptions can be changed by

using the {call} command from the Input Field where the site description is requested.

(2) The site description is also used to estimate the effect of surface roughness and vegetative cover on erosion and transport from the slope. A qualitative view of the roughness is given in the site descriptions, but the actual roughness values associated with the descriptions are assigned internally.

Answers to Common Questions About the P Factor

What is the variable ridge height option on the contouring subfactor (cropland or pasture/rangeland option)? This option allows you to define how the contour ridge heights change with time during the rotation. The program calculates a P value for each ridge height and then multiplies that by the percentage of annual EI associated with each period to derive an average annual contouring subfactor.

What is the critical slope length in the contouring subfactor (cropland or pasture/rangeland option)? The effectiveness of contouring breaks down when the slope is so long that runoff causes break-over and subsequent gullying. This point is defined by the critical slope length, which is a function of the slope steepness, ridge height, residue cover, and runoff potential. When the slope is longer than this calculated maximum, the contour credit applies only to the portion above the critical length. The portion below has a P contour subfactor of 1. RUSLE will give you a warning that this is occurring, and will adjust the overall P factor accordingly.

Why are there dual site descriptions in the contour subfactor (pasture/rangeland option only)? After a disturbance, a pasture/rangeland soil will take some years to reconsolidate to a point similar to that before the disturbance. In order to look at this consolidation effect, it is necessary to detail just how the site responds to consolidation and what effect this has on runoff. This information is given by describing the site both immediately after disturbance and after enough time has passed for relatively complete consolidation. The program then assumes an exponential decay function, and allows you to look at any year within that range.

What is the stripcropping subfactor (cropland option only)? The stripcropping P subfactor defines the effectiveness of contoured or cross-slope strips in causing deposition where it might benefit future productivity, and in slowing and spreading the runoff. These strips can be any combination of crops and/or tillage practices that would affect the surface roughness, infiltration rates, or hydraulic roughness seen by the runoff.

Why does the stripcropping subfactor require {call}ing the contouring routine (cropland option only)? Because stripcropping is closely linked to contouring, the RUSLE program uses the contouring routines to provide information on row grade and critical slope length. If it is needed, the call to the contouring subroutine occurs automatically. When the contouring routine is called from the stripcropping routine, the site description used should be for the "smoothest" strip within the stripcropping rotation.

What is the stripcropping subfactor strip width (cropland option only)? The stripcropping subfactor program requires a complete description of the slope, including the condition and width of each strip. There are two ways of specifying strip width. The first is to indicate the position of the bottom of the strip as a percentage of the total slope length. For example, if a 120-ft slope is divided into four 30-ft strips, their relative positions would be at (30/120), (60/120), (90/120), and (120/120), or 25%, 50%, 75%, and 100%, respectively. The other option is to specify the actual strip widths in feet, which in the above example would be 30, 30, 30, and 30. The disadvantage of this second style is that the total slope length has already been specified in the LS factor. If the total length calculated by adding these strip widths varies from that entered in LS by more than 10%, the RUSLE program issues a warning and requires a response before proceeding.

What is the Other Mechanical Disturbance subfactor (pasture/rangeland option only)? Mechanical disturbance of the soil takes two possible forms: (1) disturbance on the contour, which results in roughness on the contour and redirection of runoff along the rows; and (2) a more random mechanical disturbance, which results in a rough surface that can slow runoff and in depressional areas that can store runoff and increase infiltration. The option chosen depends on whether the roughness that is left after the disturbance is primarily oriented or random. If the roughness has a definite orientation (ridges), choose the contouring option, even though the ridges may not be directly on the contour. If the roughness is more random, choose the Other Mechanical Disturbance option.

SYSTEM CONSIDERATIONS: USING RUSLE WITH YOUR EQUIPMENT

All computer requirements and instructions for loading and running RUSLE are described in detail in "Getting RUSLE To Work on Your Machine."

Using a Printer

RUSLE is meant primarily to be a tool to make it easy to compare cropping and management alternatives, and to speed up these repeated calculations. Although RUSLE will print out some results and inputs, it is not designed to generate documents.

For machines that use DOS, RUSLE looks for an attached printer, as it does also for the 3B2 and 6386 machines running either DOS or UNIX. When run under BSD UNIX, the print routines will look in a file named "printer.use" for the name of the network printer. Check your manuals or consult with a site specialist if problems arise.

Most of the printouts are meant to fit on 8½" x 11" paper. The exception is the printout of LS tables, which may be up to 132 characters wide. If your printer cannot be configured to handle this many characters within 8½ in, you must use wider paper. Note that copies of the tables are available in chapter 4 of this handbook.

Making Copies of RUSLE To Share With Others

RUSLE contains a routine that allows you to copy the program onto a diskette(s) to share with others. This routine is available from the RUSLE Information option of the RUSLE Main Menu, and works only on DOS. This option is not available in UNIX.

Refer to "Using an Input File Created Earlier or Elsewhere" and to "Using Database Sets Created Earlier or Elsewhere" for information on how to send information you have entered to another user.

Reporting Problems and Trouble

RUSLE is a relatively new and complex computer program. A user may find problems that did not arise in preliminary testing. It will greatly help the developers and programmers of RUSLE if you report problems that you find, giving as much information as possible about when and how the problems occurred. This information includes the following:

- screen you were on and question being answered
- command you gave just before the problem showed up
- what (if anything) showed up on the screen
- how the problem manifested itself (program locked up, gave unreasonable answer, and so on.)

Please send this information to:

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SUMMARIES

Command Keys

A complete list of all possible commands and a brief description of what each does are given below. The command description or name is given in braces, { }, and the associated DOS key for each command is given in brackets, [ ]. The keys may differ on some machines, but the command description is always as shown here.

{FUNC} [TAB] places the cursor onto the Function Line to let you do the required housekeeping chores (see "Calling a Function" or "The Functions: Program Housekeeping"). When the cursor is on the Function Line, use {esc}ape to bring it back to the Main Screen.

{esc} [ESC] allows you to {esc}ape from the current screen or question without giving an answer. This is most commonly used in three places: (1) if you have gotten into a screen or series of screens and want to get back out; (2) after an error or warning message has been displayed, and you want to continue; and (3) to continue the program after a result has been displayed.

{help} [F1] shows one or more screens of additional information to help answer the current question (see "Help"). This usually includes a brief description of how the variable is used in the calculations and also suggestions for possible answers.

{clear} [F2] {clear}s (sets to 0) all variables associated with the current screen. This is most useful when you want to get a fresh start on a screen containing several mistakes.

{cont} [F3] {cont}inues program movement to the next logical screen in the sequence. For example, when you have answered all the questions on one screen, this command moves you to the next screen or initiates the calculations. For screens that require only one input or command, the {cont}inue command acts just like an [ENTER], telling the program to accept the current value and to move on.

{call} [F4] {call}s a subroutine on which the answer might depend. Use of this command will automatically put you into the required subroutine; when you exit from that, you will return to the current question.

The {call} command is used in three different instances, as follows:

(1) When an answer is calculated from the results of several different factors. An example is in estimation of soil loss from the factor values. Each factor is {call}ed individually by use of this command.

(2) When the question asks for the Identifier of a Database Set, as when entering a city code, a crop name, or an operation name. Use of the {call} from one of these locations allows you to examine or modify the information within the associated Database. "Databases" gives more detail.

(3) When the calculation requires information entered in another portion of the program. An example of this is the value of average field slope, which is used in several places but is calculated within the LS factor. If this value has already been calculated, it will be shown; if not, the {call} command must be used to move to that calculation.

{list} [F6] displays a list from which you can select an option or item, as explained in "Input Field." If you have previously selected one of the choices, the list may not be shown but this command will appear as an option. Use of this command displays the list and allows you to move through it using the [ARROW] keys.

There are places in the program where the list is also shown but the marker arrow is not visible. In these cases a {list} command will move the marker arrow into the list, where the marker can be controlled with the [ARROW] keys.

{save} [F7] {save}s the data shown on the screen into a Database Set named by the Identifier at the top of the screen. Changes made within the CITY, CROP, or OPERATIONS

Database routines will not be saved into those Databases unless this command is used before exiting those routines. If changes have been made, you will be asked whether or not you want to save them before you are allowed to exit.

{dupe} [F8]	is used only in the crop listing on the initial C-factor input screen; this duplicates an entire operation listing screen into another location within the list. For example, if I {dupe} "corn" from the first place on the list into the fifth, the program will duplicate all operations associated with that first corn onto the fifth screen. It will not change the dates, so this must be done by moving to that screen and modifying them individually.
{info} [F9]	gives information on the Current Input List. When you {save} a Current Input List into an Input File, you are also saving a list of comments describing that List. Use of this command allows you to look at (and change) the descriptive information for the Current Input List.
{desc} [F10]	gives information on the current CROP or OPERATIONS Database Set. These Sets also contain a series of descriptive comments, which can be viewed or changed from anywhere this command is available.
{ins} [INS]	is used to insert a line of information just above the line on which the cursor is resting.
{del} [DEL]	is used to delete the line of information on which the cursor is resting.
{1st} [HOME]	is used to jump to the first in a series of screens or to the beginning of a list.
{last} [END]	is used to jump to the last in a series of screens or to the end of a list.
{pgup} [PG UP]	is used to move to the previous screen in a series of screens or up one screen in a long list of information.
{pgdn} [PG DN]	is used to move to the next screen in a series of screens or down one screen in a long list of information.

Terminology

command : is an instruction given to RUSLE to control the flow of the program. A *command* is usually given by pressing a key. At any point in the program, the available *commands* are shown on the *Command Line.*

Command Line: is made up of the bottom two lines of the screen, and contains a list of all the available *commands* at any point in the program. The bottom line shows the three- or four-letter description of the *command*, and the upper line shows the keystroke used to execute it.

Current Input List: is a list of the current values for all answers to the questions. This is updated every time a new value is entered or a new selection is made from a list, such as the entering or selection of a new city.

Database Set: is all of the CROP, CITY, or OPERATIONS information associated with a specific *Identifier.* For instance, for the CITY Database, this is all the climatic data for a specific city or region.

file(s): is an operating system file. See your manual or site specialist for a more complete description.

Function: is a set of routines used by RUSLE to perform housekeeping tasks. For RUSLE, these consist of the FILE Function to move information back and forth between the *Current Input List* and the *Input Files*, the EXIT Function to leave the program quickly, the HELP Function to obtain general information about the program, and the SCREEN Function to change screen coloring.

Function Line: is a list of the available *Functions,* shown on the top line of the screen. These can be reached with the {FUNC} *command* to move the cursor to the *Function Line*, using the [ARROW] keys to get the correct *Function* and option, and pressing [ENTER].

Header Line: is the top line of the *Main Screen*, and the second line down from the top of the actual screen. This shows the program version and the screen name.

Identifier:	is a name or number with which to associate the information in a particular *Database Set*. When a list of the names or numbers is shown, selection of the one you want brings in all associated information.
input:	is a response typed into an *Input Field* or chosen from a list in response to a program question.
Input Field:	is the place where the cursor rests while waiting for your response to a question. You can respond with either an *input* or a *command*.
Input File:	is a copy of the *Current Input List* that has been SAVEd. This copy is stored as a file with the name it was given in SAVEing, along with a ".rus" suffix.
Main Screen:	is the central part of the screen. It contains all the questions and areas for response.
Suggestion Line:	is seen within the line forming the bottom of the *Main Screen*. This line displays the suggested *command* or course of action.

APPENDIX A. CONVERSION TO SI METRIC SYSTEM

SI metric equivalents are not included in the procedures and tables presented in this handbook because direct conversion of each English unit is awkward in many instances and undesirable for a procedure used in the United States. Converting the RUSLE as a whole may be more appropriate. SI metric units can then be selected so that each of the interdependent factors will have a metric counterpart whose values will be expressed in numbers that are easy to visualize and to combine in computations.

A convenient unit for measuring cropland soil losses is metric tons per hectare (table A-1). **EI** values can be obtained by expressing rainfall energy in megajoule· millimeter per hectare· h· yr and expressing intensities in millimeters per hour. Factor **K** will then be in metric tons· hectare· hour per hectare· megajoule· millimeter or metric tons per hectare per unit **EI**. If 22.1 meters is taken as the basic slope length and 9 percent is retained as the basic slope gradient, the **LS** factor will not be affected. Using these units is recommended and is assumed in the following paragraphs.

The RUSLE factors will normally be derived directly in the English units by procedures outlined in Foster et al. (1981). However, the conversion factors in table A-2 will facilitate comparisons of the metric factor values with the English values published in this handbook. Details of the conversions are shown in Foster et al. (1981).

Table A-1.
Dimensions of universal soil loss equation (USLE) factors

Factor	Symbol	Dimensions		Typical U.S. customary units
Rainfall intensity	i or I	[1] $\frac{length}{time}$	$\frac{L}{T}$	$\frac{inch}{hour}$
Rainfall energy per unit of rainfall	e	$\frac{length \cdot force}{area \cdot length}$	$\frac{LF}{L^2L}$	[2] $\frac{foot \cdot tonf}{acre \cdot inch}$
Storm erosivity	EI	$\frac{length \cdot force \cdot length}{area \cdot time}$	$\frac{LFL}{L^2T}$	[3] $\frac{hundreds\ of\ foot \cdot tonf \cdot inch}{acre \cdot hour}$
Soil loss	A	$\frac{mass}{area \cdot time}$	$\frac{M}{L^2T}$	$\frac{ton}{acre \cdot year}$
Annual erosivity	R	$\frac{length \cdot force \cdot length}{area \cdot time \cdot time}$	$\frac{LFL}{L^2TT}$	$\frac{hundreds\ of\ foot \cdot tonf \cdot inch}{acre \cdot hour \cdot year}$
Soil erodibility	K	$\frac{mass \cdot area \cdot time}{area \cdot length \cdot force \cdot length}$	$\frac{ML^2T}{L^2LFL}$	$\frac{ton \cdot acre \cdot hour}{hundreds\ of\ acre \cdot foot \cdot tonf \cdot inch}$
Slope length	L	$\left(\frac{length}{length}\right)^m$	$\left(\frac{L}{L}\right)^m$	
Slope steepness	S	Dimensionless		
Cover-management	C	Dimensionless		
Supporting practices	P	Dimensionless		

[1]F=forces, L=length, M=mass, T=time, m=exponent that varies from 0.2 to 0.5
[2]Tonf indicates ton force. Ton without a subscript indicates ton.
[3]This notation, "hundreds of," means that the numerical value of the factor is 0.01 times its true value. That is, if R=125, its true value is 12,500 ft· tonf· in (acre· h· yr)$^{-1}$. The converse is true for "hundreds of" in the denominator of a fraction.

Source: Foster et al., 1981.

Table A-2.
Conversion factors for universal soil loss equation (USLE) factors.

To convert from	U.S. customary units	Multiply by	To obtain:	SI Units
Rainfall intensity, i or I	$\frac{inch}{hour}$	25.4	$\frac{millimeter}{hour}$	[1] $\frac{mm}{h}$
Rainfall energy per unit of rainfall, e	$\frac{foot \cdot tonf}{acre \cdot inch}$	$2.638 \cdot 10^{-4}$	$\frac{megajoule}{hectare \cdot millimeter}$	[2] $\frac{MJ}{ha \cdot mm}$
Storm energy, E	$\frac{foot \cdot tonf}{acre}$	0.006701	$\frac{megajoule}{hectare}$	[3] $\frac{MJ}{ha}$
Storm erosivity, EI	$\frac{foot \cdot tonf \cdot inch}{acre \cdot hour}$	0.1702	$\frac{megajoule \cdot millimeter}{hectare \cdot hour}$	$\frac{MJ \cdot mm}{ha \cdot h}$
Storm erosivity, EI	[4] $\frac{hundreds\ of\ foot \cdot tonf \cdot inch}{acre \cdot hour}$	17.02	$\frac{megajoule \cdot millimeter}{hectare \cdot hour}$	$\frac{MJ \cdot mm}{ha \cdot h}$
Annual erosivity, R[5]	$\frac{hundreds\ of\ foot \cdot tonf \cdot inch}{acre \cdot hour \cdot year}$	17.02	$\frac{megajoule \cdot millimeter}{hectare \cdot hour \cdot year}$	$\frac{MJ \cdot mm}{ha \cdot h \cdot y}$
Soil erodibility, K[6]	$\frac{ton \cdot acre \cdot hour}{hundreds\ of\ acre \cdot foot \cdot tonf \cdot inch}$	0.1317	$\frac{metric\ ton \cdot hectare \cdot hour}{hectare \cdot megajoule \cdot millimeter}$	$\frac{t \cdot ha \cdot h}{ha \cdot MJ \cdot mm}$
Soil loss, A	$\frac{ton}{acre}$	2.242	$\frac{metric\ ton}{hectare}$	$\frac{t}{ha}$
Soil loss, A	$\frac{ton}{acre}$	0.2242	$\frac{kilogram}{meter^2}$	$\frac{kg}{m^2}$

[1]Hour and year are written in U.S. customary units as h and yr and in SI units as h and y. The difference is helpful for distinguishing between U.S. customary and SI units.
[2]The prefix mega (M) has a multiplication factor of $1 \cdot 10^6$.
[3]To convert ft · tonf to megajoule, multiply by $2.712 \cdot 10^{-3}$. To convert acre to hectare, multiply by 0.4071.
[4]This notation, "hundreds of," means numerical values should be multiplied by 100 to obtain true numerical values in given units. For example, R=125 (hundreds of ft · ton · in $(acre \cdot h)^{-1}$=12,500 ft · tonf h. The converse is true for "hundreds of" in the denominator of a fraction.
[5]Erosivity, EI or R, can be converted from a value in U.S. customary units to a value in units of Newton/hour (N/h) by multiplying by 1.702.
[6]Soil erodibility, K, can be converted from a value in U.S. customary units to a value in units of metric ton · ha $(Newton \cdot h)^{-1}$ $[t \cdot h(ha \cdot N)^{-1}]$ by multiplying by 1.317.
Source: Foster et al. 1981

APPENDIX B. CALCULATION OF EI FROM RECORDING-RAINGAGE RECORDS

The energy of a rainstorm can be computed from recording-raingage data. The storm is divided into successive increments of essentially uniform intensity, and a rainfall energy-intensity equation (for example, equations [B-3] and [B-5]) is used to compute the energy for each increment. Because the energy equation and energy-intensity table have been frequently published with energy expressed in $ft \cdot tonf \cdot acre^{-1}$, this unit was retained in table B-1. However, for computation of EI values, storm energy is expressed in hundreds of foot-tons per acre. Therefore, energies computed by the published formula or by table B-1 must be divided by 100 before multiplying by I_{30} to compute EI.

Soil-loss prediction with USLE does not require the computation of EI values by application personnel, but the procedure is included here for the benefit of those who may wish to compute them.

Mathematically, R is

$$R = \frac{1}{n} \sum_{j=1}^{n} \left[\sum_{k=1}^{m} (E) \left(I_{30}\right)_k \right] \qquad \text{[B-1]}$$

where
E = total storm kinetic energy,
I_{30} = maximum 30-min rainfall intensity,
j = index of number of years used to produce average,
k = index of number of storms in each year,
n = number of years used to obtain average R,
m = number of storms in each year, and
R = average annual rainfall erosivity.

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

where

e_r = rainfall energy per unit depth of rainfall per unit area ft · tonf · acre^{-1} · in^{-1}, and

ΔV_r = depth of rainfall for the rth increment of the storm hyetograph which is divided into m parts, each with essentially constant rainfall intensity (in).

Unit energy, e, is a function of rainfall intensity and is computed as

$$e_k = 1099 \left[1 - 0.72 \exp \left(-1.27 i_r \right) \right] \qquad \text{[B-3]}$$

and

$$i_r = \frac{\Delta V_r}{\Delta t_r} \qquad \text{[B-4]}$$

where

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

i_r = rainfall intensity (in · h^{-1}).

The unit energy equation [B-3] was suggested by Brown and Foster (1987) as a replacement to the relationship used in Agriculture Handbook 537 because the equation not only includes more data for its development but also has a better functional form at low intensities. Equation [B-3] was used for the preparation of the isoerodent maps in the western United States whereas the isoerodent maps in the eastern United States were calculated using the following equation:

$$e_k = 916 + 331 \log_{10}(i_r) \qquad \text{[B-5]}$$

We do not recommend using equation [B-5] for future calculations of unit energy.

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

$$R = \sum EI_{30}(10^{-2}) \qquad \text{[B-6]}$$

where
R = average annual rainfall erosivity in

$$\frac{\text{hundreds of ft} \cdot \text{tonf} \cdot \text{in}}{\text{acre} \cdot \text{h} \cdot \text{yr}}$$

and the division by 100 is made for convenience of expressing the units.

In the western United States, all storms were included in the calculation of R, except storms where the precipitation occurred as snow. Erosion index calculations in the eastern United States were computed for storms exceeding 0.5 in of precipitation. Rains of less than 0.5 in, separated from other showers by 6 h or more, were omitted as insignificant unless the maximum 15-min intensity exceeded 0.95 in $\cdot$ h^{-1}.

Sample Calculation of EI From Recording-Raingage Records

The kinetic energy of a given amount of rain depends on the sizes and terminal velocities of the raindrops, and these are related to rainfall intensity. The computed energy per inch of rain at each intensity is obtained by solving equations [B-3] and [B-4], or by using table B-1 and reading energy values for the intensity obtained from the recording raingage. The energy of a given storm depends on all the intensities at which the rain occurred and the amount that occurred at each intensity. A recording-raingage record of the storm will provide this information. Clock time and rain depth are read from the chart at each point where the slope of the pen line (from a cumulative record) changes, and are tabulated as shown in the first two columns of the sample computation in table B-2. Clock times (col. 1) are subtracted to obtain the time intervals given in column 3, and the depths (col. 2) are subtracted to obtain the incremental amounts tabulated in column 4. The intensity for each increment (col. 5) is the incremental amount times 60, divided by column 3.

The energy per inch of rain in each interval (col. 6) is obtained by entering table B-2 with the intensity given in column 5 or by solving equations [B-3] and [B-4]. The incremented energy amounts (col. 7) are products of columns 4 and 6. The total energy for this 90-min rain is 1,254 ft $\cdot$ tonf $\cdot$ $acre^{-1}$. This is multiplied by a constant factor of 10^{-2} to convert the storm energy to the dimensions in which EI values are expressed.

The maximum amount of rain falling within 30 consecutive minutes was 1.08 in, from 4:27 to 4:57. I_{30} is twice 1.08, or 2.16 in $\cdot$ h^{-1}. The storm EI value is 12.54(2.16) = 27.1. When the duration of a storm is less than 30 min, I_{30} is twice the amount of rain.

Comparison of the new unit energy relationship (eq. [B-3]) with the one from Agriculture Handbook 537 (eq. [B-5]) shows less than a 1% difference in the energy of some sample storms (see tables B-3 and B-4).

Table B-1.
Kinetic energy of rainfall expressed in ft · tonf · acre^{-1} · in^{-1}

Intensity (in/h)	0	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
0	308	318	328	337	347	356	366	375	384	393
0.1	402	411	420	428	437	445	453	461	469	477
.2	485	493	501	508	516	523	530	537	545	552
.3	558	565	572	579	585	592	598	604	611	617
.4	623	629	635	641	646	652	658	663	669	674
.5	680	685	690	695	700	705	710	715	720	725
.6	730	734	739	743	748	752	757	761	765	770
.7	774	778	782	786	790	794	798	801	805	809
.8	813	816	820	823	827	830	834	837	840	843
.9	847	850	853	856	859	862	865	868	871	874
1.0	877	903	927	947	956	981	995	1,008	1,019	1,028
2.0	1,037	1,044	1,051	1,056	1,061	1,066	1,070	1,073	1,076	1,079
3.0	1,081									

Table B-2.
Sample calculation of storm EI_{30}

Chart readings		For each increment			Energy	
Time	Depth (in)	Duration (min)	Amount (in)	Intensity ($in \cdot h^{-1}$)	Per inch	Total
4:00	0.00					
:20	.05	20	0.05	0.15	445	22
:27	.12	7	.07	.6	730	51
:36	.35	9	.23	1.53	985	227
:50	1.05	14	.7	3	1081	757
:57	1.2	7	.15	1.29	945	142
5:50	1.25	8	.05	.38	611	31
:15	1.25	20	0	0	308	0
:30	1.3	15	.05	.2	485	24
Total		90	1.30			1,254

Total storm $EI_{30} = 1{,}254(10^{-2})(2.16) =$ 27.09 hundred ft · tonf · in · acre^{-1} · h^{-1}.

Table B-3.
Sample calculation of storm EI for storm of July 22, 1964, at raingage 63.056, using revised equation [B-3] for computing rainfall energy

Chart readings		For each increment			Energy	
Time	Depth (in)	Duration (min)	Amount (in)	Intensity ($in \cdot h^{-1}$)	Per inch	Total
18:15	0					
:19	.35	4	0.35	5.25	1,081	378
:22	.47	3	.12	2.4	1,061	127
:27	1	5	.53	6.36	1,081	573
:30	1.62	3	.62	12.4	1,081	670
18:45	2.06	15	.44	1.76	1,015	447
Total		30	2.06			2,195

Table B-4.
Sample calculation of storm EI for storm of July 22, 1964, at raingage 63.056, using original equation [B-5] for computing rainfall energy

Chart readings		For each increment			Energy	
Time	Depth (in)	Duration (min)	Amount (in)	Intensity ($in \cdot h^{-1}$)	Per inch	Total
18:15	0					
:19	.35	4	0.35	5.25	1,074	376
:22	.47	3	.12	2.4	1,042	125
:27	1	5	.53	6.36	1,074	569
:30	1.62	3	.62	12.4	1,074	666
18:45	2.06	15	.44	1.76	997	439
Total		30	2.06			2,175

APPENDIX C. ESTIMATING RANDOM ROUGHNESS IN THE FIELD

Random roughness is the nonoriented surface roughness that is sometimes referred to as cloddiness (Allmaras et al. 1966, Römkens and Wang 1986). Such roughness is usually created by the action of tillage implements. Random roughness is an important component in computing the soil-loss ratio (ch. 5). It can be contrasted with oriented roughness such as the ridges and furrows created by the passage of a tillage implement through the field. Oriented roughness in ridges and furrows is a component of the P factor (ch. 6).

Random roughness is defined as the standard deviation of elevation from a plane across a tilled area, after oriented roughness is accounted for by appropriate statistical procedures. Random roughness can be determined by mechanical profile meters or by more sophisticated devices such as laser profilers. At this time, no rapid, inexpensive technique is available to measure random roughness in the field. Frequently roughness is estimated as either a mean or a range in clod size. It has also been estimated in terms of the number of hits on clods of greater than a given size using a beaded line. Neither technique provides a value of random roughness as needed by RUSLE or other models.

Based on the need for rapid field assessment of random roughness and the lack of a suitable field technique, photographs of areas of selected random roughness conditions were taken to be used as visual guides to estimate random roughness in the field.

Procedure

It was thought essential to document a wide range of surface conditions, from very fine to very rough. Plot areas on the Palouse Conservation Field Station near Pullman, WA, were inspected for suitable conditions. By conducting additional tillage on selected plots, a wide range of roughness conditions was established on nine plot areas. A 6-ft-wide mechanical profile meter with pins on 1/2-in spacing was used to obtain roughness measurements. A 35-mm single-lens-reflex camera with a wide-angle lens was used to record the pin-top heights against a grid background (McCool et al. 1981). The profile meter was set up parallel to the tillage direction, and 10 lines were taken across a 1-m-deep plot. No attempt was made to establish a common datum elevation for all lines. This research differed from that of Allmaras et al.

(1966), in which all points on a rectangular grid were measured from a common datum. Hence, only random roughness parallel to tillage lines is considered in this study.

Black-and-white enlargements, 8x12 in, were obtained from the profile meter photos, and the pin-top elevations were digitized. A regression line was fitted to each set of readings for use as a reference datum, and the standard deviation was calculated for each cross section. The average standard deviation or random roughness was calculated for each plot by averaging these 10 values.

An undisturbed area measuring 1x1 m beside the profile meter transect was photographed at an oblique angle to provide an image similar to that seen by an observer standing a few feet from the plot. These photographs were taken at right angles to the tillage direction.

Results

The nine plot areas yielded random roughness values, R_t, ranging from 0.25 to 2.15 in. Photos of these plots are presented in figures C-1 through C-9. These figures can be used in the field to estimate random roughness. The soil-loss ratio is moderately sensitive to random roughness. Estimating random roughness as 0.50 when it is actually 0.25 results in a 15% error in the soil-loss ratio.

During the data analysis, it was found that the R_t value was linearly related to the difference in elevation between the highest and lowest pin-top reading (i.e., range) for a given cross section. The data from each of the cross sections is plotted in figure C-10. The R_t values were linearly fitted to the range in pin-top elevations as shown by the line in figure C-10, with a coefficient of determination of 0.93.

Thus random roughness can also be estimated by determining the distance from the highest to the lowest point along a furrow or ridge. Averaging a number of these readings in a field provides an average value to use with figure C-10 to obtain a value of R_t.

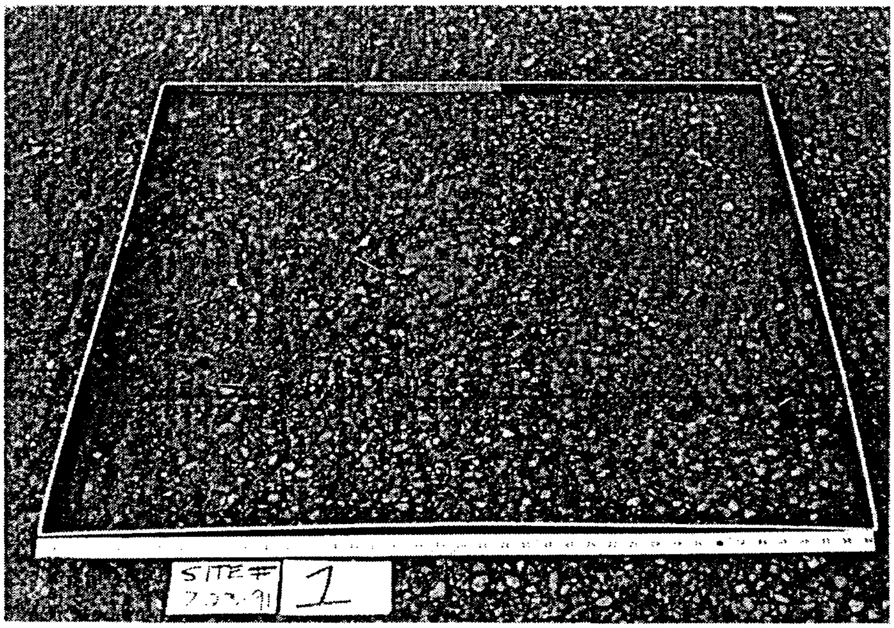

Figure C-1. Random roughness, R_t, of 0.25 in, site 1

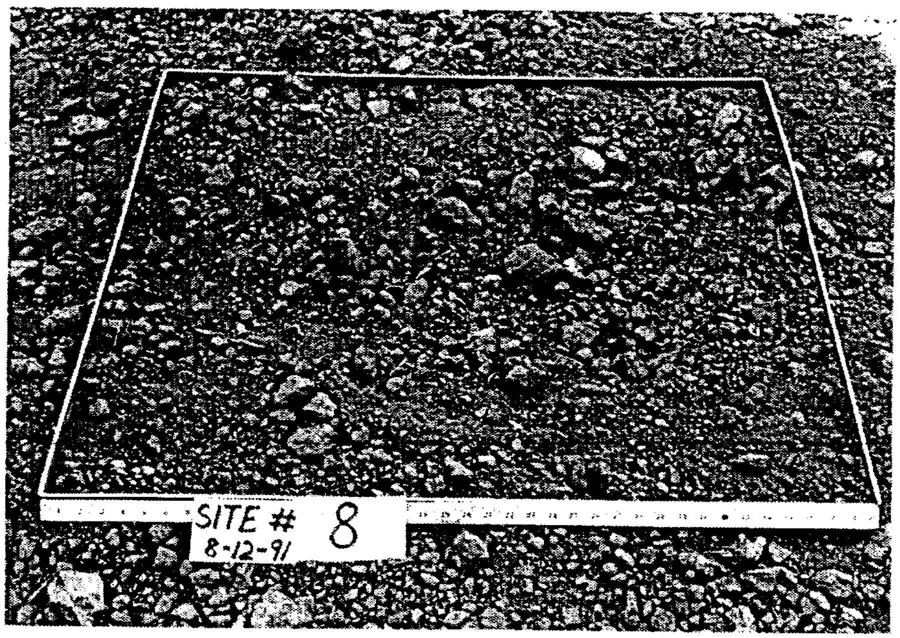

Figure C-2. Random roughness, R_t, of 0.40 in, site 8

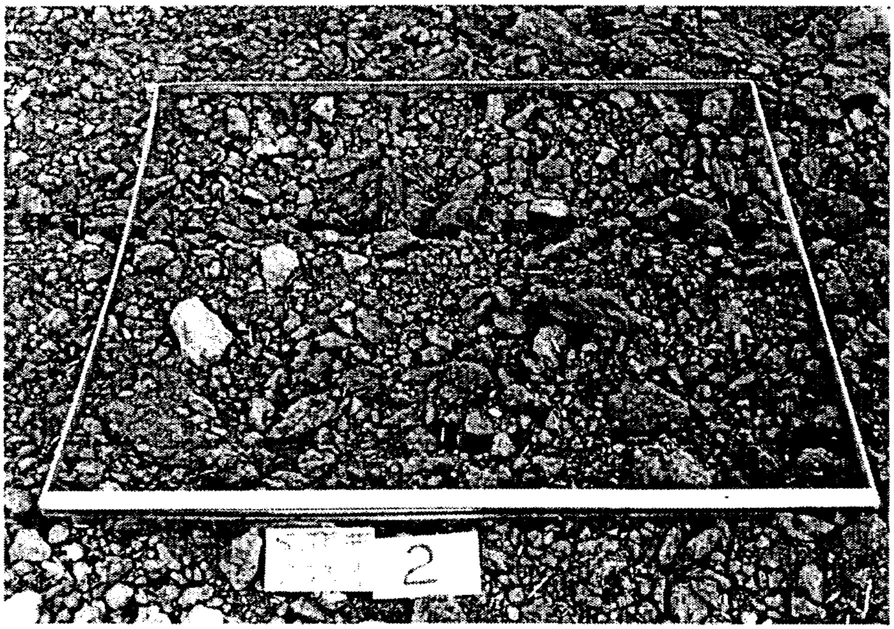

Figure C-3. Random roughness, R_t, of 0.65 in, site 2

Figure C-4. Random roughness, R_t, of 0.75 in, site 6

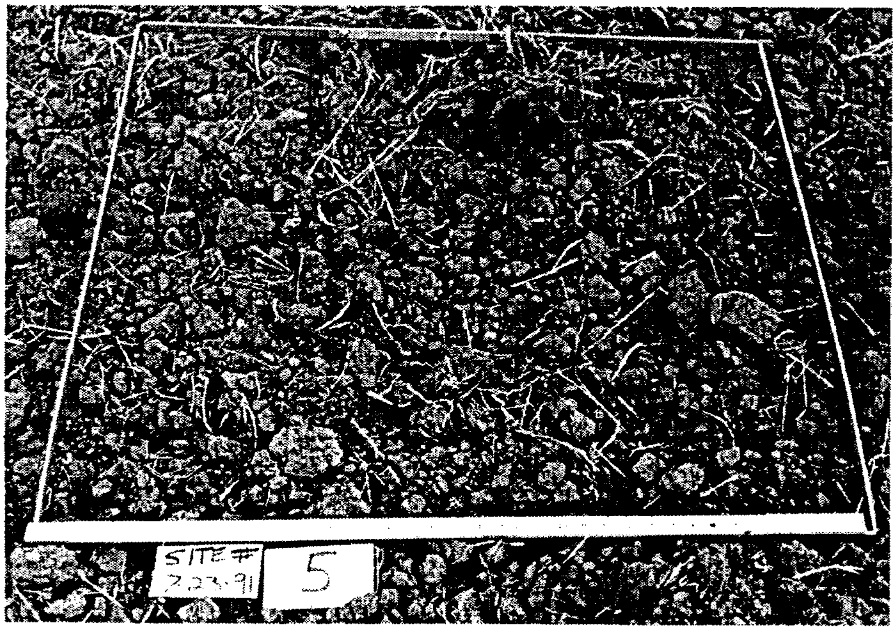

Figure C-5. Random roughenss, R_t, of 0.85 in, site 5

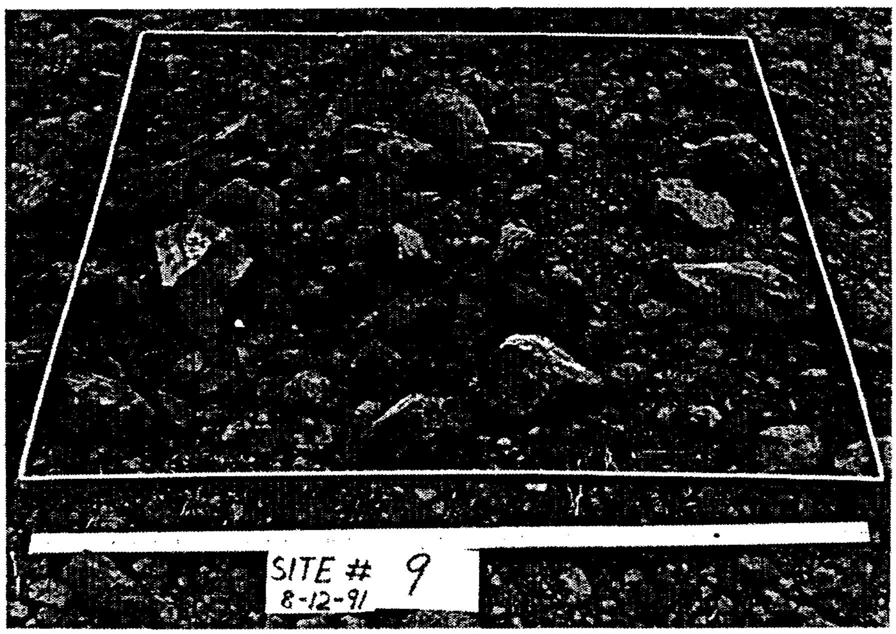

Figure C-6. Random roughness, R_t, of 1.05 in, site 9

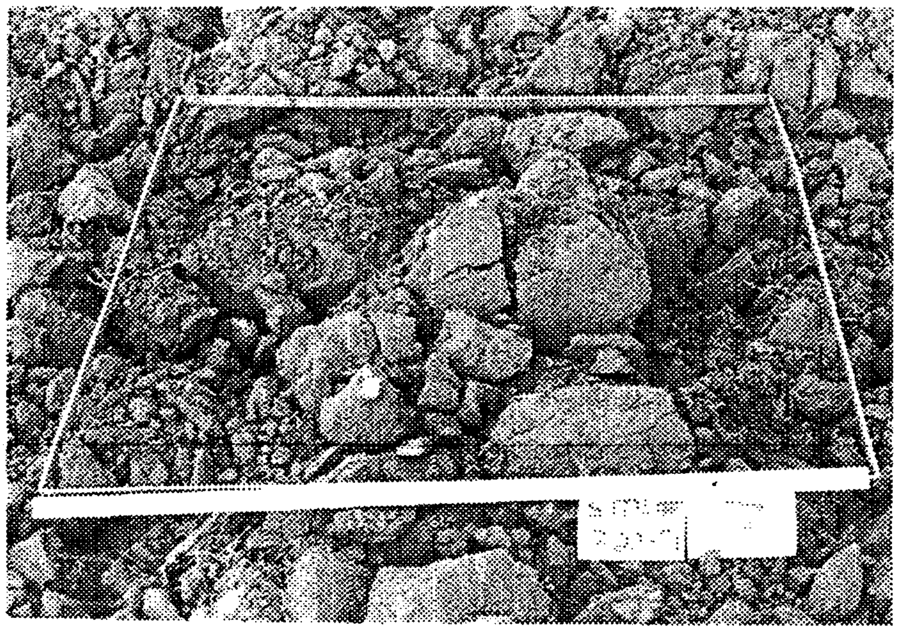

Figure C-7. Random roughness, R_t, of 1.60 in, site 7

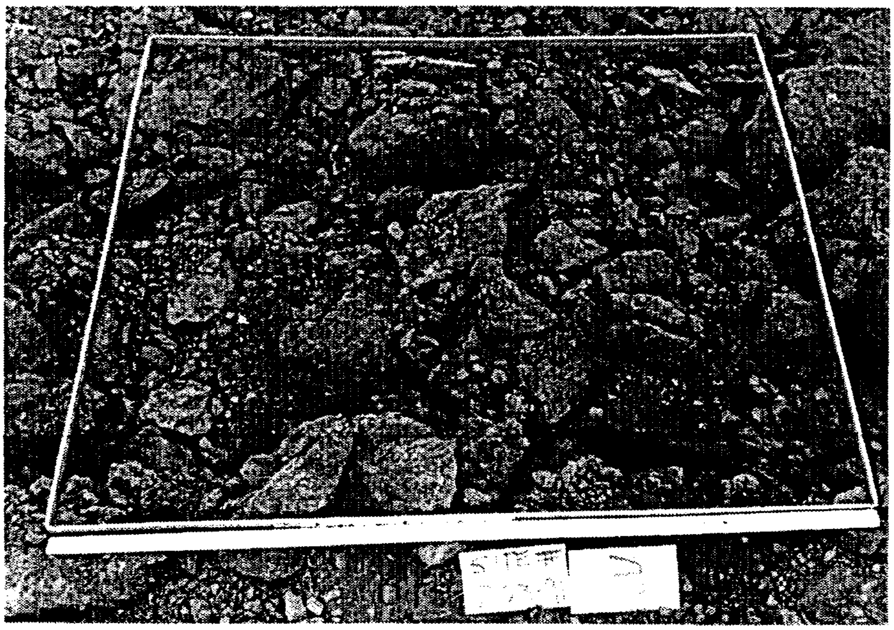

Figure C-8. Random roughness, R_t, of 1.70 in, site 3

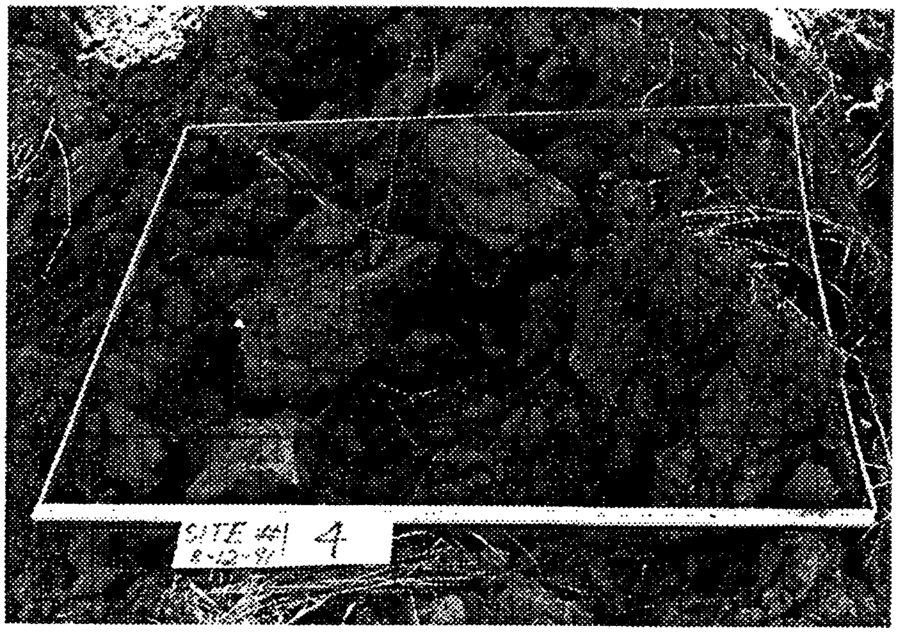

Figure C-9. Random roughness, R_t, of 2.15 in, site 4

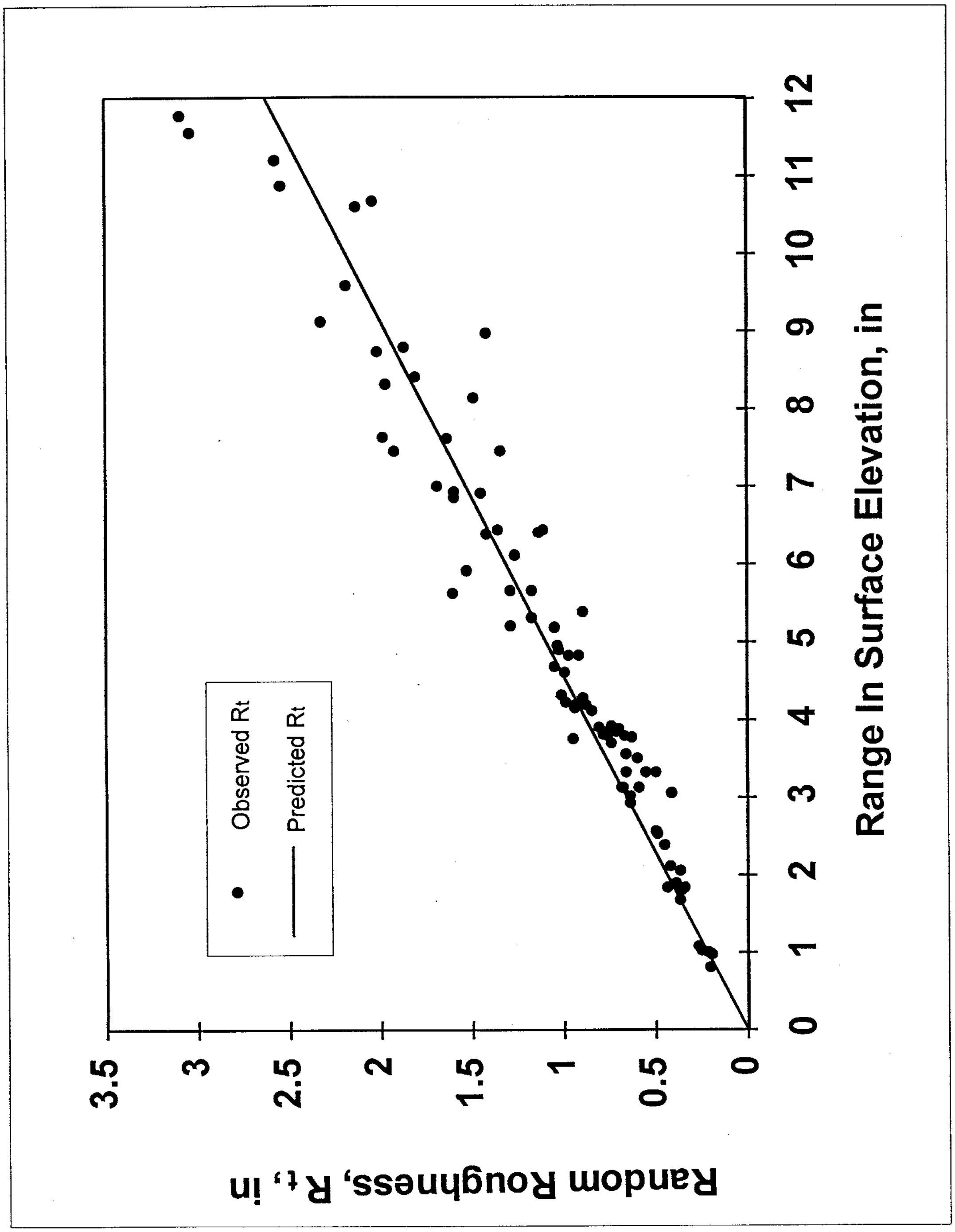

Figure C-10. Random roughness, R_t, versus range in surface elevation along a 6-ft transect

APPENDIX D. PARAMETER VALUES FOR MAJOR AGRICULTURAL CROPS AND TILLAGE OPERATIONS

The following information and data are to be used to prepare data files for crops and tillage operations used in application of RUSLE to cropland. Data presented for the crops and tillage operations represent "core" values that are to be used as starting points. Procedures are given that can be used to adjust the core values to represent conditions that differ from those described by the core data. Guidelines are also given on how to develop parameter values for crops and tillage operations not listed in the tables by extracting data from the literature or by comparing characteristics of the given crop or operation to crops and operations listed in the "core" data.

Data presented in the following tables were developed by the USDA Agricultural Research Service (ARS) and the Natural Resources Conservation Service (NRCS) for use by NRCS in its national implementation of RUSLE. The values and procedures are based on a review of data in the literature and on the judgment of numerous technical specialists in NRCS and the ARS RUSLE development team.

Use of these values and procedures can greatly help to ensure consistency in the application of RUSLE. If you get inconsistent results with RUSLE, first make checks using "core" values. Then carefully evaluate adjustments to the "core" values to ensure that reasonable adjustments have been made and that RUSLE is responding as expected to each adjustment.

Procedure for Adjusting Values for a "Core" Crop

If RUSLE is being applied to a crop included in the "core" data but the yield differs from the yield of the core crop, adjustments to the parameter values given for the core crop in table 5-1 or 5-2 are needed.

Residue:Yield Ratio

RUSLE has been designed to use a constant residue:yield ratio over the range of yields given in table D-1. If the yield of the given crop falls outside of the range given for the core crop, the residue:yield ratio can be varied with yield. In general, assumption of a constant residue:yield ratio for yields above the upper limit is acceptable. However, this ratio increases significantly as yield decreases below the lower limit. If the residue:yield ratio is varied as a function of yield outside of the given range, the ratios should be chosen to match the constant ratio value at the upper and lower limits.

The residue:yield ratios given in table D-1 are based on commonly accepted, typical values for this ratio. However, this ratio can vary with crop variety, region, and other factors. A value for this ratio can be selected that differs from the "core" value given in table D-1, but the assumption of a constant value must be observed within the yield range given in table D-1.

Root Mass

Root biomass is adjusted using multiplication factors in table D-2 where root biomass is assumed to be linearly adjusted as a function of aboveground biomass. If yield is within the range where the residue:yield ratio is assumed to be constant, root biomass can be adjusted linearly with yield. One way to make the adjustment is to first determine the multiplication factor based on a ratio of the aboveground biomass. Each root biomass value for the core crop can be multiplied by this factor to determine values for the given crop.[3] The procedure is illustrated in table D-3.

Canopy

Canopy cover (percentage) is adjusted according to the square root (0.5 power) of the ratio of aboveground biomass for the given crop to that for the core crop. The multiplication factors are given in table D-2. If the resulting canopy value exceeds 100%, a value of 100% should be assigned to the canopy value. If the yield is within the range where a constant residue:yield is assumed, yield values can be used to form the ratio of biomass values to determine a multiplication factor. All canopy values of the core crop are multiplied by the adjustment factor to obtain the new set of canopy values. The procedure is illustrated in table D-3.

Effective Fall Height

Effective fall height is adjusted according to the 0.2 power of the ratio of aboveground biomass for the given crop to that for the core crop. The multiplication factors are given in table D-2. If the yield is within the range

[3]The following guide should be used in rounding numbers. Root biomass values are rounded to nearest 10 lb/acre per 4 in depth, canopy percentage to nearest 5 percent, and fall height to the nearest 0.1 ft.

where a constant residue:yield is assumed, yield values can be used to form the ratio of biomass values to determine a multiplication factor. All effective fall height values of the core crop are multiplied by the adjustment factor to obtain the new set of canopy values. The procedure is illustrated in table D-3.

Length of Growing Season and Dormancy

Adjustments may be needed for length of growing season for crops like corn and soybeans and length of the dormancy season for crops like winter wheat. The adjustment made for length of growing season is to add or subtract days from the period of full canopy before senescence begins. Length of the dormancy period is adjusted by adding or subtracting days to the dormancy period. In the southern part of the United States, reduced growth can continue throughout the dormancy period. The core data should be adjusted to account for this effect.

Crops Not Listed Among Core Crops

Situations will arise where RUSLE will be applied to crops not listed in the core data set. Several options are available for obtaining values for these crops. Key variables are amount of aboveground biomass, amount of root biomass at harvest, amount of canopy, and fall height at harvest.

Obtain Data From the Literature

The first option involves selecting published values in the literature. Try to find as much published data as possible. Variations among the sources can be large. The ratio of aboveground biomass to root biomass is not constant during the growing season. Select the root biomass value at maturity as the starting point. Choose values during the growing season that form an S-shaped curve similar to the data shown for the core crops. The same applies for canopy and effective fall height. Choose a residue:yield ratio value that can be assumed to be constant over the mid 50% yield range of the crop.

Obtain Data From NRCS

The second option is to contact the State Agronomist in an office of the Natural Resources Conservation Service (NRCS) of the USDA. Very likely NRCS has already developed a data set for a crop that can be used directly or that can be modified.

Compare Crop Characteristics to Characteristics of a Core Crop

The third alternative is to compare characteristics of the given crop to those of a similar core crop and adjust parameter values accordingly. For example, peanuts might be compared to soybeans.

Relation of Ground Cover Percent to Mass

In many cases, ground cover is the single most important factor affecting erosion. Therefore, the single most important crop variable is amount of residue at harvest and at planting time. Table D-4 lists values for the "core" crops for relating percent ground cover to mass.

Percent ground cover is not an accurate indicator of amount of biomass when percent cover exceeds 90%, as at harvest. The exponential shape of the curve that describes the relation of residue cover to residue mass is not sensitive to mass at high percent cover values. Mass can change greatly with little detectable change in cover above 90%, especially for covers greater than 95%. However, percent cover for values less than 75% is a reliable indicator of cover mass on the surface.

Even though percent cover is the single most important variable affecting erosion, loss of residue is on a mass basis. While cover is readily measured, mass of cover is not easily measured. Soil particles must be carefully washed from the residue, and leaves and stems must be carefully recovered. Also, the residue rapidly loses mass shortly after harvest, which is not reflected in a corresponding loss of cover.

If RUSLE is using the proper mass of residue at harvest but is giving a poor estimate of cover before spring tillage, two possibilities should be checked. One is that the decomposition parameter value used to compute loss of residue is in error; the other possibility is that the relationship of residue cover to residue mass is in error.

If the residue cover after planting is not correct but was correct before the first tillage operation at planting time, the most likely cause is that the value of residue left by the tillage operation is incorrect. If the residue after planting is correct but is not correct at the end of the growing season, the decomposition parameter value is incorrect.

Be Cautious

Because erosion is sensitive to cover, care should be taken to ensure that cover values are reasonable. However, when adjustments are needed, analyze the reason for the problem and make adjustments carefully and methodically. Sometimes the problem is not as it appears.

Decomposition Parameter Values

Loss of residue over time is computed in RUSLE as a function of temperature and rainfall. Parameter values for decomposition are given in table D-5.

Data used in RUSLE to evaluate the adequacy of the decomposition parameter values should be field measurements of the loss of residue cover. Obviously, other factors such as soilborne organisms can affect residue loss. These effects are empirically captured in the decomposition parameter values. Thus, a decomposition parameter value should be based on field measurements and not laboratory decomposition tests.

The decomposition computations in RUSLE do not consider standing stubble separate from biomass on the soil. As a consequence, RUSLE may overestimate the loss of standing stubble. However, a decomposition parameter value can be applied to the biomass in the soil that is different from the parameter value for biomass on the soil.

RUSLE does not treat the plant components of leaves, stems, and roots separately. All components are assumed to be lost at the same rate. Furthermore, RUSLE does not vary the decomposition parameter value based on the state of decomposition to consider, for example, that decomposition may initially proceed more rapidly than in later stages.

Decomposition is related more closely to soil moisture than to the rainfall values used in RUSLE to compute loss of residue. Also, temperature varies within a day, and both temperature and rainfall vary from day to day. Monthly values in RUSLE are disaggregated into smoothed daily values for the RUSLE computations. The result is that decomposition parameter values for a given crop may need adjustment by climatic region. For example, a much larger decomposition parameter value is needed for wheat in the Northwestern Wheat and Range Region than in other parts of the United States.

Given these considerations and the limitations of the simple equations used in RUSLE to compute loss of biomass, decomposition parameter values are chosen to provide the best overall results.

Adjusting Parameter Values for Operations in the Core List

Table 5-5 contains parameter values for the core list of field implements used in many cropland operations. When an operation in the core list does not match the operation as applied in your situation, the following adjustments can be made.

Depth of Incorporation

For a given type of implement, a single value is used for depth of incorporation. For example, a value of 6 in is used for all chisel plows regardless of actual depth of tillage. Values for depth of incorporation are chosen based on information given in table D-6.

Roughness

A roughness value assigned to a tillage operation can be adjusted up or down one roughness step as shown in table D-7. For example, a moldboard plow has a roughness value of 1.9 in for its core value. It could be assigned a value of 2.3 for a clay soil that is very rough or a value of 1.5 for a sandy soil that is relatively smooth after plowing. The roughness index as used in RUSLE represents both the effects of depressional storage and the degree of pulverization.

Amount of Residue Left

Since surface cover has such a great effect on erosion, the value for the amount of residue left by an operation should be selected carefully. In general, values should be rounded to the nearest 10% or perhaps to the nearest 5%. Consideration should be given to whether the residue is fragile or nonfragile. Nonfragile residues are assumed in table 5-5. A very important consideration, especially if information is obtained from the literature, is whether or not residue mass or percent cover was used to indicate how much residue was left by the tillage operation.

Obtaining Parameter Values for Operations Not in the Core List

If a particular operation is not in the core list, values for the operation can often be obtained from the NRCS, which has developed values for an array of operations. This approach is preferred because the NRCS values have been tested and evaluated for consistency with other operations. The next best alternative is to choose values based on data in literature. The third and last desirable option is to compare characteristics of the particular operation against those of operations in the core list. If values are obtained from the literature or by comparison with operations in the core list, the following must be observed. The depth of incorporation is based on type of tillage operation as described in table D-6. The value of roughness that is assigned to a tillage operation is based on the tillage occurring in a medium-textured soil at a high level of management, meaning that large amounts of residue from a high yielding crop like corn has been routinely incorporated into the soil.

Table D-1. Residue:yield ratio and yield range over which to use a constant residue:yield ratio

Crop	Residue:yield ratio	Range[1]
Corn	1.0	50 to 150 $bu(acre)^{-1}$
Soybeans	1.5	15 to 45 $bu(acre)^{-1}$
Cotton	[2]4.5	300 to 1000 $lbs(acre)^{-1}$ lint
Sorghum	1.0	40 to 90 $bu(acre)^{-1}$
Winter wheat	1.7	25 to 60 $bu(acre)^{-1}$
Spring wheat	1.3	25 to 60 $bu(acre)^{-1}$
Spring oats	2.0	30 to 80 $bu(acre)^{-1}$

[1]If yield is less than the minimum value in the range, the residue:yield ratio may need to be increased. If yield is greater than the maximum value in the range, the residue:yield ratio may need to be decreased.
[2]Value given is for shredding stalks in the fall. Use 3.0 for stalks shredded in the spring.

Table D-2. Multiplication factors to adjust RUSLE plant data from core data

Ratio of biomass at maturity of given crop to biomass of core crop	Multiplication factor for root biomass[1]	Multiplication factor for canopy percent[2]	Multiplication factor for fall height[3]
0.1	0.1	0.32	0.63
.2	.2	.45	.72
.3	.3	.55	.79
.4	.4	.63	.83
.5	.5	.71	.87
.6	.6	.77	.90
.7	.7	.84	.93
.8	.8	.89	.96
.9	.9	.95	.98
[4]1.0	1.0	1.00	1.00
1.1	1.1	1.05	1.02
1.2	1.2	1.10	1.04
1.3	1.3	1.14	1.05
1.4	1.4	1.18	1.07
1.5	1.5	1.22	1.08
1.6	1.6	1.26	1.10
1.7	1.7	1.30	1.11
1.8	1.8	1.34	1.12
1.9	1.9	1.38	1.14
2.0	2.0	1.41	1.15

[1]Adjustment factor for roots = (M_g / M_c), where M_g is aboveground biomass for given crop and M_c is aboveground biomass for core crop.
[2]Adjustment factor for canopy percenter = $(M_g / M_c)^{0.5}$
[3] Adjustment factor for fall height = $(M_g / M_c)^{0.2}$
[4]Represents core crop

Table D-3. Data adjustment examples for root biomass, percentage of canopy cover, and fall height[1].

	Root biomass percent adjustments		Canopy percent adjustments		Fall height adjustment in feet	
Days	Core crop	Given crop	Core crop	Given Crop	Core Crop	Given Crop
30	180	110	10	10	0.5	0.4
45	350	210	50	40	1.0	0.9
60	530	320	80	60	1.7	1.5
75	840	500	100	80	2.5	2.2
90	1060	640	100	80	3.0	2.7
150	1060	640	70	55	3.0	2.7

[1]The following example is used:

- Core crop is corn at 125 $bu(acre)^{-1}$
- Given crop is corn at 75 $bu(acre)^{-1}$. Ratio of biomass at maturity for given crop to that core crop = 0.6.

Table D-4. Percent cover to mass relationship for core crops.

	Mass (lbs(acre)$^{-1}$) at various percentages of residue cover		
Crop	30	60	90
Corn	950	2400	6050
Soybeans	600	1600	—
Cotton	1600	4150	—
Sorghum	1050	2700	6750
Winter wheat	600	1550	3850
Spring oats	600	1550	3850

Table D-5. Decomposition coefficient values

Crop	Coefficient
Alfalfa	0.020
Brome grass	.017
Corn	.016
Cotton	.015
Peanuts	.015
Small grain	[1].008
Small grain cover crop killed while in vegetative stage	.017
Sorghum	.016
Soybeans	.025
Sunflowers	.016
Tobacco	.015

[1] Use 0.017 for the Northwestern Wheat and Range Region.

Table D-6. Depth of incorporation according to type of tillage operation

Operation	Depth of incorporation (in)
Primary tillage operations that invert soil, such as moldboard plow	8
Primary tillage operations that do not invert soil, such as chisel plows and heavy plowing disks	6
Operations involving widely spaced shanks that inject significant amounts of biomass into the soil, such as manure injectors	6
Secondary tillage operations involving disks, such as tandem disk	4
Bedding and ridging operations, such as listers, hippers, and similar tools (cultivators used in ridge-till cropping are not included in this category)	4
Secondary tillage operations involving shank type tools that mix the soil significantly, such as field cultivators	3
Shank type operations using widely spaced shanks where minimal mixing occurs, such as subsoilers and anhydrous fertilizer knife-type applicators	2
Secondary tillage operations and other operations that disturb only a shallow upper layer or that leave crop residue in a shallow upper layer, such as harrows, planters, row cultivators, and tools where minimal mixing occurs	2

Table D-7. Adjustments to random roughness index in inches to represent smoother and rougher surfaces than represented by "core" value

Smoother surface	Core roughness value	Rougher surface
0	0.1	0.2
0.1	.2	.4
.2	.4	.8
.4	.8	1.2
.8	1.2	1.6
1.2	1.6	2.0
1.6	2.0	2.4
2.0	2.4	2.8

Procedure: Identify a "core" roughness value. If the site specific condition is significantly smoother than the core surface, use the roughness value from the "smoother surface" column, and conversely for a rougher surface.

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Technical and Grammatical Problems in AH703

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Don McCool

Page #	Problem
vii	B_{us} should be $lb \cdot acre^{-1} \cdot in^{-1}$
xv	T should be $ton \cdot acre^{-1} \cdot yr^{-1}$
22	It is implied that Req includes irrigation. This is incorrect.
28	"Maps------is"
33	The abbreviations "ww/p", etc need to be defined.
34, last par.	Change to "measurements of the ratio of rill to interrill soil loss".
89	Presenting K without units is extremely misleading. This implies that K is numerically the same regardless of the EI system used.
152	For equation 5-7, it should be indicated that temperatures must be in degrees C. The text presents values for T_o and A in degrees F, but using T_a in degrees F gives erroneous answers.
153	Equation 5-9 is incorrect. The minus sign should be before the brace "[" instead of before the "c_{ur}".