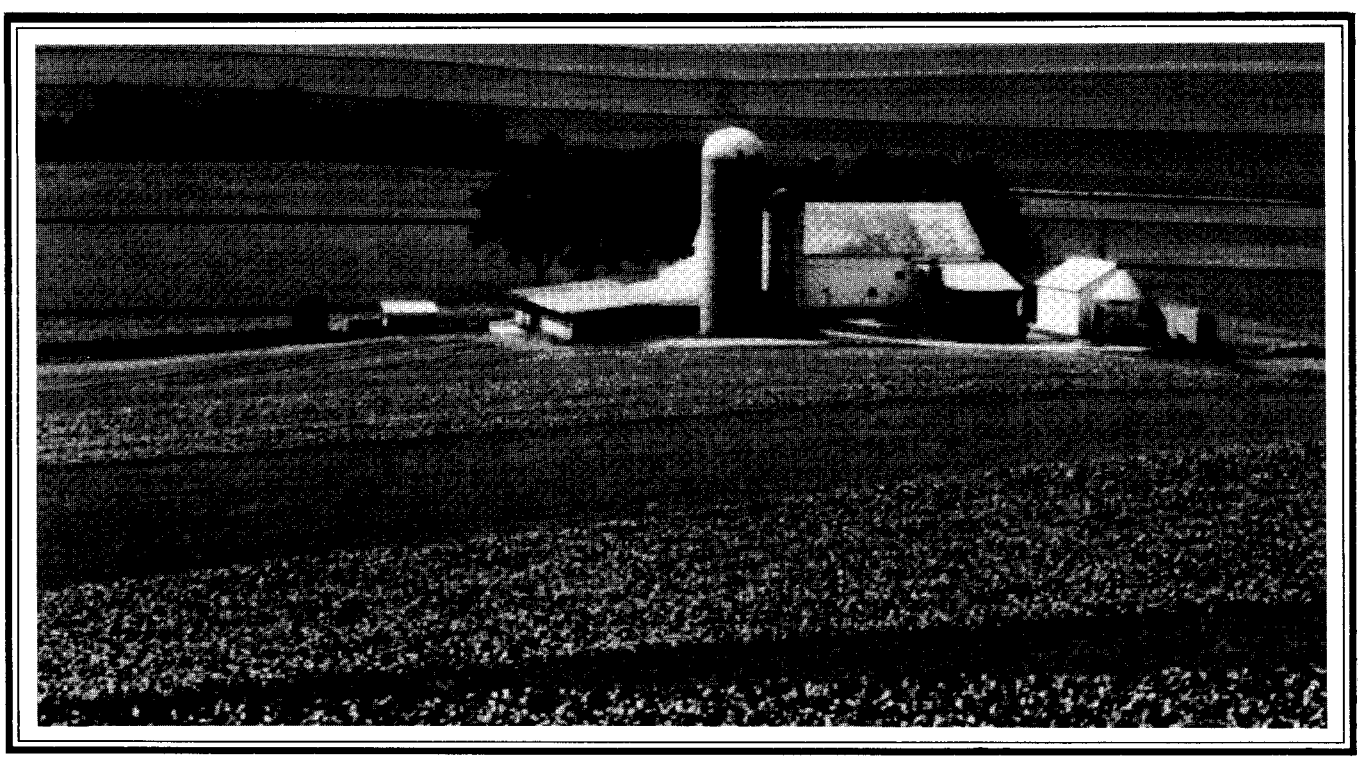
USDA

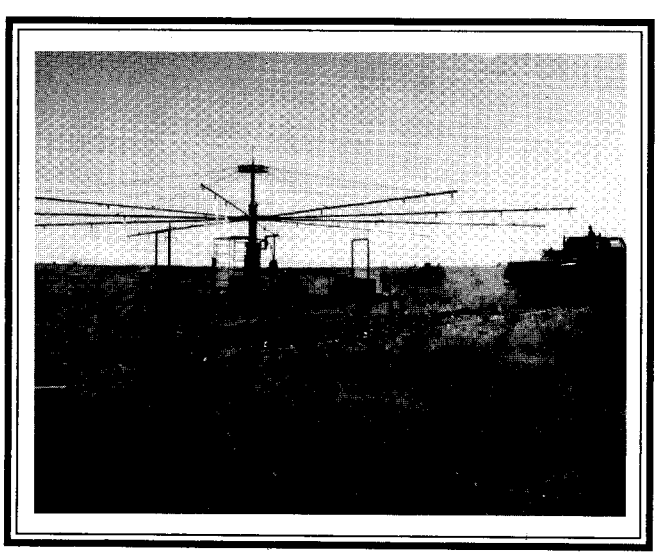
United States
Department of
Agriculture

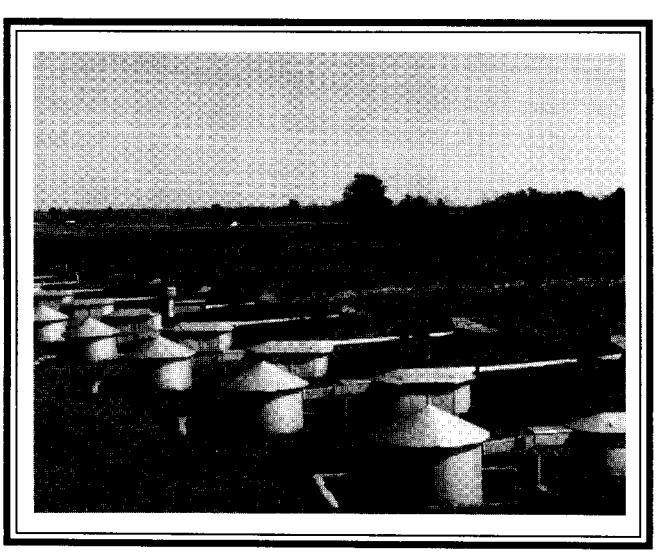
Agricultural
Research
Service

Agriculture
Handbook
Number 703

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)

K.G. Renard, G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder, Coordinators*

Note: See the errata at the end of the document

*Renard (retired) was research hydraulic engineer, USDA-ARS, Southwest Watershed Research Center, 2000 East Allen Road, Tucson, AZ. Foster is director, USDA-ARS, Sedimentation Laboratory, Oxford, MS. Weesies is conservation agronomist, USDA-NRCS, National Soil Erosion Research Laboratory, Purdue University, Building SOIL, West Lafayette, IN. McCool is agricultural engineer, USDA-ARS, Washington State University, Pullman, WA. Yoder is assistant professor, Agricultural Engineering Department, University of Tennessee, Knoxville, TN.

ABSTRACT

Renard, K.G., G.R. Foster, G.A. Weesies, D.K. McCool, and D.C. Yoder, coordinators. Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation (RUSLE). U.S. Department of Agriculture, Agriculture Handbook No. 703, 404 pp.

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

Mention of a trade name in this publication is solely to provide specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture over others not mentioned.

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.

Copies of this publication may be purchased from the National Technical Information Service, 5285 Port Royal Road, Springfield, VA 22161.

The U.S. Department of Agriculture (USDA) prohibits discrimination in its programs on the basis of race, color, national origin, sex, religion, age, disability, political beliefs, and marital or familial status. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact the USDA Office of Communications at (202) 720-2791. To file a complaint, write the Secretary of Agriculture, U.S. Department of Agriculture, Washington, DC 20250, or call (202) 720-7327 (voice) or (202) 720-1127 (TDD). USDA is an equal opportunity employer.

Issued July 1996

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· acre^{-1}· 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· acre^{-1}· 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· acre^{-1}· yr^{-1})
B_a	above-ground biomass (lb· acre^{-1})
B_b	below-ground root biomass (lb· acre^{-1})
B_s	weight of residue on the surface (lb· acre^{-1})
B_{si}	weight of a particular type of residue (lb· acre^{-1})
B_{ur}	mass density of live and dead roots in the upper layer of soil (lb· acre^{-1}· in^{-1})
B_{us}	mass density of incorporated surface residue in the upper layer of soil (lb· acre^{-1}· 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· in· lb^{-1})
c_{us}	coefficient describing the effectiveness of incorporated surface residue in controlling erosion (acre· in· lb^{-1})
D	- period length (d) (ch. 5) - if > 0, erosion rate at a point (mass· $area^{-1}$· $time^{-1}$) (ch. 6) - if < 0, deposition rate (mass· $area^{-1}$· $time^{-1}$) (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· ft^{-1}· yr^{-1})
g	sediment load (ton· ft^{-1}· yr^{-1})
g_{db}	sediment load at location where deposition begins within strip (ton· ft^{-1}· yr^{-1})
g_{de}	sediment load at location where deposition ends within strip (ton· ft^{-1}· yr^{-1})
g_p	sediment load at the end of the slope that would occur if the strips caused no deposition (ton· ft^{-1}· yr^{-1})
g_λ	sediment load at the end of the slope (ton· ft^{-1}· yr^{-1})
H	distance raindrops fall after striking the crop canopy (ft)
I	precipitation intensity (in· h^{-1})
I_{30}	maximum 30-min intensity (in· h^{-1})
i	- rainfall intensity (in· h^{-1}) - subscript indicating a particular segment or strip
i_m	rainfall intensity (metric) (mm· h^{-1})
K	soil erodibility factor (ton· acre· h· [hundreds of acre-ft· tonf· 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· $acre^{-1}$) - transport capacity of runoff (ton· ft^{-1}· 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.

Technical and Grammatical Problems in AH703

March 1, 2001

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}".