DRAFT

Science Documentation

Revised Universal Soil Loss Equation Version 2

(RUSLE2)

George R. Foster, Research Hydraulic Engineer (retired)
National Sedimentation Laboratory
USDA-Agricultural Research Service
Oxford, Mississippi

Prepared for
USDA-Agricultural Research Service
Washington, D.C.

January 1, 2005

Acknowledgements

Preface

The Revised Universal Soil Loss Equation, Version 2 (RUSLE2) is used to guide conservation and erosion control planning at the local field office level. RUSLE2 estimates average annual rill and interrill erosion based on site-specific conditions. In a typical application, the planner identifies several potential erosion control alternatives for the site and estimates erosion for each alternative. The planner then the chooses the alternative that provides adequate erosion control and best meets other requirements..

RUSLE2 is computer-based technology that involves a computer program, mathematical equations, and a large database. The RUSLE2 user describes a specific site by making selections from the database. RUSLE2 uses this information in its mathematical equations to compute erosion estimates for the site.

RUSLE2 can be used to estimate rill and interrill erosion where mineral soil is exposed to the erosive forces of impacting raindrops and water drops falling from vegetation and surface runoff produced by Hortonian overland flow. RUSLE2 is land use independent and can be applied where ever these conditions exist. RUSLE2 can be used on cropland, pastureland, rangeland, constructions site, reclaimed mine land, landfills, mine tailings, mechanically disturbed and burned forestlands, military training sites, and similar lands.

This document describes the RUSLE2 science, which is primarily embodied in the mathematical equations used in RUSLE2. The RUSLE2 User's Reference Guide, a companion document, describes how RUSLE2 works, how to interpret values computed by RUSLE2, how to select and enter values into the RUSLE2 database, and how to judge the adequacy of RUSLE2. Additional information is available on the RUSLE2 Internet site maintained by the USDA-Agricultural Research Service: http://msa.ars.usda.gov/ms/oxford/nsl/rusle/index.html. Additional information is also available on RUSLE2 Internet sites maintained by the USDA-Natural Resources Conservation Service and the University of Tennessee.

Table of Contents

Glossary of Terms

Term	Description
10 yr EI	Storm EI with a 10-year return period
10 yr-24 hr EI	Storm EI for the 10 yr-24 hr precipitation
10 yr-24 hr precipitation	24 hour precipitation amount having a 10 year return period
Antecedent soil moisture subfactor	See cover-management subfactors
Average annual, monthly, period, and daily erosion	RUSLE2 computes average daily erosion, which represents the average erosion that would be observed if erosion was measured on that day for a sufficiently long period. Average period, monthly, and annual erosion are sums of the average daily values
Average erosion	Average erosion is the sediment load at a given location on the overland flow path divided by the distance from the origin of overland flow path to the location
b value, also b_f value	Coefficient in equation for effect of ground cover on erosion, values vary daily with rill-interrill erosion ratio and residue type
Buffer strips	Dense vegetation strips uniformly spaced along overland flow path, can cause much deposition
Burial ratio	Portion of existing surface (flat) cover mass that is buried by a soil disturbing operation (dry mass basis-not area covered basis)
Calibration	Procedure of fitting an equation to data to determine numerical values for equation's coefficients
Canopy cover	Cover above soil surface, does no contact runoff, usually vegetation
Canopy shape	Standard shapes used to assist selection of fall height values
Canopy subfactor	See cover-management subfactors
Climate description	Input values for variables used to represent climate, stored in RUSLE2 database under a location name
Concentrated flow area	Area on landscape where channel flow occurs, ends overland flow path
Conservation planning soil loss	A conservation planning erosion value that gives partial credit to deposition as soil saved, credit is function of location on overland flow path where deposition occurs
Contouring	Support erosion control practice involving ridges-furrows that reduces erosion by redirecting runoff around hillslope
Contouring failure	Contouring effectiveness is lost where runoff shear stress exceeds a critical value
Contouring description	Row grade used to describe contouring, stored in RUSLE2 database under name, ridge height in operation description used in cover-management description also key input
Core database	RUSLE2 database that includes values for base conditions used to validate RUSLE2, input values for a new condition must be consistent with values in core database for similar conditions
Cover-	Values for variables that describe cover-management, includes

management description	dates, operation descriptions, vegetation descriptions, yields, applied external residue and amount applied, named and saved in RUSLE2 database
Cover-management subfactors	Cover-management subfactor values used to compute detachment (sediment production) by multiplying subfactor values, subfactor values vary through time
Canopy	Represents how canopy affects erosion, function of canopy cover and fall height, canopy varies through time
Ground cover	Represents how ground cover affects erosion, function of portion of soil surface covered
Surface roughness	Represents how soil surface roughness affects erosion, function of roughness index
Soil biomass	Represents how live and dead roots in upper 10 inches and buried residue in upper 3 inches and less affects erosion
Soil consolidation	Represents how a mechanical disturbance affects erosion, erosion decreases over time after last disturbance as the soil consolidates
Ridging	Represents how ridges increase detachment (sediment production)
Ponding	Represents how a water layer on soil surface reduces erosion
Antecedent soil moisture	Represents how previous vegetation affects erosion by reducing soil moisture, used only in Req zone
Critical slope length	Location where contouring fails on an uniform overland flow path
Cultural practice	Erosion control practice such as no-till cropping where cover-management variables are used to reduce erosion
Curve number	An index used in NRCS curve number method to compute runoff, RUSLE2 computes value as function of hydrologic soil group and cover-management conditions
Database	RUSLE2 database stores both input and output information in named descriptions
Dead biomass	Represents live above ground and root biomass converted to dead biomass by kill vegetation process in an operation description, dead biomass decomposes
Dead root biomass	A kill vegetation process in an operation description converts live root biomass to dead root biomass, dead roots decompose at the same rate as surface and buried residue
Decomposition	Loss of dead biomass as a function of material properties, precipitation, and temperature; decomposition rate for all plant parts and buried and surface biomass is equal; decomposition rate for standing residue is significantly decreased because of no soil contact
Deposition	Process that transfers sediment from sediment load to soil surface. Net deposition causes sediment load to decrease with distance along overland flow path; depends on sediment characteristics and degree that sediment load exceeds sediment transport capacity; enriches sediment load in fines; computed as a function of sediment particle class fall velocity, runoff rate, and difference between sediment

	load and transport capacity
Deposition portion	Portion of overland flow path where net deposition occurs
Detachment	Separates soil particles from soil mass by raindrops, waterdrops falling from vegetation, and surface runoff; net detachment causes sediment load to increase along overland flow path; detachment is non-selective with respect to sediment characteristics; computed as function of erosivity, soil erodibility, distance along overland flow path, steepness of overland flow path, cover-management condition, and contouring
Disaggregation	Mathematical procedure used to covert monthly precipitation and temperature values to daily values assuming that values vary linearly, daily precipitation values sum to monthly values, daily monthly temperature average monthly value
Diversion/terrace/ sediment basin	A set of support practices that intercept overland flow to end overland flow path length.
Diversions	Intercepts overland flow and directs it around hillslope in channelized flow, grade is sufficiently steep that deposition does not occur but not so steep that erosion occurs
EI_{30}	Storm (rainfall) erosivity, product of storm energy and maximum 30 minute intensity, storm energy closely related to rain storm amount and partly to rainfall intensity
Enrichment	Deposition is selective, removing the coarse particles and leaving the sediment load with increased portion of fine particles
Enrichment ratio	Ratio of specific surface of sediment after deposition to specific surface area of soil subject to erosion
Eroding portion	Portion of overland flow path where net detachment (erosion) occurs
Erosivity	Index of erosivity of rainfall at a location, closely related to rainfall amount and intensity, monthly erosivity is average annual sum of individual storm values in month, annual erosivity is average sum of values in year, storm rainfall amount must be ½ inch (12 mm) or more to be included in sum
Erosivity density	Ratio of monthly erosivity to monthly precipitation amount
External residue	Material, usually biomass, added to soil surface or placed in the soil; affects erosion as surface residue and buried residue
Fabric (silt) fence	Fabric about 18 inches wide placed against upright posts on the contour, porous barrier that ponds runoff and causes deposition, widely used on construction sites
Fall height	Fall height is the effective height from which waterdrops fall from canopy, depends on canopy shape, canopy density gradient, and top and bottom canopy heights
Filter strip	A single strip of dense vegetation at the end of an overland flow path, can induce high amounts of deposition
Final roughness	Soil surface roughness after roughness has decayed to unit plot conditions, primarily represents roughness provided by soil resistant clods, porous barrier

Flattening ratio	Describe how much standing residue that an operation flattens, ratio of standing residue before operation to standing residue after operation, values depend on operation and residue, dry mass basis.
Flow interceptors	Topographic features (ridge-channel) on an overflow path that collects overland flow and directs the runoff around hillslope; ends overland flow path; diversions, terraces, and sediment basins are flow interceptors
Gradient terraces	Terraces on a uniform grade
Ground cover	Represents the portion of the soil surface covered by material in direct contact with soil; includes plant litter, crop residue, rocks, algae, mulch, and other material that reduces both raindrop impact and surface flow erosivity
Ground cover subfactor	See cover-management subfactors
Growth chart	The collection of values that describe temporal vegetation variables of live root biomass in upper 4 inches (100mm), canopy cover, fall height, and live ground cover; values are in a vegetation description
Hortonian overland flow	Overland generated by rainfall intensity being greater than infiltration rate; although flow may be concentrated in micro-channels (rills), runoff is uniformly distributed around hillslope
Hydraulic (roughness) resistance	Degree that ground cover, surface roughness, and vegetation retardance slow runoff; daily values vary as cover-management conditions change
Hydraulic element	RUSLE2 hydraulic elements are a channel and a small impoundment
Hydraulic element flow path description	Describes the flow path through a sequence of hydraulic elements, named and saved in RUSLE2 database
Hydraulic element system description	Describes a set of hydraulic element paths that are uniformly spaced along the overland flow path described without the hydraulic element system being present, named and saved in RUSLE2 database
Hydrologic soil group	Index of runoff potential for a soil profile at a given geographic location, at a particular position on the landscape, and the presence or absence of subsurface drainage
Impoundment	A flow interceptor, impounds runoff, results in sediment deposition, represents impoundments typical of impoundment terraces on cropland and sediment basins on construction sites
Impoundment parallel terrace	Parallel terraces, impoundments where terraces cross concentrated flow areas, impoundment drains through a riser into underground pipe
Incorporated biomass	Biomass incorporated (buried) in the soil by a soil disturbing operation, also biomass added to the soil from decomposition of surface biomass, amount added by decomposition of surface material function of soil consolidation subfactor
Inherent organic	Soil organic matter content in unit plot condition

matter	
Inherent soil erodibility	Soil erodibility determined by inherent soil properties, measured under unit plot conditions, see soil erodibility
Initial conditions	Cover-management conditions at the beginning of a no-rotation cover-management description
Initial input roughness	Roughness index value assigned to soil disturbing operation for the base condition of a silt loam soil with a high biomass on and in the soil, actual initial roughness value used in computations is a function of soil texture, soil biomass, existing roughness at time of soil disturbance, and tillage intensity
Injected biomass	Biomass placed in the soil using an add other residue/cover process in a soil disturbing operation description, biomass placed in lower half of disturbance depth
Interrill erosion	Erosion caused by water drop impact; not function of distance along overland flow path unless soil, steepness, and cover-management conditions vary, interrill areas are the spaces between rills, very thin flow on interrill areas
Irrigation	Water artificially added to the soil to enhance seed germination and vegetation production
Land use independent	RUSLE2 applies to all situations where Hortonian overland flow occurs and where raindrop impact and surface runoff cause rill and interrill erosion of exposed mineral soil, the same RUSLE2 equations are used to compute erosion regardless of land use
Live above ground biomass	Live above ground biomass (dry matter basis), converted to standing residue (dead biomass) by a kill vegetation process in an operation description.
Live ground (surface) cover	Parts of live above ground biomass that touches the soil surface to reduce erosion.
Live root biomass	RUSLE2 distributes input values for live root biomass in upper four inches (100 mm) over a constant rooting depth of 10 inches (250 mm). A kill vegetation process in an operation description converts live root biomass to dead root biomass. Primarily refers to fine roots that are annually produced, RUSLE2 uses live and dead root biomass in the upper 10 inches to compute a value for the soil biomass subfactor
Local deposition	Deposition that occurs very near, within a few inches (several mm), from the point of detachment in surface roughness depressions and in furrows between ridges, given full credit for soil saved
Long term roughness	Roughness that naturally develops over time; specified as input in cover-management description; depends on vegetation characteristics (e.g., bunch versus sod forming grasses, root pattern near soil surface) and local erosion and deposition, especially by wind erosion; RUSLE2 computes roughness over time; fully developed by time to soil consolidation
Long term vegetation	Permanent vegetation like that on pasture, range, reclaimed mined land, and landfills; vegetation description can include temporal

	values starting on seeding date through maturity or only for the vegetation at maturity
Management alignment offset	Used to sequence cover-management descriptions along an overland flow path to create alternating strips
Mass-cover relationship	Equation used to compute portion of soil surface covered by a particular residue mass (dry basis)
Mass-yield relationship	Equation used to compute standing biomass (dry basis) as a function of production (yield) level
Maximum 30 minute intensity	Average rainfall intensity over the continuous 30 minutes that contains the greatest amount in a rain storm
Non-erodible cover	Cover such as plastic, standing water, snow, and other material that completely eliminates erosion, material can be porous and disappear over time
Non-uniform overland flow path	Soil, steepness, and/or cover-management vary along an overland flow path; path is divided into segments where selections are made for each segment
NRCS curve number method	Mathematical procedure used in RUSLE2 to compute runoff based on the 10 yr-24 hr precipitation amount; a daily runoff value is computed based on how cover-management temporally varies
NWWR	Northwest Wheat and Range Region, a region in the Northwestern US covering eastern Washington and Oregon, northern Idaho, see Req zone
Operation	An operation changes soil, vegetation, or residue; typically represents common farm and construction activities such as plowing, blading, vehicular or animal traffic, and mowing, also represents burning and natural processes like killing frost and germination of volunteer vegetation.
Operation disturbance depth	Surface residue buried by a soil disturbing operation is a function of operation disturbance depth, RUSLE2 computes effect between minimum and maximum depths
Operation description	Information used to describe an operation, named and stored in the RUSLE2 database
Operation processes	An operation is described by a sequence of processes, describes how an operation changes cover-managements conditions that affect erosion
No effect	Has no effect on computations, commonly used to reference dates in a cover-management description and to cause RUSLE2 to display information for a particular set of dates
Begin growth	Tells RUSLE2 when to begin using data from a particular vegetation description
Kill vegetation	Converts live above ground biomass to standing residue and to convert live root biomass to dead root biomass
Flatten standing residue	Converts a portion of the standing residue to surface residue
Disturb (soil)	Mechanically disturbs soil, required to bury surface residue,

surface	resurfaces buried residue, creates roughness and ridges, and places material (external residue) directly into the soil
Add other cover	Adds material (external residue) to the soil surface and/or places it in the soil
Remove live above ground biomass	Removes a portion of the live above ground biomass, leaves a portion of the affected biomass as surface (flat) residue
Remove residue/cover	Removes a portion of standing and surface (flat) residue
Add nonerodible cover	Adds nonerodible cover such as plastic, water depth, snow, or other material that allows no erosion for portion of soil surface covered, cover disappears over time, cover can be porous, cover has no residual effect, not used to represent erosion control blankets and similar material.
Remove nonerodible cover	Removes nonerodible cover, cover has no residual effect
Operation speed	Surface residue buried by a soil disturbing operation is a function of operation speed, RUSLE2 computes effect between minimum and maximum speeds
Overland flow path	Path taken by overland flow on a smooth surface from its point of origin to the concentrated flow area that ends the overland flow path, runoff is perpendicular to hillslope contours
Overland flow path description	Steepness along an overland flow path, a uniform profile is where steepness does not vary with distance along overland flow path, a convex profile is where steepness increases with distance, a concave profile is where steepness decreases with distance, and a complex profile is a combination of convex, concave, and/or uniform sub-profiles, description involves segment lengths and segment steepness
Overland flow path length	Distance along the overland flow path from the origin of overland flow to the concentrated flow area (channel) that intercepts runoff to terminate overland flow, does not end where deposition begins, see USLE slope length and steepness
Overland flow path segments	Overland flow path is divided into segments to represent spatial variability along an overland flow path, conditions are considered uniform within each segment
Overland flow path steepness	Steepness along the overland flow path, not hillslope steepness, see USLE slope steepness
Permeability index	Index for the runoff potential of the soil under the unit plot condition; used in RUSLE2's soil erodibility nomographs, similar to hydrologic soil group
Plan description	Collection of RUSLE2 profile descriptions used to computed weighted averages for a complex area based on the portion of the area that each profile represents, description named and saved in

	RUSLE2 database
Ponding subfactor	See cover-management subfactors
Porous barriers	Runoff flows through a porous barrier, does not affect overland flow path, typically slows runoff to cause deposition, examples are stiff grass hedges, fabric (silt) fences, gravel dams, and straw bales
Precipitation amount	Includes all forms of precipitation, RUSLE2 disaggregates input monthly values into daily values to compute decomposition and temporal soil erodibility
Production (yield) level	A measure of annual vegetation live above ground biomass production, user defines yield measure and preferred units on any moisture content basis, input value used to adjust values in a vegetation description at a base yield, maximum canopy cover in base vegetation description must be less than 100 percent.
Profile description	Information used to describe profile, includes names for location, topography, soil, cover-management, and support practices used to make a particular RUSLE2 computation, profile descriptions are named and stored in RUSLE2 database
Profile shape	See overland flow path description
Rainfall (storm) energy	Computed as sum of products of unit energy and rainfall amount in storm intervals where rainfall intensity is assumed uniform, storm energy is closely related to rain storm amount
Rainfall intensity	Rainfall rate express as depth (volume of rainfall/per unit area) per unit time
Remote deposition	Deposition that occurs a significant distance (tens of feet, several months) from the point where the sediment was detached; examples include deposition by dense vegetation strips, terraces, impoundments, and toe of concave overland flow paths; only partial credit given to remote deposition as soil saved; credit depends on location of deposition along overland flow pat; very little credit given for deposition near end of overland flow path
Req	Equivalent erosivity for the winter months in the Req zone, used to partially represent Req effect
Req effect	Refers to Req equivalent erosivity; erosion per unit rainfall erosivity in the winter period in the Req zone much greater than in summer period; winter effect much greater than in other regions because of a greatly increased soil erodibility; effect partially results from an elevated soil water content and soil thawing
Req zone	Region where erosion is elevated in the winter months because of the Req effect, region primarily in eastern WA and OR, portions of ID, CA, UT, CO, and limited area in other western US states
Residue	Has multiple meanings in RUSLE2, generally refers to dead biomass, such as crop residue, created when vegetation is killed; plant litter from senescence; and applied mulch material such as straw, wood fiber, rock, and erosion control blankets used on construction sites; material is generally assumed to be biomass that decomposes; also used to represent material like rock that does not

	decompose
Residue description	Values used to describe residue, named and stored in the RUSLE2 database
Residue type	Refers to fragility and geometric residue characteristics, affects residue amount buried and resurfaced by of an operation; affects degree that residue conforms to surface roughness, affects erosion control on steep slopes like those on construction sites
Resurfacing ratio	Portion (dry mass basin) of the buried residue in the soil disturbance depth that a soil disturbing operation brings to the soil surface, function of residue and operation properties
Retardance	Degree that vegetation (live above ground biomass) and standing residue slows runoff, varies with canopy cover, function of production (yield) level, part of vegetation description
Ridge height	Height of ridges created by a soil disturbing operation, major variable along with row grade that determines contouring effectiveness, decays as a function of precipitation amount and interrill erosion
Ridge subfactor	See cover-management subfactors
Rill erosion	Caused by overland flow runoff, increases with distance along the overland flow path
Rill to interrill erosion ratio	Function of slope steepness, rill to interrill soil erodibility, and how cover-management conditions affect rill erosion different from interrill erosion
Rock cover	Rock cover entered in the soil description represents naturally occurring rock on soil surface, operations do not affect this rock cover, rock cover created by an operation that adds other cover (rock residue) is treated as external residue, soil disturbing operations bury and resurface rock added as external residue
Root biomass	See dead and live root biomass
Root sloughing	Annual decease in root biomass, RUSLE2 adds the decrease in live root biomass to dead residue biomass pool
Rotation	Refers to whether a list of operation descriptions in a cover-management descriptions are repeated in a cycle, length of cycle is rotation duration, list of operation descriptions are repeated until average annual erosion value stabilizes, eliminates need to specify initial conditions, operation descriptions in a no-rotation cover-management descriptions are sequentially processed in a single time, first operation descriptions in cover-management description establish initial conditions
Rotation duration	Time before the list of operation descriptions in a rotation type cover-management description repeats, length of cycle, time period over which RUSLE2 makes its computation in a no-rotation cover-management description
Rotational strip cropping	A rotation type cover-management description that involves periods of dense vegetation that are sequenced along the overland flow path to create strips of alternating dense vegetation that cause deposition

Row grade	Grade along the furrows separated by ridges, usually expressed as relative row grade, which is the ratio of grade along the furrows to steepness of the overland flow path
Runoff	RUSLE2 computes runoff using NRCS curve number method and the 10 yr-24 hour precipitation, used to compute contouring effect, contouring failure (critical slope length), and deposition by porous barriers, flow interceptors, and concave overland flow path profiles
Sediment basin	Small impoundment typical of those used on cropland and construction sites, discharge is usually through a perforated riser that completely drains basin in about 24 hours
Sediment characteristics	Deposition is computed as a function of sediment characteristics, which are particle class diameter and density and the distribution of sediment among particle classes
Sediment particle classes	RUSLE2 uses sediment particle classes of primary clay, silt, and sand and small and large aggregate classes, diameter of aggregate classes and the distribution of sediment among particle classes at point of detachment is function of soil texture, RUSLE2 computes how deposition changes the distribution of sediment particle classes
Sediment load	Mass of sediment transported by runoff per unit hillslope width
Sediment transport capacity	Runoff's capacity for transporting sediment, depends on runoff rate, overland flow path steepness, and hydraulic roughness; deposition occurs when sediment load is greater than transport capacity
Sediment yield	Sediment load at the end of the flow path represented in a RUSLE2 computation, flow path ends at overland flow path unless hydraulic elements (channel or impoundment) are present, sediment yield for site only if RUSLE2 flow path ends at site boundary
Segments	The overland flow path divided into segments based on topography, soil, and cover-management to represent spatial variation
Senescence	Decrease in vegetation canopy cove; senescence adds biomass to surface (flat) residue unless RUSLE2 is instructed that a decrease in canopy cover, such as leaves drooping, does not add to surface residue
Shear stress	Total runoff shear stress is divided into two parts of that acting on the soil (grain resistance) and that acting on surface residue, surface roughness, live vegetation, and standing residue (form resistance); shear stress acting on the soil is used to compute sediment transport capacity, total shear stress is used to compute contouring failure; also as function of runoff rate and steepness of overland flow path
Short term roughness	Roughness created by a soil disturbing operation, decays over time as a function of precipitation amount and interrill erosion
Slope length exponent	Exponent in equation used to compute rill-interrill erosion as a function of distance along overland flow path, function of rill to interrill erosion ratio.
Soil biomass subfactor	See cover-management subfactors
Soil consolidation	Represents how wetting/drying and other processes cause soil

effect	erodibility to decrease over time following a mechanical soil disturbance, increase in soil bulk density (mechanical compaction) not the major cause; affects runoff, accumulation of biomass in upper 2 inch (50 mm) soil layer, and soil biomass effectiveness
Soil consolidation subfactor	See cover-management subfactors
Soil description	Describes inherent soil properties affect erosion, runoff, and sediment characteristics at point of detachment, named and saved in RUSLE2 database
Soil disturbance width	Portion of the soil surface disturbed, weighted effects of disturbance computed as a function of erosion on disturbed and undisturbed area to determine an effective time since last disturbance, effective surface roughness, and effective ground cover
Soil disturbing operation	Operation description that contains disturb soil process
Soil erodibility	RUSLE2 considers two soil erodibility effects, one based on inherent soil properties and one based on cover-management, inherent soil erodibility effect represented by K factor value empirically determined from erosion on unit plot, part related to cover-management is represented in cover-management subfactors
Soil erodibility nomograph	Mathematical procedure used to compute a K factor value, i.e., inherent soil erodibility
Soil loss	Proper definition is the sediment yield from a uniform overland flow path divided by the overland flow path length, loosely used as the net removal of sediment from an overland flow path segment
Soil loss from eroding portion	Net removal of sediment from the eroding portion of the overland flow path
Soil loss tolerance (T)	Erosion control criteria, objective is that “soil loss” be less than soil loss tolerance T value, special considerations much be given to non-uniform overland flow paths to avoid significantly flawed conservation and erosion control plans
Soil mechanical disturbance	Mechanical soil disturbance resets soil consolidation effects, disturb soil process must be included in an operation description to create surface roughness and ridges and to place biomass into the soil
Soil saved	Portion of deposited sediment that is credit as soil saved, computed erosion is reduced by soil saved to determine a conservation planning soil loss value, credit depends on location of deposition along overland flow path
Soil structure	Refers to the arrangement of soil particles in soil mass, used to compute soil erodibility (K) factor values
Soil texture	Refers to the distribution of primary particles of sand, silt, and clay in soil mass subject to erosion
Standing residue	Created when live vegetation is killed, decomposes at a reduced rate, falls over at a rate proportional to decomposition of surface residue
Strip/barrier	Support practice, describes porous barriers, named and stored in the

description	RUSLE2 database
Subfactor method	See cover-management subfactors
Subsurface drainage description	Support practice that lowers water table to reduce soil water content, runoff, and reduces erosion; RUSLE2 uses difference between hydrologic soil groups for drained and undrained conditions to compute erosion as affected by subsurface drainage
Support practices	Erosion control practice used in addition to cultural erosion control practice, hence a support practice; includes contouring, filter and buffer strips, rotational strip cropping, silt (fabric) fences, stiff grass hedges, diversions/terraces, gravel dams, and sediment basins
Surface (flat) residue	Material in direct contact with the soil surface, main source is plant litter, crop residue, and applied mulch (external residue).
Surface roughness	Random roughness, combination of soil peaks and depressions that pond runoff, created by a soil disturbing operation, decays as a function of precipitation amount and interrill erosion
Surface roughness index	A measure of surface roughness, standard deviation of surface elevations measured on a 1 inch (25 mm) grid about mean elevation, effect of ridges and land steepness removed from measurements
Surface roughness subfactor	See cover-management subfactors
Temperature	Input as average monthly temperature, disaggregated into daily values, used to compute biomass decomposition and temporal soil erodibility
Template	Determines the computer screen configuration of RUSLE2 and inputs and outputs, determines the complexity of field situations that can be described with RUSLE2
Terraces	Flow interceptors (channels) on a sufficiently flat grade to cause significant deposition
Three layer profile schematic	Some RUSLE2 templates include a overland flow path schematic having individual layers to represent cover-management, soil, and topography, used to graphically divide the overland flow path into segments to represent complex conditions
Tillage intensity	Degree that existing soil surface roughness affects roughness left by a soil disturbing operation
Tillage type	Identifies where a soil disturbing operation initially places buried residue in soil, also refers to how operation redistributes buried residue and dead roots
Time to soil consolidation	Time required for 95 percent of the soil consolidation effect to be regained following a soil disturbing operation
Topography	Refers to steepness along the overland flow path and the length of the overland flow path
Uniform slope	Refers to an overland flow path where soil, steepness, and cover-management along the overland flow path do not vary along flow path
Unit rainfall	Energy content of rainfall per unit of rainfall, function of rainfall

energy	intensity
Unit plot	Base condition used to determine soil erodibility; reference for effects of overland flow path steepness and length; cover-management, and support practices; continuous tilled fallow (no vegetation; tilled up and downhill, maintained in seedbed conditions; topographic, cover-management, support practice factor values equal 1 for unit plot condition
USLE slope length and steepness	USLE slope length is distance to a concentrated flow (e.g., terrace or natural waterway) or to the location where deposition occurs. USLE soil loss is sediment yield from this length divided by length (mass/area), USLE steepness is steepness of the slope length, uniform steepness often assumed
Validation	Process of ensuring that RUSLE2 serves its intended purpose as a guide to conservation and erosion control planning.
Vegetation description	Information used by RUSLE2 to represent the effect of vegetation on erosion, includes temporal values in growth chart, retardance, and biomass-yield information, named and stored in RUSLE2 database
Verification	Process of ensuring RUSLE2 correctly solves the mathematical procedures in RUSLE2
Worksheet description	A form in RUSLE2 program, used to compare conservation and erosion control practices for a given site, form used to compare profile descriptions, named and saved in the RUSLE2 database

ABOUT RUSLE2

1. Introduction

The Revised Universal Soil Loss Equation, Version 2 (RUSLE2) is a computer program that estimates rill and interrill erosion by solving a set of mathematical equations (Toy et al., 2002)). RUSLE2 makes estimates based on site specific conditions, which allows erosion control practices to be tailored to each specific site. The RUSLE2 user describes the site by making selections from the RUSLE2 database. RUSLE2 uses this information to compute its erosion estimates. The purpose of RUSLE2 is to serve as a guide to conservation and erosion control planning. RUSLE2 is land use independent and applies to all conditions where rill and interrill erosion occurs when mineral soil is exposed to the erosive forces of impacting raindrops and water drops falling from vegetation and runoff produced by Hortonian overland flow. RUSLE2 computes erosion and deposition along a single overland flow path. RUSLE2 also computes deposition in channels and small impoundments that end overland flow paths.

RUSLE2 has three major components. One component is the science component that includes the mathematical equations that RUSLE2 uses to compute erosion and deposition. Inputs to the equations are user selected to represent the four major factors that affect erosion at a specific site. Those factors are climate (determined by location), inherent soil properties including soil erodibility, topography, and land use.

The second major RUSLE2 component is the RUSLE2 database. The RUSLE2 user makes selections from the database to describe site-specific conditions. The database contains information that describes climate(weather), soils, cover-management systems, vegetations, residues, operations, porous strips and barriers, flow interceptors including diversion and terrace channels and small impoundments, surface drainage systems, irrigation, overland flow paths, worksheets, and plan view (collections of overland flow paths). A single overland flow is the basic RUSLE2 computational unit. Erosion for multiple erosion control alternatives for a single overland flow path or multiple overland flow paths can be compared in a worksheet. A plan view is used to compute erosion on overland flow areas in spatially complex areas.

The third major RUSLE2 component is the computer program. The program includes a powerful computational engine that organizes and solves the mathematical equations, database maintenance tools, and an interface (computer screen) that accepts user inputs and displays computed values.

The USDA-Agricultural Research Service had overall lead responsibility for developing RUSLE2 and lead responsibility for developing the science (i.e., mathematical equations used in RUSLE2). The University of Tennessee had lead responsibility for developing the RUSLE2 computer program including its interface and computational engine. The USDA-Natural Resources Conservation Service had lead responsibility for developing the RUSLE2 database for cropland. Other organizations developed database information, user guides, and instructional material for RUSLE2. For example, the University of Denver developed database information and other materials for application of RUSLE2 to construction sites, reclaimed mined land, landfills, and other highly disturbed lands.

This document describes the RUSLE2 science, which is primarily embodied in the mathematical equations used in RUSLE2 to compute erosion and deposition estimates.

1.2. Major requirements

The RUSLE2 erosion prediction technology was to meet several requirements, many of which affected RUSLE2's science and the equations. These requirements included:

1.2.1. Purpose of RUSLE2 is to serve as a guide to conservation and erosion control planning at the local field office level.

1.2.2. Be easy to use.

1.2.3. Be robust.

1.2.4. Input values be physically meaningful to typical RUSLE2 users and directly measurable where possible.

1.2.5. Not require resources beyond those available at the filed office level, especially for the USDA-Natural Resources Conservation Service that was the primary target RUSLE2 user.

1.2.6. Produce useful information for conservation and erosion control planning.

1.2.7. Lead to desired conservation and erosion control planning decisions as expected based on available erosion research data, accepted erosion science, field experience, and professional judgment.

1.2.8. Apply to Hortonian overland flow where rill and interrill erosion is caused by mineral being exposed to the erosive forces of impacting raindrops and waterdrops falling from vegetation and surface runoff.

1.2.9. Be land use independent by using relationships based on the fundamental variables that affect erosion.

1.2.10. Produce accurate erosion estimates comparable to measured research values and estimated by the Universal Soil Loss Equation (USLE).

1.2.11. Be an evolution of the USLE and RUSLE1.

1.2.12. Thoroughly and carefully review and evaluate to ensure that RUSLE2 performs acceptably. Provide recommendations on how to best apply RUSLE2.

1.3. Major guiding principles used to develop RUSLE2 science

The following principles were established to guide the development of the RUSLE2 science according to the requirements listed in **Section 1.2**.

1.3.1. The USLE is valid and accepted in term of its conceptual basis, equation structure, empirical derivation, and computed values for conventionally tilled cropland.

1.3.2. The USLE is valid for conservation and erosion control planning.

1.3.3. RUSLE2 development will start from the USLE structure and extend that structure and empirical derivation.

1.3.4. RUSLE2 will represent main effects that can be considered in the conservation and erosion control planning. These main effects are those established by empirical data and fundamental erosion science.

1.3.5. Erosion data available for empirically deriving RUSLE2 equations are very limited. The data set is small in relation to the many variables and their many complex interactions that affect erosion. The dataset is not a statistically robust data set because of non-uniform coverage of important variables. The data have much unexplained variability that can not be resolved.

1.3.6. Equations will be chosen that best represent main effects rather than using regression procedures to fit equations to data to provide the best overall statistical fit. Equations will be chosen based on main effects conclusively established by empirical data, by fundamental erosion science, by practical experience, professional judgment, and overall good judgment (common sense).

1.3.7. First empirically establish mathematical relationships using experimental data and **then use process-based equations** based on fundamental erosion science to extend the RUSLE2 beyond the available research data.

1.3.8. Consistent with the USLE unit plot concept, start from a mean, typical, or accepted value and use normalized variables to compute values that deviate about the value for a base condition to capture main effects. Equations and limits will be selected to produce a robust erosion prediction technology.

1.3.9. Minimize use of zones and classes to avoid step changes (discontinuities) between zones and classes.

1.3.10. Achieve land-use independence by having a single set of equations that vary as a continuous function of the major variables that affect erosion across all land uses.

1.3.11. Make judgments in the context of reasonableness and appropriateness for conservation and erosion planning and implementation. Do the results make good overall sense? If one had perfect knowledge, what would be the decision? RUSLE2 is a tool for conservation and erosion control planning, not a scientific product designed to produce new scientific knowledge and understanding.

2. BASIC MATHEMATICAL STRUCTURE

RUSLE2 computes values for the three fundamental erosion processes of detachment (sediment production), transport, and deposition.[1] The empirical equation form of the USLE is used to compute detachment while process-based equations are used to compute sediment transport and deposition. These equations, which are written for a point in time and a location on an overland flow path, are integrated in both time and distance to produce average annual and spatial estimates for segments along the overland flow path and for the entire overland flow path.

2.1. Detachment (Sediment Production) Equation

The USLE in its original form is:

$$A = RKLSCP \qquad [2.1]$$

where: A = average annual erosion rate (mass/area) for the slope length λ, R = erosivity factor, K = soil erodibility factor, L = slope length factor, S = slope steepness factor, C = cover-management factor, and P = support practice factor. The USLE, equation 2.1, has two parts, the part that computes unit plot erosion and the part that adjusts unit plot erosion to represent actual field conditions. The part that computes unit plot erosion is:

$$A_u = RK \qquad [2.2]$$

where: A_u = average annual erosion for the unit plot.[2] The terms LSCP are normalized with respect to the unit plot and, therefore, have a value of 1 for unit plot conditions.[3] In effect, the USLE computes erosion for unit plot conditions with the product RK and then uses the terms LSCP to adjust the unit plot erosion to account for differences between unit plot conditions and actual field conditions.

Equation 2.2 is a temporal integration of the basic USLE equation that computes unit plot erosion for individual storms as:

$$a_{us} = (EI_{so})K \qquad [2.3]$$

where: a_{us} = the unit plot erosion from the storm that has the erosivity EI_{30}, E = total storm energy, and I_{30} = average intensity over the continuous 30 minutes with the most rainfall in the storm. The linear relationship between unit plot erosion and storm

---

[1] Refer to the RUSLE2 User's reference Guide for detailed explanations of RUSLE2 terms.
[2] The unit plot is 72.6 ft (22.1 m) long on a 9 percent slope, maintained in continuous fallow, tilled to a seedbed condition up and down hill periodically to control weeds and break crusts that form on the soil surface.
[3] The terms A_u, R, and K have dimensions and units. The terms LSCP are ratios of erosion from a given field condition to erosion for the unit plot condition, and these terms are, therefore, dimensionless and have no units.

erosivity EI_{30} means that the erosivity factor R can be computed for a locations as:

$$R = \left[\sum_{i=1}^{m} \sum_{j=1}^{n_j} \left(EI_{30} \right)_j \right] / m \qquad [2.4]$$

where: EI_{30} = storm erosivity for storm events greater than 0.5 inches (12 mm), n_j = the number of storms in the *jth* year, m = number of years in the record being used to compute erosivity.[4]

The linear relationship between erosion on the unit plot and erosivity mathematically means that average daily erosion can be computed as:[5]

$$a_{ui} = r_i K \qquad [2.5]$$

where: a_{ui} = average daily erosion from the unit plot and r_i = the average daily erosivity on the *ith* day.

Although the terms LSCP vary with time as field conditions change, the cover-management factor C is the only one of these terms that is mathematically integrated with time in the USLE. An average annual representative value is selected for the other terms. The mathematical equation used in the USLE to compute erosion for a crop stage period is:

$$a_k = KLS\,\mathrm{Pr}_k\, c_k \qquad [2.6]$$

where: a, r, and c = the erosion, erosivity, and cover-management (soil loss ratio) factors, respectively, for the *kth* crop stage.[6] The erosivity for the *kth* crop stage is given by:

$$r_k = f_k R \qquad [2.7]$$

where: f_k = the portion of the average annual erosivity that occurs during the *kth* crop stage.[7] Therefore, the average annual cover management C factor in the USLE is computed as:

$$C = \left(\sum_{k=1}^{n} f_k c_k \right) / m \qquad [2.8]$$

where: n = the number of crop stages over the period of m years involved in the

---

[4] See RUSLE2 User's Reference Guide for a detailed description of the computation of RUSLE2 erosivity values.
[5] Daily erosion computed by RUSLE2 is a long-term average erosion for that day.
[6] A crop stage period is a time interval over which a constant soil loss ratio can be assumed. The soil loss ratio is the ratio of erosion with a given cover-management condition to the unit plot erosion for the same period, with all other conditions being the same between the two cover-management conditions.
[7] Erosivity varies during the year. The empirical curve that describes this temporal distribution is referred to as the EI distribution.

computational duration, such as years in a crop rotation or years after disturbance of a construction site, used to compute erosion.

The mathematics of the USLE equation structure, therefore, allows RUSLE2 to compute an average daily erosion on the *ith* day as:

$$a_i = r_i k_i l_i Sc_i p_{ri} p_{ci} p_{di} \qquad [2.9]$$

where: p_r = a ponding subfactor, p_c = a contouring subfactor, and pd = a subsurface drainage subfactor.[8] The average daily erosion computed by equation 2.9 is the average erosion (mass/area) for the slope length λ. All terms in equation 2.9 use average daily values except for the slope steepness factor that is assumed to be constant in RUSLE2 for all conditions except for variations in slope steepness.[9]

2.1.1. Equation for rill and interrill detachment combined

Equation 2.9 is converted to an equation that computes rill and interrill erosion combined at a point so that RUSLE2 can be applied to non-uniform overland flow paths where soil, steepness, and cover-management vary along the overland flow path. This equation is (Foster and Wischmeier, 197?):

$$D_{ti} = (m+1) r_i k_i (x/\lambda_u)^m Sc_i p_{ri} p_{ci} p_{di} \qquad [2.10]$$

where: D_t = average daily net detachment by both rill and interrill erosion (mass/area) on the *ith* day at a point at the distance x from the origin of the overland flow path, λ_u = the unit plot length (72.6 ft, 22.1 m), and m = slope length exponent. The value for each term, except erosivity r, is the value for the term at the location x on the overland flow path.

2.1.2. Equation for interrill erosion

Interrill erosion is assumed to occur even when RUSLE2 computes deposition (see **Sections 2.3.1, 2.3.6, and 2.3.8**). The RUSLE2 equation for interrill erosion is:

$$D_i = 0.5 rkS_i cp_c \qquad [2.11]$$

where: D_i = daily interrill erosion (mass/area), and S_i = the slope steepness factor for interrill erosion. Equation 2.11 for interrill erosion is similar to equation 2.10 for rill and interrill erosion combined except that equation 2.11 has no distance (x) term, has a slope

---

[8] RUSLE2 describes the effect of other support practices besides contouring on erosion. Those effects are described using process-based equations that compute deposition rather than a P factor value as in the USLE.

[9] Lower case symbols are used in equation 2.9 to distinguish between the daily factor values used in RUSLE2 and the average annual factor values used in the USLE. An upper case symbol is used for the slope steepness factor because a constant value is used in RUSLE2 that is equivalent to the USLE slope steepness factor value.

steepness factor specifically for interrill erosion, and has a 0.5 factor. The reason for not having a distance term is that detachment on interrill areas is caused by impacting raindrops and waterdrops falling from vegetation. Detachment on interrill areas is assumed to occur uniformly along the overland flow path provided soil, steepness, or cover-management does not change along the overland flow path (Foster and Meyer, 1975; Foster et al., 1977a; Toy et al., 2002). The reason for a slope steepness factor specific for interrill erosion is that the detachment forces produced by impacting waterdrops differ from the detachment forces produced by flow in rill areas. The interrill erosion slope steepness factor in equation 2.11 was empirically derived from experimental data (Lattanzi et al., 1974; Foster, 1982; McGregor et al., 1990). The slope steepness factor in the equation 2.10 represents the effect of slope steepness on rill and interrill erosion combined. The 0.5 factor results from the assumption that interrill erosion and rill erosion are equal for unit plot conditions (Foster and Meyer, 1975; Foster et al., 1977b; McCool et al., 1989).

2.1.3. Ratio of rill to interrill erosion

The slope length exponent m in equation 2.10 is a function of the ratio of rill to interrill erosion. RUSLE2 computes the slope length exponent m as (Foster et al., 1977b; McCool et al., 1989):

$$m = \beta/(1+\beta) \qquad [2.12]$$

where: β = ratio of rill to interrill erosion. The typical slope length exponent in the USLE is 0.5, which is the value computed by equation 2.12 when rill and interrill erosion are equal. The slope length exponent m computed by equation 2.12 varies about 0.5 as the ratio of rill erosion to interrill erosion varies about 1. The base condition for rill erosion equaling interrill erosion is for unit plot conditions.

The ratio of rill to interrill erosion is computed from:[10]

$$\beta = \left(\frac{K_r}{K_i}\right)\left(\frac{c_{pr}}{c_{pi}}\right)\left(\frac{\exp(-b_r f_{ge})}{\exp(-0.025 f_{ge})}\right)\left(\frac{s/0.896}{3s^{0.8}+0.56}\right) \qquad [2.13]$$

[10] Equations 2.12 and 2.13 illustrate an important design principle in RUSLE2. The terms that represent interrill erosion in equation 2.13 differ from those in equation 2.11 used to compute absolute interrill erosion, which seems inconsistent. The design philosophy in RUSLE2 is that RUSLE2 starts from accepted empirical values, which is 0.5 for the slope length exponent. Empirical values are used to the extent that they can be determined from experimental data, especially to represent main effects. The best possible empirical value is determined from the experimental data, and then the accepted empirical value is adjusted using process-based equations. The adjustment is up or down about the accepted empirical value, which is almost always a ratio in RUSLE2 because the LSCP variables are non-dimensional ratios. This approach of adjusting up or down about an accepted empirical ratio value rather than computing absolute values gives RUSLE2 increased robustness and avoids RUSLE2 giving seriously erroneous values when it is extrapolated. The ratio of rill to interrill ratio can be computed more accurately than can an absolute value for interrill erosion. The advantage of equation 2.11 is that it computes values that are close to erosion values computed by the USLE, which is a more conservative and robust approach than computing an absolute value of interrill erosion using variables from equation 2.13.

The ratio K_r/K_i = the rill to interrill inherent soil erodibility ratio (see **Section 4.2**), which is computed as a function of soil texture to reflect how some soils are inherently more susceptible to rill erosion than to interrill erosion than are other soils. The term c_{pr}/c_{pi} = the rill to interrill prior land use soil erodibility (see **Section 6.2.2**) reflects how soil consolidation and soil biomass affect rill erosion differently from how it affects interrill erosion. The ratio $\exp(-b_r f_{ge})/\exp(-0.025 f_{ge})$ reflects how ground cover affects rill erosion more than it affects interrill erosion, where b_r and 0.025 = coefficients that express the relative effectiveness of ground cover for reducing rill erosion and interrill erosion, respectively (see **Section 6.2**), and f_{ge} = an effective ground cover expressed as a percent (see **Section 6.2.2**). The term $[(s/0.0896)/(3s^{0.8}+0.56)]$ where s = sine of the slope angle reflects how slope steepness affects rill erosion differently than it does interrill erosion (Foster, 1982). This term assumes that rill erosion varies linearly with steepness is in the middle of a range from about 0.7 to 1.4 for experimental data (Govers, 1991). Equations 2.12 and 2.13 assume that rill erosion varies with a slope length exponent of 1 (McCool et al., 1989), which is consistent with the maximum slope length exponent of observed in the experimental plot data used to derive the USLE [AH537 (Wischmeier and Smith, 1978)] and variation of erosion with discharge on steep slopes (Meyer et al., 1972) but is less than a value of 0.75 reported in other field research (Glover, 1991; McCool et al., 1989).

The slope length exponent base value is 0.5. Equations 2.12 and 2.13 increase or decrease this value as rill erosion increases or decreases relative to interrill erosion. The terms in equation 2.13 represent the main variables that affect rill erosion relative to interrill erosion.

2.2. Spatial and Temporal Integration

RUSLE2 requires both a spatial and temporal integration. The spatial integration is by solving the governing equations along the overland flow path each day. Temporal integration is by summing daily values to obtain totals for the computational duration. The average annual erosion is the sum of the daily values divided by the number of years (duration) in the computation.

If RUSLE2 were applied to only spatially uniform overland flow paths, equation 2.9 could be analytically solved for each day and the values summed to compute total erosion for a **rotation duration**. However, the solution is complex when soil, steepness, and cover-management vary along the overland flow path (i.e., spatially non-uniform overland flow paths), especially when deposition occurs.[11] RUSLE2 performs a spatial integration each day to compute daily spatially-distributed erosion, deposition, and sediment load values along the overland flow path. The spatial integration process in RUSLE2 is referred to as **sediment routing**, a common term used in hydraulic analyses.

---

[11] RUSLE2 is much more powerful than the USLE because the USLE can not be applied to spatially non-uniform conditions that cause deposition (Foster and Wischmeier, 197?).

2.3. Sediment Routing (Spatial Integration)

2.3.1. Continuity equation

The RUSLE2 governing equation that is spatially integrated is the steady state continuity (conservation of mass equation) given by (Foster, 1982):

$$dg/dx = D_i + D_{rorp} \qquad [2.14]$$

where: g = sediment load (mass) per unit width per unit time, x = distance along the overland flow path from its origin, D_i = interrill erosion rate (mass per unit area per unit time), and D_{rorp} = either rill erosion rate (D_r) (mass per unit area per unit time) or deposition (D_p) (mass per unit area per unit time) by runoff in rill areas.

Equation 2.14 is solved numerically because it can not be analytically solved except for the special case of a uniform overland flow path where neither soil, steepness, nor cover-management vary along the overland flow path. RUSLE2 applies in the general case where any or all of these variables change along the overland flow path. The numerical solution requires that the overland flow path be divided into segments as illustrated in Figure 2.1 where the soil, steepness, and cover-management conditions are uniform over each segment. The numerical form of equation 2.14 for this computation is:

$$g_i = D_{i(i)}(x_i - x_{i-1}) + \int_{x_{i-1}}^{x_i} D_{rorp(i)}\,dx + g_{i-1} \qquad [2.15]$$

where: the *ith* subscript refers to the current segment where equation 2.15 is solved to compute a value for the sediment load g_i leaving the segment. The lower and upper ends of the segment are delineated by x_i and x_{i-1}, respectively, and the segment length is the difference $x_i - x_{i-1}$. Equation 2.12 is applied sequentially along the overland flow path

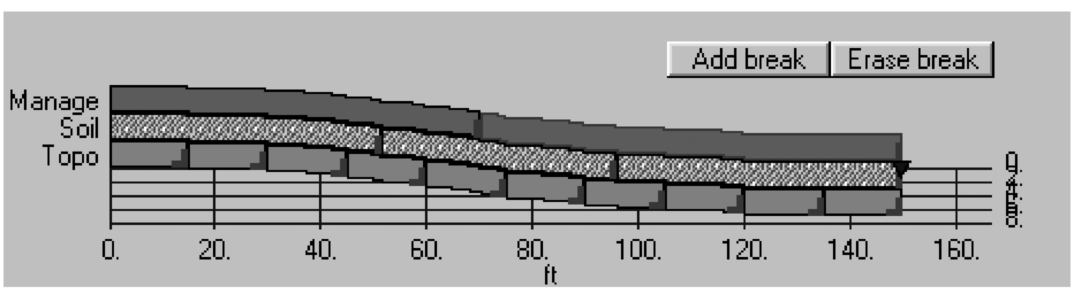


Figure 2.1. Schematic of the three layers that represent an overland flow path (a RUSLE2 hillslope(overland flow path) profile).

starting at x = 0, which is the origin of the overland flow path where the incoming sediment load g_{i-1} to the first segment is zero because no runoff enters the upper end of the overland flow path. The sediment load, g_{i-1}, entering the *ith* segment is known from the computation for the upslope *(i-1)th* segment. If rill erosion occurs, interrill and rill erosion combined are computed with equation 2.10 rather computing interrill erosion and rill erosion separately as implied in equation 2.15. Equation 2.10 is solved analytically over the segment because soil, steepness, and cover-management are assumed to be uniform over the segment. If deposition occurs, interrill erosion D_i is computed with equation 2.11 and the integral for D_p (i.e., deposition) is solved numerically (see **Section 2.3.6**).

An important RUSLE2 assumption is step changes in input variables and certain computed variables where segments adjoin. Each soil, steepness, and cover-management variable is constant over a segment, but these variables make step changes at the common point between two segments. For example, the steepness values for two segments are not averaged to obtain a single steepness value at the intersection of two segments. Consequently, computed detachment and deposition values are discontinuous (i.e., step change) across segment intersections where soil, steepness, or cover-management change between segments. However, runoff rate and sediment load are continuous at common points between segments. These step changes must be considered when selecting segments to representing variables that vary continuously along the overland flow path, such as a concave overland flow path (profile) where steepness continuously decreases from its upper end to lower end. RUSLE2 could have been constructed to accommodate both step and continuous changes with distance, but the benefits of being able to represent both continuous and step changes were judged insufficient to merit the increased complexity in the equations, input, and programming. RUSLE2 represents step changes, such as those associated with buffer strips and intersection of land slopes on construction sites, because step changes seem to occur more frequently than continuous changes in variables along an overland flow path.

2.3.2. Transport capacity-detachment limiting concept

RUSLE2 uses the transport capacity-detachment limiting concept to compute rill detachment or deposition (Foster et al., 1981). The assumption is that rill erosion occurs where runoff transport capacity exceeds sediment load. Rill erosion is assumed not to be affected by the degree that sediment load fills runoff's sediment transport capacity, except where rill erosion would overfill transport capacity if rill erosion were to occur at its capacity rate. In this situation, rill erosion occurs at the rate that just fills transport capacity.[12]

A very important RUSLE2 assumption is that detachment and deposition by flow in rill areas at a point on an overland flow path can not occur simultaneously. Another important assumption is that both rill and interrill erosion are non-selective (Foster et al., 1985). When rill and interrill detachment occur, the detached sediment contains all of the sediment classes having a distribution and size based solely on soil texture (see **Section**

[12] The concept of the interaction between rill erosion, sediment load, and transport capacity is valid, especially in ideal conditions and has advantages for RUSLE2 (Foster and Meyer, 1975; Foster, 1982). However, rill erosion in most field conditions is highly variable along rills where very intense local erosion occurs (e.g., at headcuts) and intervening areas of very low rill erosion. Because the hydraulic equations used in RUSLE2 do not represent this high degree of spatial non-uniformity, RUSLE2 can not adequately capture this important interaction.

4.7). That is, neither rill nor interrill detachment processes can "reach into the soil" and selectively remove sediment from particular sediment classes and not remove sediment from other particle classes. The basis of this assumption is that most soils are cohesive. Detachment is a process that separates soil particles from the soil mass by breaking cohesive bonds within the soil. This separation process produces sediment in all sediment classes because not all bonds in the soil are uniformly broken, much like striking a piece of concrete with a hammer produces a mixture of particles.[13]

Another important RUSLE2 assumption is that interrill erosion occurs simultaneously with deposition in rill areas. When flow causes rill erosion, small incised channels are eroded. When deposition by runoff in rill areas occurs, the deposition is spread across the slope so that deposition covers the entire local area unless ridges are present (Toy et al., 2002). Therefore, a case can be made that no interrill erosion occurs on depositional areas, especially where deposition rate are high and flow is deep to protect the underlying soil surface from raindrop impact. However, even in these cases, deposition and water depths are quite spatially non-uniform, resulting in very local areas that are not protected by deposited sediment or deep water. Also, many soil disturbing operations, such as tillage, leave surface roughness and ridges where soil protrudes above the flow and is directly exposed to interrill erosion. The RUSLE2 assumption is that interrill erosion occurs simultaneously with deposition by flow occurs, which has the important benefit of allowing RUSLE2 to compute local deposition in soil surface roughness, furrows between ridges, and similar local roughness features.[14]

2.3.3. Basic deposition equation

RUSLE2 computes deposition when sediment load exceeds transport capacity using (Foster et al., 1981; Foster, 1982):

$$D_p = (a_d V_f / q)(T_c - g) \qquad [2.16]$$

where: α_d = a deposition coefficient to be determined by calibration, V_f = fall velocity of the sediment in still water, q = overland flow (runoff) rate (volume/width·time) where flow depth is assumed to be uniform across the slope, T_c = transport capacity (mass/width·time). Equation 2.16 is solved for each sediment class (see **Section 4.7**). The distribution of the total transport capacity among the sediment classes is assumed to

---

[13] Soils can contain gravel that runoff does not transport. Conceptually, those particles are not assumed in RUSLE2 to be a part of the cohesive soil mass. The reason that gravel particles are not transported is that the runoff does not have sufficient transport capacity to move these particles. The effect of gravel and rock fragments on erosion is taken into account in RUSLE2 (see **Section 4.6**).

[14] Equation 2.11, which computes interrill erosion, actually computes sediment load delivered to rill flow rather than detachment on interrill areas. An improved approach is to use separate equations to compute detachment, deposition, and sediment transport on interrill areas, but that approach was judged to be too complex for RUSLE2. The RUSLE2 limitation regarding interrill erosion is that RUSLE2 does not compute sufficient enrichment of fines in the sediment although interrill erosion is appropriately computed. However, this limitation can be overcome by using the procedure described by Foster (1982) that can be used to compute distribution of sediment by sediment class delivered from interrill areas as a function of soil surface roughness.

equal the distribution of the total sediment load among the classes. Equation 2.16 gives RUSLE2 its capability for computing deposition's selectivity where coarse, dense sediment is deposited more readily than fine, less dense sediment. The orders of magnitude variation in sediment fall velocity among the sediment classes is the major factor in computing selective deposition.

2.3.4. Sediment transport capacity equation

The RUSLE2 equation for sediment transport capacity of runoff in the rill areas is (Foster and Meyer, 1972; Foster and Meyer, 1975; Nearing et al., 1989, Finkner et al., 1980):

$$T_c = K_T \zeta q s \qquad [2.17]$$

where: the coefficient K_T reflects the transportability of the sediment and the coefficient ζ reflects the degree that increased hydraulic resistance (roughness) reduces sediment transport capacity. RUSLE2 assumes that all sediment regardless of its composition is equally transportable, and therefore, a single value for sediment transportability is used in RUSLE2 (see **Section 2.3.4**). This assumption is questionable because the transportability of coarse sediment is much less than for fine sediment. Sediment transport capacity equations are available that could be used to vary sediment transportability as a function of sediment characteristics, but these equations were judged not to be sufficiently robust for RUSLE2 (Foster and Meyer, 1972; Alonso et al., 1981). Also, slight spatial variations in overland flow hydraulics that can not be described in RUSLE2 dramatically affect runoff's sediment transport capacity. Using a complex sediment transport equations did not seem warranted when RUSLE2 does not capture important details in describing flow hydraulics. Furthermore, the effect of sediment transportability is partially captured by the RUSLE2 soil erodibility factor (see **Section 4.1**).[15]

A value for the transportability coefficient K_T was obtained by fitting RUSLE2 to experimental data where deposition occurred on a concave profile for an overland flow path (Foster et al., 1980). Sediment transport capacity equals sediment load at the location where deposition begins. Values for K_T were adjusted until computed sediment transport capacity matched the measured sediment load at the location where deposition began in the field study. The K_T value was validated by computing deposition on the same slope used to determine a K_T value and by computing deposition for other laboratory and field experimental data (Foster et al., 1980; Neibling and Foster, 1982; Lu et al., 1988) and by computing deposition for a wide range of field conditions and inspecting those results for reasonableness and consistency with field observations (see the **RUSLE2 User's Reference Guide**).[16]

---

[15] RUSLE2 is a hybrid empirical/process-based model. Many of the variables and equations used in RUSLE2 are not nice and crisp where elemental properties and processes are described. For example, the RUSLE2 soil erodibility factor represents both detachability and transportability. RUSLE2 has been validated to ensure that it acceptably computes erosion over the vast majority of situations where RUSLE2 is applied. See the RUSLE2 User's Reference Guide for a discussion of RUSLE2's validation.

[16] The RUSLE2 calibrated value for K_T is 250,000. This value is based on the following set of units. T_c:

The coefficient ζ represents the effect of hydraulic resistance on runoff's sediment transport capacity. This coefficient, which is the ratio of transport capacity with a hydraulic rough surface to transport capacity for a hydraulic smooth surface, varies from essentially 0 for a very hydraulic rough surface to 1 for a hydraulically smooth surface. Hydraulic resistance (roughness) is provided by soil surface roughness, ground cover (material in direct contact with the soil surface), and vegetation retardance. Flow over a soil surface applies a total shear stress. Part of the shear stress is applied to form roughness (soil surface roughness, ground cover, and vegetation retardance) and the other part is applied to grain roughness (the individual soil particles and aggregates at the soil-flow interface). The shear stress exerted on grain roughness is assumed to be responsible for sediment transport (Foster et al., 1981; Foster, 1982). The grain roughness shear stress decreases as form roughness increases, and consequently values for ζ decrease as form roughness increase (see **Section 3.4.1**). RUSLE2 computes a change in ζ, and thus sediment transport capacity, as cover-management conditions change.

2.3.5. Runoff

RUSLE2 uses flow rate values for runoff to compute sediment transport capacity (see **Section 2.3.4**), contouring effectiveness (see **Section 7.1**), and contouring failure (see **Section 3.4.3**). Discharge rate at a location along an overland flow path is computed from:

$$q = q_{i-1} + \sigma_i (x - x_{i-1}) \qquad [2.18]$$

where: q = discharge rate (volume/width·time) at the location x between the segment ends x_{i-1} and x_i, q_{i-1} = discharge rate at x_{i-1}, and σ_i = excess rainfall rate (rainfall rate - infiltration rate) on the *ith* segment. Excess rainfall rate is computed using the NRCS runoff curve number method that computes runoff depth (see **Section 3.3.1.1**). RUSLE2 assumes that excess rainfall rate equals runoff depth and the difference between the two is accounted for in calibration coefficients such as the K_T value for sediment transport capacity in equation 2.17. The important principle is that RUSLE2 is capturing much of a main effect of runoff greatly affecting certain processes and variables. RUSLE2 computes excess rainfall rate as a function of hydrologic soil group, surface roughness, ground cover, soil biomass, and soil consolidation to represent the effect of cover-management on runoff. Consequently, RUSLE2 computes how cover-management conditions affect runoff.

In most cases, runoff rate q increases within each segment, where the rate of increase depends on infiltration within the segment. RUSLE2 computes a decreasing runoff rate within a segment if infiltration rate in the segment is sufficiently high (see **Sections 2.3.8.3.3 and 3.3.1.1**).

2.3.6. Numerical solution of deposition equation

---

lbs_m/(sec·ft width), q: ft3/(sec·ft width), s: dimensionless

The deposition equation, equation 2.16 combined with the continuity equation, equation 2.14, must be integrated to compute deposition over a segment of an overland flow path. RUSLE2 solves these equations numerically because an analytical solution was found. Equations 2.15 and 2.16 along with an equation for transport capacity were written in discrete form for each sediment class as:

$$\frac{D_1 + D_2}{2} = \frac{a_d V_f}{[(q_1 + q_2)/2]}\left(\frac{T_1 + T_2}{2} - \frac{g_1 + g_2}{2}\right) \quad [2.19]$$

$$g_2 = g_1 + D_i \Delta x + \left(\frac{D_1 + D_2}{2}\right)\Delta x \quad [2.20]$$

and

$$T = (g / g_t) T_t \quad [2.21]$$

where: D_i = interrill erosion, D = deposition rate of the *kth* sediment class, a_d = a deposition coefficient, V_f = fall velocity for the *kth* sediment class, q = flow rate per unit width, T = transport capacity for the *kth* sediment class, T_t = the total sediment transport capacity for all sediment classes, g = sediment load for the *kth* sediment class, g_t = total sediment load, and Δx = the length of the distance step used in the numerical integration. The subscript 1 refers to the upper end of the distance step and the subscript 2 refers to the lower end of the distance step.

These equations are combined and solved for the deposition rate D_2, which is the only unknown, at the lower end of the distance step. The solution is by trial and error because a value for sediment transport capacity for a sediment class is not known until a value for the total sediment load is computed, which can not be computed until an estimate of sediment load has been computed for each sediment class. The trial and error solution starts with the sediment load distribution computed in the previous distance step. This distribution is updated with each trial and error iteration until the total sediment load becomes stable.

An alternative approach and perhaps simpler approach is to numerically solve equations 2.15 as:

$$g_2 = D_i \Delta x + \left(\frac{D_1 + D_2}{2}\right)\Delta x + g_1 \quad [2.22]$$

Substitution for D_2 using equation 2.14 in equation 2.22 gives:

$$g_2 = D_i \Delta x + \left(\frac{D_1 + (aV_f / q_2)(T_2 - g_2)}{2}\right)\Delta x + g_1 \quad [2.23]$$

Equation 2.23 is solved for the sediment load g_2, which is the only unknown in equation

2.23, at the end of the distance step. A trial and error solution is also required for this procedure as well because of transport capacity of a single sediment class as computed in equation 2.21depends on the total sediment load.

Regardless of the numerical procedure, a deposition rate of each sediment class must be determined at the upper end of the *ith* segment to start the step by step solution of the equations. The deposition rate at the end of the *(i-1)th* segment can not be used because deposition values are not continuous at common points between segments. Deposition rate change stepwise at these points. Discharge rate and sediment load are continuous at these points. The deposition rate at the upper end of the *ith* segment is computed from:

$$D_1 = (a_d V_f / q_{i-1})(T_{i-1} - g_{i-1}) \qquad [2.24]$$

where equation 2.24 is solved for each sediment class and the sediment transport capacity for each class is given by equation 2.21. The sediment load g_{i-1} is the sediment load at the end of the upslope *(i-1)th* segment, which is the same as the sediment load at the upper end of the *ith* segment.

A value for the deposition coefficient a_d determined by calibration until the distribution among the sediment classes computed for deposition matched observed distributions (Foster et al., 1980).[17] This calibration coefficient is partly needed to adjust for runoff depth rather than excess rainfall rate being used to compute runoff rate.

The numerical procedure that divides a segment, which by definition is uniform in soil, steepness, and cover-management, into sub-segments of Δx length must be such that the detachment and erosion computations are not affected by arbitrary division of a uniform segment into sub-segments as illustrated in Figure 2.2. Also, the computations for a segment must not be affected by downslope conditions, including overland flow path length beyond the segment. The RUSLE2 procedure avoids these problems by assuming that the entire overland flow path is divided into a particular number of segments. The number of sub-segments used in RUSLE2 for an overland flow path length is 200. The sub-segments are only used in the segments having deposition. Thus, the density of sub-segments within a particular segment is the same for all segments. The number of sub-segments within a segment x_{i-1} to x_i is:

$$n_i = [(x_i - x_{i-1}) / \lambda_o] n_o \qquad [2.25]$$

where: n_i = an integer number of sub-segments within the *ith* segment, λ_o = the overland flow path length, and n_o = 200, the number of sub-segments for the entire overland flow path length. The length of the sub-segment Δx used in the numerical solution of the deposition equations is:

$$\Delta x = (x_i - x_{i-1}) / n_i \qquad [2.26]$$

---

[17] The calibrated value for the deposition coefficient was 3 when the units were: V_f: ft/sec, q: ft^3/(ft width·sec), T_c: lbs_m/(ft width·sec), and g: lbs_m/(ft width·sec)

These equations ensure that the end sub-segments within a particular segment begin and end on the segment ends.

A sensitivity analysis was conducted to determine how the sediment delivery ratio (sediment yield/sediment production) for an overland flow path like the ones in Figure 2.2 varied as a function of n_o, the number of sub-segment for the entire overland flow path length. The variation in sediment delivery ratio was about 5 percent as the number of sub-segments for the overland flow path length varied from 100 to 10,000. The value of 200 was chosen, which to give acceptable accuracy while minimizing computer run time.

2.3.7. Concept of a representative storm

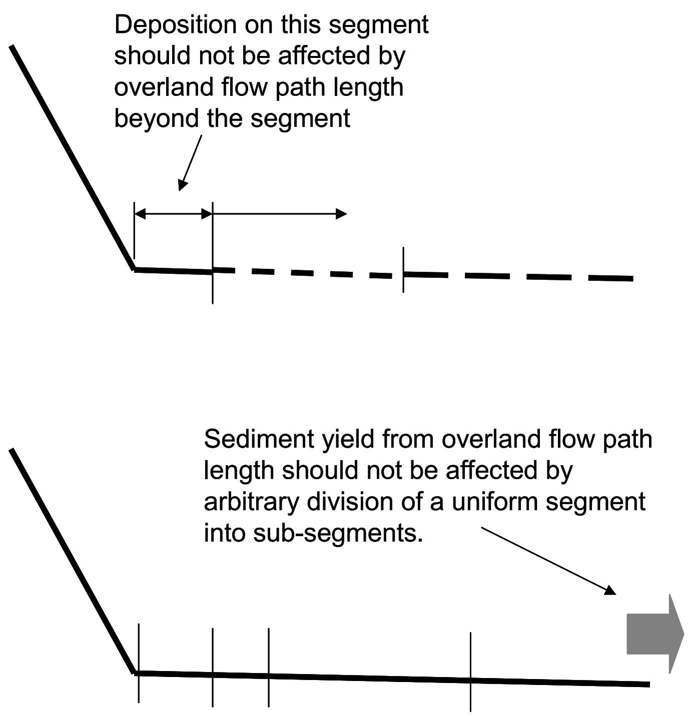


Figure 2.2. Situations where overland flow path lengths and segment divisions should have not effect on computed deposition.

Runoff is a key variable used by RUSLE2 to compute erosion reduction by support practices including contouring, porous barriers, and flow interceptors and deposition on concave overland flow path profiles. RUSLE2, as a guide to conservation planning, should compute variation in the relative effectiveness of support practices by location. The intent is to capture the fact that support practices like contouring are less effective in the southern US than in the northern US because of differences in storm severity (Foster et al., 1997).

RUSLE2 uses the 10 year-24 hour P_{10y24h} precipitation amount as an index of storm severity that varies by location to compute erosion reduction by support practices.[18] A more erosive storm than an average annual storm is used because support practice effectiveness and its loss, especially for contouring, depend on large storm severity (Foster et al., 1997).

The effect of support practices and concave overland flow path profile shape on erosion

[18] The 10 year-24 hour precipitation used in RUSLE2 is a replacement for the 10 year EI procedure used in RUSLE1.

and deposition is more a function of runoff than the combination of raindrop impact and runoff. RUSLE2 uses a representative storm in process-based equations to compute these effects. The daily erosion and deposition values computed using this representative storm are scaled to match the daily detachment values computed with equation 2.10 (**see Section 2.1**). The same storm is used in the process-based equations for each day, but the computed daily runoff values vary as cover-management conditions change. The intent is not to compute actual runoff on each day but to compute values that show the how relative effectiveness of support practice and concave overland flow profiles changes daily for the index storm. The index storm captures main differences between locations. Rather than using a single P factor value like the USLE and RUSLE1, RUSLE2 computes comparable P-factor type effects for each day.

In addition to runoff computed from the P10y24h storm, RUSLE2 also uses an erosivity value for this index storm. The storm erosivity r_{10y24h} associated with the 10 year-24 precipitation amount P_{10y24h} is computed from:

$$r_{10y24h} = 2\alpha_{mx} P_{10y24h} \quad [2.27]$$

where: α_{mx} = the maximum monthly erosivity density at the location. Monthly erosivity density is the ratio of average monthly erosivity to average monthly precipitation amount (see **Section 3.2.1.4.1**).

2.3.8. Solving the sediment routing equations segment by segment

The sediment routing equations are solved using the value for the 10 year-24 hour precipitation amount P_{10y24h} used as a representative storm. Although the same storm is used each day, computed sediment load changes daily as cover-management conditions change. Daily sediment load values computed using the representative storm are scaled to compute daily sediment load values appropriate for the daily erosivity values (see **Section 2.3.9**).

2.3.8.1. Inconsistency between slope effect in detachment and sediment transport capacity equations

Assumptions were made regarding inconsistencies between the empirical detachment equation, equation 2.10, and the process-based sediment transport capacity equation, equation 2.17. The inconsistencies result primarily from differences in the slope effect in the equations. The slope effect in equation 2.10 for detachment is a two piece linear equation (see **Section 5.6**), whereas the slope effect in equation 2.17 for sediment transport capacity is a single linear term. Equations 2.10 and 2.17 are sufficiently close at the unit plot 9 percent steepness that the slope effect in equation 2.10 can exceed the slope effect in equation 2.17 at both flat and steep steepness depending on the values for the other terms in the equations. Although equation 2.10 is generally assumed to represent detachment limiting in RUSLE2, this empirical equation reflects a mixture of both detachment and transport capacity limiting at low slope steepness. When inconsistencies occur between the empirical USLE formulation and the process-based equations, RUSLE2 gives the empirical USLE erosion estimate for uniform overland flow paths.[19] The inconsistencies between these two slope effects could not be reconciled for non-uniform overland flow paths at low steepness, but RUSLE2 was very carefully evaluated to ensure that the inconsistencies have little effect in conservation planning.

2.3.8.2. Boundary values

Boundary values must be determined for each segment to solve the sediment routing equations. The equations are solved sequentially starting with the first segment at the origin of the overland flow path and then moving downslope segment by segment. The computed values for runoff and sediment load at the end of the last segment become boundary values for the next segment. The major boundary values for the first segment at x = 0 is that no inflow of either runoff or sediment occurs (i.e., $q_0 = 0$ and $g_0 = 0$).

2.3.8.3. Special boundary conditions cases

Five special cases were used to organize the sediment routing computations and to set boundary values.

2.3.8.3.1. Case 1: First segment

The first segment is a special case because of the no inflow boundary condition and because the sediment load leaving this segment must equal the sediment load computed by the USLE (i.e., equation 2.10), (assuming the RUSLE2 factor values are used in the USLE. The first segment directly matches the uniform slope assumptions for the USLE). Many conservation and erosion control planning applications of RUSLE2 involve a uniform overland flow path. In these situations, RUSLE2 uses a single uniform overland flow path segment and only the equations for the Case 1: First Segment special case in its sediment routing computations.

An important logic check for the first segment is whether local deposition is computed within the segment. RUSLE2 computes no deposition if the rate of increase in sediment transport capacity with distance dT_c/dx is greater than the interrill erosion rate D_i within the first segment. The rate of increase in transport capacity in the first segment is computed as:

$$(dT_c / dx)_1 = K_{T(1)}\zeta_1\sigma_1 s_1 \qquad [2.28]$$

where: the subscript 1 refers to the first segment on the overland flow path and where excess rainfall rate σ is computed using the 10 year-24 hour representative storm P_{10y24h} and the interrill erosion rate D_i is computed with the representative storm erosivity r_{10y24h} (see **Section 3.2.4**).

---

[19] These inconsistencies could be eliminated by developing RUSLE2 so that it uses all process-based equations rather than combining the empirical USLE equation with process-based equations. However, the RUSLE2 hybrid approach combines the best of the empirical USLE approach with the best of the process-based approach.

2.3.8.3.1.1. $dT_c/dx > D_i$ - No local deposition

RUSLE2 computes no local deposition in the first segment when the rate of increase in sediment transport capacity with distance dT_c/dx is greater than the interrill erosion rate D_i, because runoff's sediment transport capacity is sufficient to transport the sediment load produced by interrill erosion. The interrill erosion rate $D_{i10y24h}$ in the first segment is computed using the erosivity r_{10y24y} value computed with equation 2.27 for the P_{10y24h} representative storm. In that case, the sediment load leaving the segment is given by equation 2.15 after rill and interrill erosion are combined into a single term as:[20]

$$g_{t(1)} = r_{10y24h} k_1 S_1 c_1 p_{c(1)} x_1^{m_i+1} / \lambda_u^{m_i} \qquad [2.29]$$

where: g_t = the total sediment load for all sediment classes.[21] The sediment load $g_{1,k}$ of each sediment class at the end of the first segment is given by:

$$g_{1,k} = \psi_k g_{t(1)} \qquad [2.30]$$

where: ψ_k = the fraction of the sediment in the *kth* sediment class. This special case is detachment limiting. Therefore, the resulting sediment load at the end of segment 1 for Case 1 when $dT_c/dx > D_i$ equals the distribution of sediment among the sediment classes at the point of detachment because detachment is assumed to be non-selective (see **Section 4.7.5**). The enrichment ratio is one (1) for this case because no deposition is computed (see **Section 4.7.6**).

2.3.8.3.1.2. $dT_c/dx < D_i$ - Local deposition occurs

When the interrill erosion rate D_i within the first segment exceeds the rate of increase in transport capacity with distance dT_c/dx, local deposition is computed. Even though local deposition is computed, equation 2.29 is used to compute sediment load at the end of the first segment to ensure that RUSLE2 gives the USLE result for the first segment. However, local deposition enriches the sediment in fines. RUSLE2 computes quasi-deposition and -sediment load values to estimate the distribution of the sediment among the sediment classes for the sediment leaving the first segment. The sole purpose of this computation is to obtain the sediment distribution; this computation does not affect the

---

[20] The units for sediment load depend on the units used for erosivity r, soil erodibility k, distance x, and length λ_u. For example, in the US customary units system for the USLE, the typical units for sediment load g would be $(tons_m/acre \cdot day) \cdot ft$. These set of units are multiplied by $(2000\ lbs_m/ton)/(43560\ ft^2/acre)$ to obtain a consistent set of units of lbs for mass and ft for length. In RUSLE2, erosion values are computed for each day using a daily erosivity value (see **Sections 2.1 and 3.1**), which is the reason for the day unit in sediment load. The sediment amount values have mass units. In the US customary USLE units, lbs-mass and lbs-force are equal. In the SI system, kg is the recommended unit for sediment mass, although the output would likely be displayed in metric tonnes. See AH703 (Renard et al., 1997) for additional discussion of USLE/RUSLE units.

[21] Equation 2.29 is the USLE equation form when the slope length λ is substituted for x_i and the equation is divided by slope length λ to compute average erosion for the slope length.

value computed for sediment load at the end of the first segment, which is computed with equation 2.29.

Equations 2.14, 2.16, 2.17, and 2.18 were solved in closed form to compute the quasi-deposition and -sediment load values in segment 1 (Renard and Foster, 1983). The equation used to compute deposition is:

$$D_{q(1,k)} = [(a_d V_{f(k)} / \sigma_1)/(1 + a_d V_{f(k)} / \sigma_1)]\{[(dT_c / dx)_1 - D_{i(1)}]\psi_k\} \quad [2.31]$$

$$g_{q(1,k)} = \psi_k T_{c(1)} - q_1 D_{q(1,k)} / (a_d V_{f(k)}) \quad [2.32]$$

$$q_1 = \sigma_1 x_1 \quad [2.33]$$

$$T_{cl(1)} = K_{T(1)} \zeta_1 q_1 s_1 \quad [2.34]$$

where: D_q and g_q are the quasi-deposition and -sediment load variables used specifically to compute the distribution of the sediment load among the sediment classes for the first segment when local deposition occurs and T_{cl} = the sediment transport capacity at the lower end of the segment. The subscript k refers to sediment class and the subscript 1 refers to the first segment and the lower end of the first segment. Equations 2.31-2.34 are solved for each sediment class. The fraction of the sediment load in each sediment class for the sediment load at the end of the first segment is computed as:

$$\omega_{1,k} = g_{q(1,k)} / \sum_{k=1}^{5} g_{q(1,k)} \quad [2.35]$$

where: $\omega_{1,k}$ = the portion of the total sediment load leaving the first segment that is composed of sediment in the *kth* sediment class. The sediment load in each sediment class is computed as:

$$g_{1,k} = \omega_{1,k} g_{t(1)} \quad [2.36]$$

The enrichment ratio for the sediment at the end of the first segment is greater than 1 based on the portion of the interrill erosion that RUSLE2 computes as deposited in the first segment. Enrichment ratio is based specific surface area of the sediment (see **Section 4.7.6**).

2.3.8.3.2. Case 2: Detachment over entire segment

Two boundary conditions must be met for detachment to be computed over an entire segment. The incoming sediment load at the upper end of the segment must be less than transport capacity at the upper end of the segment. The mathematical condition for this check is that $g_{i-1} < T_{cu(i)}$ where $T_{cu(i)}$ = transport capacity at the upper end of the *ith* segment. This transport capacity is computed using the discharge rate q_{i-1} and the slope steepness s_i and sediment transport capacity coefficient ζ_i for the ith segment. Therefore, transport capacity at the upper end of the *ith* segment $T_{cu(i)}$ does equal the transport capacity $T_{cl(i-1)}$ at the lower end of the *(i-1)th* segment if steepness and/or cover-management changes between the segments.

The second condition is that the potential sediment load at the end of the sediment computed as the sum of the incoming sediment load plus the sediment produced by interrill erosion within the segment is less than the transport capacity at the lower end of the segment. This potential sediment load is computed as:

$$g_{p(i)} = g_{i-1} + D_{i(i)}(x_i - x_{i-1}) \quad [2.37]$$

where: g_p = potential sediment load. The boundary condition is that this potential sediment load be less than transport capacity at the end of the segment, i.e., $g_{p(i)} < T_{cl(i)}$.

2.3.8.3.2.1. Sediment load when rill erosion occurs at capacity rate:

A subsequent check must also be made to determine if rill erosion can occur at its capacity over the segment. A second potential sediment load is computed as:

$$g_{p(i)} = g_{i-1} + r_{10y24h} k_i S_i c_i p_{c(i)} (x_i^{m_i+1} - x_{i-1}^{m_i+1}) / \lambda_u^{m_i} \quad [2.38]$$

where rill erosion is assumed to occur at its capacity rate. If this potential sediment load is less than sediment transport capacity at the lower end of the segment, rill erosion is assumed to occur at its capacity rate and the sediment load leaving the segment is given by equation 2.38.

The distribution of the sediment load among the sediment classes is computed by:

$$g_{i,k} = g_{i-1,k} + \psi_k (g_{i,k} - g_{i-1,k}) \quad [2.39]$$

which results from detachment being non-selective.[22] That is, the distribution of the sediment added within the sediment load, $g_i - g_{i-1}$, is assumed to be the same as sediment at the point of detachment.

2.3.8.3.2.2. Sediment load when rill erosion at less than capacity rate:

If potential load computed by equation 2.39 exceeds the transport capacity at the end of the segment, rill erosion is limited to the rate that will just fill transport capacity, which means that sediment load at the end of the segment is given by:

$$g_i = T_{Cl(i)} \quad [2.40]$$

---

[22] Sediment characteristics at the point of detachment change as soil texture changes by segment. RUSLE2 starts at the first segment with the five sediment classes for that segment based on soil texture. RUSLE2 adds sediment classes to represent soil texture changes in the segments along the overland flow path.

Even though rill erosion is not computed at its capacity rate, some rill erosion is computed, and, therefore, no local deposition is computed. The distribution of the sediment load at the end of the segment is given by equation 2.39.

2.3.8.3.3. Case 3: Detachment on upper portion of segment, deposition on lower portion of segment

An example where detachment occurs on the upper portion of a segment and deposition occurs on the lower portion of the segment is illustrated in Figure 2.3. Infiltration rate on the *ith* (second) segment is greater than the rainfall rate, which causes runoff rate to decrease within the segment. Sediment load increases within the segment while sediment transport capacity decreases within the *ith* segment. Deposition begins at the point where sediment load equals transport capacity.

Two conditions must be met for this case. The first condition is that the incoming sediment load is greater than sediment transport capacity at the upper end of the segment, i.e, $g_{i-1} > T_{cu(i)}$. The second condition is that the potential sediment load at the lower end of the segment computed with equation 2.37 is greater than the transport capacity at the lower end of the segment.

When this condition is met, deposition begins at the location where the sediment load equals transport capacity. The sediment load where deposition begins is given by:

$$g_b = g_{i-1} + D_{i(i)}(x_b - x_{i-1}) \qquad [2.41]$$

where: g_b = sediment load at the location x_b = where deposition begins. The sediment transport capacity $T_{c(b)}$ where deposition begins is given:

$$T_{c(b)} = K_{T(i)}\zeta_i s_i[q_{i-1} + \sigma_i(x_b - x_{i-1})] \qquad [2.42]$$

where: σ_i = the excess rainfall rate (rainfall rate – infiltration rate).[23] Equations 2.41 and 2.42 are combined and solved to determine a value for the location x_b where deposition begins.

The sediment load by sediment class at the location where deposition begins is given by:

$$g_{b,k} = g_{i-1,k} + \psi_k(g_b - g_{i-1}) \qquad [2.43]$$

[23] Excess rainfall rate is negative for situations where RUSLE2 computes a decreasing runoff rate within the segment.

Deposition is computed on the portion of the segment from x_b to x_i using equations 2.19-2.21. The main boundary values are that deposition rate is zero and sediment load equals sediment transport capacity at $x = x_b$. These equations compute values for total sediment load and sediment load for each sediment class at the lower end of the segment.

2.3.8.3.4. Case 4: Deposition over entire segment

Figure 2.4 illustrates deposition occurring over an entire segment. In this case, the width of the vegetation strip is so narrow that sediment transport capacity does not increase within the strip to where it exceeds sediment load. The first boundary condition for this case is that the incoming sediment load is greater than sediment transport capacity at the upper end of the segment. The second condition is that the interrill erosion rate D_i within the segment is greater than the increase in sediment transport capacity with distance dT_c/dx within the segment. This boundary condition is the same as the incoming sediment load plus sediment production by interrill erosion within the segment being greater than sediment transport capacity at the lower end of the segment.

Equation 2.24 is used to compute the deposition rate at the upper end of the segment, which is a boundary value along with the incoming discharge rate q_{i-1} and sediment load g_{i-1} from the immediate upslope segment. These boundary values are used in equations 2.19-2.21 to compute deposition within the segment and values for total sediment load and sediment load by sediment class at the lower end of the segment.

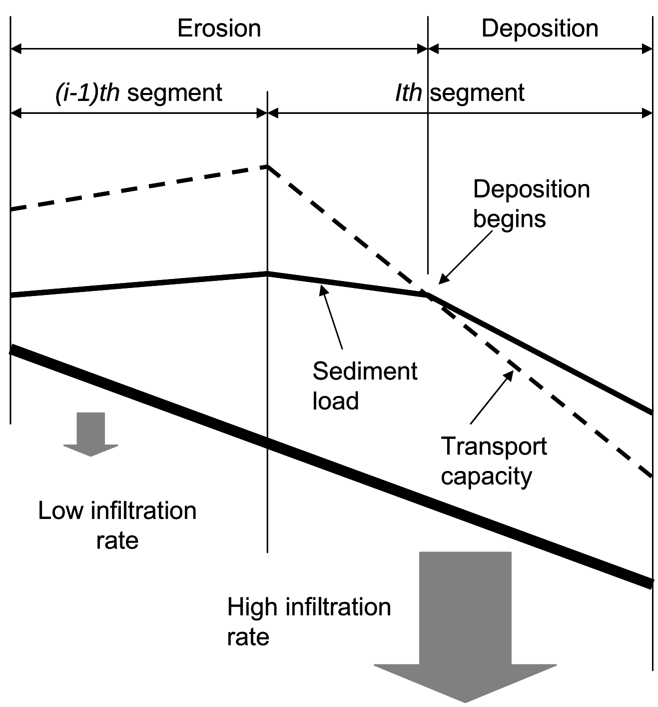


Figure 2.3. Illustration where detachment ends and deposition begins within the ith segment.

2.3.8.3.5. Case 5: Deposition over upper part of segment, detachment over lower part of segment

Figure 2.5 illustrates deposition ending within a segment. Another example of deposition ending within a segment is illustrated in Figure 2.2 provided the segment is sufficiently long.

As discussed in **Section 5.3**, RUSLE2 assumes that segments are discontinuous, even when used to represent a smooth, continuous concave overland flow path profile. The result is that RUSLE2 computes deposition on the upper portion of the segment and detachment on the lower portion of the segment if the segment is sufficiently long. This result is opposite from that for a smooth, continuously decreasing slope steepness where detachment occurs on the upper portion of the segment and deposition occurs on the lower portion of the segment where deposition begins. The error from not properly computing the location of the deposition is minimized by choosing short segment lengths to represent smooth, continuous overland flow path profiles.

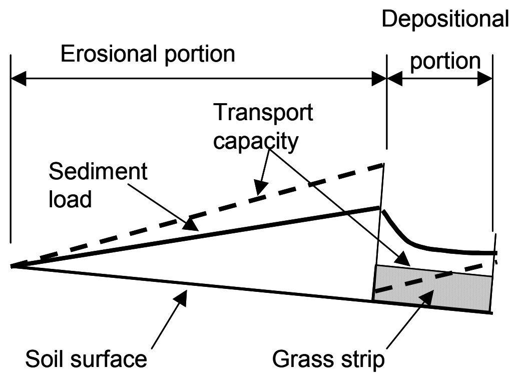


Figure 2.4. Narrow grass where deposition occurs over entire segment

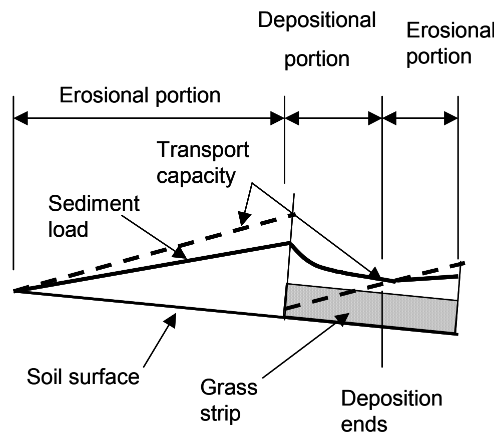


Figure 2.5. Grass strip sufficiently wide that deposition ends within segment and erosion occurs on lower portion of segment

The first boundary condition is that incoming sediment load is greater than the transport capacity at the upper end of the segment. The second boundary condition is that the incoming sediment load plus the sediment produced by interrill erosion within the segment is less than the transport capacity at the lower end of the segment, which is the same as the boundary condition that the rate of increase in transport capacity with distance dT_c/dx is greater than the interrill erosion rate D_i within the segment. These boundary conditions are required but are not sufficient to determine that deposition ends within the segment if the segment length is short. The location x_e where deposition ends within the segments is determined by solving equations 2.19-2.21 and 2.24. Deposition ends at the location where computed deposition rate becomes zero. These equations compute the total sediment load g_e and the sediment load of each sediment class $g_{e,k}$ at the location that deposition ends.

Detachment occurs on the lower portion of the segment. The potential sediment load at the end of the segment is computed from:

$$g_{p(i)} = g_e + r_{10y24h} k_i S_i c_i p_{c(i)} (x_i^{m_i+1} - x_e^{m_i+1}) / \lambda_u^{m_i} \qquad [2.44]$$

This potential sediment load is checked against sediment transport capacity at the lower end of the segment. If the sediment transport capacity at the lower end of the segment exceeds this sediment load then the sediment load leaving the segment is the potential sediment load computed by equation 2.44, i.e, $g_i = g_{p(i)}$. However, if the potential sediment load computed with equation 2.44 exceeds, the transport capacity at the end of the segment, then rill erosion is limited to the rate that will just fill sediment transport capacity. In that case, the sediment load at the end of the segment equals sediment transport capacity at the lower end of the segment, i.e., $g_i = T_{cl(i)}$.

The sediment load for each sediment class at the end of the segment is given by:

$$g_{i,k} = g_{e,k} + \psi_k (g_i - g_e) \qquad [2.45]$$

2.3.9. Scaling values computed with representative storm to create daily values

The daily sediment load values computed using the sediment routing equations and the representative storm P_{10y24h} must be scaled to compute daily sediment load values appropriate for the daily erosivity values. This scaling factor is computed as the ratio of sediment load computed at the end of each segment by the sediment routing equations and the sediment load at the lower end of each segment that would be produced if detachment occurs at detachment capacity by the representative storm. That sediment load g_{detcap} is computed as:

$$g_{\det cap(i)} = r_{10y24h} k_i S_i c_i p_{c(i)} (x_i^{m_i+1} - x_{i-1}^{m_i+1}) / \lambda_u^{m_i} \qquad [2.46]$$

The scaling factor δ_i for each segment is computed as:

$$\delta_i = g_i / g_{\det cap(i)} \qquad [2.47]$$

A sediment load based on detachment capacity comparable to $g_{det(i)}$ is computed using daily values for erosivity and the other factors as:

$$g_{daily \det cap(i)} = r k_i S_i c_i p_{c(i)} (x_i^{m_i+1} - x_{i-1}^{m_i+1}) / \lambda_u^{m_i} \qquad [2.48]$$

where: $g_{dailydetcap}$ = daily sediment load at end of *ith* segment that would be produced if full detachment occurred in each segment, r = the daily erosivity value determined from the disaggregation of the monthly erosivity values (see **Section 3.1**), and all of the other values in equation 2.48 are the same daily values used in the sediment routing equations.

The daily sediment load value is computed as the product of this daily detachment sediment load and the sediment load scaling factor as:

$$g_{daily(i)} = \delta_i g_{daily \det cap(i)} \qquad [2.49]$$

where: $g_{daily(i)}$ = average daily sediment load at the end of the *ith* segment. The average daily net erosion rate $D_{daily(i)}$for the *ith* segment is computed as:

$$D_{daily(i)} = (g_{daily(i)} - g_{daily(i-1)}) / (x_i - x_{i-1}) \qquad [2.50]$$

2.3.10. Computing average annual erosion values for conservation and erosion control planning[24]

RUSLE2 computes average annual values for four variables used in conservation and erosion control planning. These variables are average annual erosion rate for the entire overland flow path (sediment yield), average annual detachment rate for the entire overland flow path, average annual erosion rate for the eroding portion of the overland flow path, and an average annual conservation planning soil loss for the overland flow path that gives partial credit to deposition as soil saved.

2.3.10.1. Average annual erosion rate for entire overland flow path (sediment yield)

The average annual erosion rate for the entire overland flow path is the ratio of the average annual sediment amount leaving the overland flow path divided by the overland flow path length. The sediment load at the end of the last segment on the overland flow path is also known as sediment yield or sediment delivery from the overland flow path.

The average annual sediment load at the end of the overland flow path is given by:

$$G_I = \left(\sum_{n=1}^{N} g_{daily(n,I)}\right) / M \qquad [2.51]$$

where: G_I = the sediment load (i.e., sediment yield, sediment delivery) at the end of the overland flow path, N = the total number of days in the computation period (i.e., N = 365·M), and M = number of years in the computation period. The subscript n refers to each day in the computation period and the subscript I is the index value of the last segment used to describe the overland flow path.

The average annual erosion rate (sediment yield, sediment delivery) for the overland flow path is given by:

$$A_{sedyld} = G_I / \lambda_o \qquad [2.52]$$

where: A_{sedyld} = the average annual erosion rate for the overland flow path length, λ_o.

2.3.10.2. Average annual detachment rate (sediment production) for entire overland flow path

The average annual detachment rate for the entire overland flow path represents a measure of total sediment production on the overland flow path. This variable is a measure of local erosion and sediment that has been moved away from its local point of origin. RUSLE2 computes detachment on each segment in its sediment routing computations and a sediment load value based on detachment. That sediment load is

---

[24] See the RUSLE2 User's Reference Guide for detailed information on these variables and how they are used in conservation and erosion control planning.

given:

$$g_{\det(i)} = g_{\det(i-1)} + D_{i(i)}(x_i - x_{i-1}) + \Delta G_{r(i)} \quad [2.53]$$

where: g_{det} = the sediment load produced by detachment at the lower end of the *ith* segment and ΔG_r = the sediment amount produced by rill erosion within the segment. Interrill erosion D_i is assumed to occur over an entire segment regardless of whether deposition occurs. If deposition does not occur, rill detachment occurs. Rill detachment in each segment is computed as described for each of the special cases in **Section 2.3.8.3**.

These average annual sediment load $g_{det(i)}$ values are scaled using the scaling factor computed with equation 2.47. The average annual sediment load produced by detachment at the end of the overland flow path is given by:

$$G_{\det(I)} = (\sum_{n=1}^{N} g_{\det(I)})/M \quad [2.54]$$

where: $G_{det(I)}$ = the average annual sediment load at the end of the overland flow path. The average annual detachment rate for the entire overland flow path is given by:

$$A_{\det} = G_{\det(I)} / x_I \quad [2.55]$$

where: A_{det} = the average annual detachment rate for the entire overland flow path.

2.3.10.3. Average annual erosion rate for eroding portions of the overland flow path

The average annual sediment load is computed for each segment as:

$$G_i = (\sum_{n=1}^{N} g_{daily(n,i)})/M \quad [2.56]$$

The average annual erosion rate for each segment is given by:

$$D_{avan(i)} = (G_i - G_{i-1})/(x_i - x_{i-1}) \quad [2.57]$$

where: $D_{avan(i)}$ = the average annual erosion rate for the *ith* segment. Positive values for $D_{avan(i)}$ values indicate net erosion and negative values indicate deposition. The eroding portions of the overland flow path are the segments where $D_{avan(i)}$ is positive. The value for average annual erosion rate for the eroding portions of the overland flow path is computed as:

$$A_{erod} = [(G_{l1} - G_{u1}) + (G_{l2} - G_{u2}) + (G_{l3} - G_{u3}) + ...]/[(x_{l1} - x_{u1}) + (x_{l2} - x_{u2}) + (x_{l3} - x_{u3}) + ...] \quad [2.58]$$

where: A_{erod} = average annual erosion rate for the eroding portions of the overland flow path, the subscript l refers to the lower end of an eroding portion of the overland flow path, the subscript u refers to the upper end of an eroding portion of the overland flow path, and the subscript 1, 2, 3, and ... refers to individual eroding portions of an overland flow path.

2.3.10.4. Conservation planning soil loss

The conservation planning soil loss variable gives partial credit for remote deposition as soil saved. The credit that is given to remote deposition as soil saved is computed as (Foster et al., 1997):[25]

$$b_{d(i)} = 1 - (x_{du(i)} / x_I)^{1.5} \qquad [2.59]$$

where: $b_{d(i)}$ = the fraction of the deposition in the *ith* segment that is credited as soil saved (i.e., deposition benefit) and $x_{ud(i)}$ = the location of the upper edge of deposition in the segment in which the deposition occurs. Significantly reduced benefit is computed when the deposition occurs close to the overland path end, which is the location x_I. The credited deposition in a segment is computed as:[26]

$$\hat{D}_{b(i)} = \hat{D}_{a(i)} b_{d(i)} \qquad [2.60]$$

where: $\hat{D}_{b(i)}$ = deposited sediment credited as soil saved and $\hat{D}_{a(i)}$ = the computed deposition before any credit is taken. The conservation planning sediment load along the overland flow path is computed as:

$$g_{cp(i)} = g_{cp(i-1)} + \hat{D}_{b(i)} + \hat{D}_{i(i)} + \hat{D}_{r(i)} \qquad [2.61]$$

where: $\hat{D}_{i(i)}$ = the interrill detachment within the segment and $\hat{D}_{r(i)}$ = the rill detachment within the segment. Interrill erosion D_i is assumed to occur over an entire segment regardless of whether deposition occurs. If deposition does not occur, rill detachment occurs. Rill detachment in each segment is computed as described for each of the special cases in **Section 2.3.8.3**.

---

[25] Remote deposition is the deposition of sediment some distance from the location on the overland flow path that the sediment is detached. Examples of remote deposition are deposition upslope of dense vegetation strips, on the toe of concave overland flow path profiles, and in terrace channels. Local deposition is deposition very near the point of detachment such as deposition in the depressions created by random roughness and in the furrows between ridges on a low grade. Local deposition is given full credit as soil saved, which is implicit in the empirical equation structure for computing detachment. Local deposition associated with random roughness is explicitly computed only for the first segment in an overland flow path description. Deposition computed for segments other than the first segment for overland flow paths involving multiple segments is considered to be remote deposition and is given partial credit as soil saved according to equation 2.59.

[26] These computations are made using the scaled values that match the daily erosivity values.

The average annual conservation planning sediment load at the end of the overland flow path for the computation period is given by:

$$G_{cp} = (\sum_{n=1}^{N} g_{cp(n,I)})/M \qquad [2.62]$$

where: G_{cp} = the average annual sediment load for conservation planning. The conservation planning soil loss is given by:

$$A_{cp} = G_{cp} / \lambda_o$$

where: A_{cp} = the average annual conservation planning soil loss.

2.3.10.5. Comments on conservation and erosion control planning variables

The values for all four of these conservation and erosion control planning are equal for a uniform overland flow path. If a dense vegetation strip is located at the end of the overland flow path, the value for average erosion rate for the entire overland flow path (sediment yield) will be much lower than the other values because of deposition caused by the grass strip and its backwater. The highest value will the average erosion rate for the eroding portion of the overland flow path, which in this example, is the portion of the overland flow path from its origin to the location of the upper edge of the backwater created by the vegetation strip where deposition begins. The value for the average detachment rate for the entire overland flow path will be less than the average erosion rate for the eroding portion of the overland flow path because of the greatly reduced detachment in the backwater area and in the vegetation strip itself. The conservation planning soil loss will be less than the detachment value but greater than the sediment yield value because of the partial credit taken for deposition as soil saved. In this example, the conservation planning soil loss value will be closer to the detachment value than to the sediment yield value because not much credit (benefit) is given to the deposition because it occurs near the end of the overland flow path (see the RUSLE2 User's Reference Guide).

List of symbols

a = daily erosion (soil loss) (mass/area)
a_{us} = unit plot erosion (mass/area) from the storm that has the erosivity EI_{30}
A = average annual erosion (mass/area)
A_{cp} = average annual conservation planning soil loss (mass/area)
A_{det} = average annual detachment rate for the entire overland flow path (mass/time)
A_{erod} = average annual erosion rate for the eroding portions of the overland flow path (mass/area)
A_{sedyld} = the average annual erosion rate for the overland flow path length (mass/area)
A_u = average annual erosion for the unit plot (mass/area)
b_d = fraction of the deposition in a segment credited as soil saved (i.e., deposition benefit)
b_r = b value, coefficient for ground cover effectiveness for rill erosion
c = daily cover-management (soil loss ratio) factor
c_{pr}/c_{pi} = rill to interrill prior land use soil erodibility ratio
C – USLE cover-management factor
D = deposition rate for a sediment class [mass/(area·time)]
D_{avan} = average annual erosion rate (mass/area)
$\hat{D}_a$ = computed deposition before any credit is taken for deposition benefit (mass/area)
D_{avan} = average annual erosion rate (mass/area)
$\hat{D}_b$ = deposited sediment credited as soil saved (mass/area)
$D_{daily(i)}$ = average daily net erosion rate for a segment [(mass/area·day)]
D_i = detachment by interrill erosion (mass/area)
D_i = interrill erosion rate [mass/(unit area·unit time)]
D_p =deposition rate by runoff in rill areas [mass/(unit area·unit time)]
D_q = quasi-deposition rate used to compute distribution among sediment classes for first segment when local deposition occurs [mass/(unit area·unit time)]
D_r = rill erosion rate [mass/(unit area·unit time)]
$\hat{D}_{r(i)}$ = rill detachment within a segment (mass/width)
D_{rorp} = either rill erosion rate (D_r) or deposition (D_p) (mass per unit area per unit time) by runoff in rill areas [mass/(unit area·unit time)]
D_t = detachment by both rill and interrill erosion (mass/area)
$\exp(-b_r f_{ge})/\exp(-0.025 f_{ge})$ = rill erosion surface cover effect to interrill erosion surface cover effect ratio
E = total storm energy (force·length/area)
EI_{30} = storm erosivity [(force·length/area)·(length/time)]
f_{ge} = effective ground cover (percent)
f_k = portion of average annual erosivity that occurs during *kth* crop stage (fraction)
g = sediment load [mass/(unit width· time)]
g = sediment load for a sediment class [mass/(unit width· time)]
g_b = sediment load at the location where deposition begins within segment [mass/(unit width· time)]
g = sediment load for conservation planning (mass/width)
g_{daily} = average daily sediment load [mass/(unit width· time)]
$g_{dailydetcap}$ = daily sediment load that would be produced if detachment occurred at

detachment capacity [mass/(unit width· time)]
g_{det} = sediment load produced by detachment (mass/width)
g_{detcap} = sediment load that would result from detachment at capacity rate [mass/(width· time)]
g_0 = 0, sediment load at x = 0 [mass/(width· time)]
g_p = potential sediment load at end of segment [mass/(width· time)]
g_q = quasi-deposition rate used to compute distribution among sediment classes for first segment when local deposition occurs
g_t = total sediment load for all sediment classes [mass/(unit width· time)]
G_{cp} = average annual sediment load for conservation planning(mass/width)
$G_{det(I)}$ = average annual sediment load produced by detachment at the end of the overland flow path (mass/width)
G_I = sediment load (i.e., sediment yield, sediment delivery) at the end of the overland flow path (mass/width)
I_{30} = average intensity over the continuous 30 minutes with most rainfall in storm (distance/time)
J_m = number of storms in the *mth* year
k = daily soil erodibility factor [(mass/area)/erosivity unit]
K – USLE soil erodibility factor
(K_r/K_i) = rill to interrill soil erodibility ratio
K_T = sediment transportability (dimensions??)
L = slope length factor
L = USLE slope length factor
m = daily slope length exponent
M = number of years
M = number of years in the computation period
n = number of sub-segments within a segment (integer)
n_o = 200, number of sub-segments for the entire overland flow path length, used to solve numerical deposition equation
N = total number of days in the computation period (i.e., N = 365·M)
p_c = daily contouring subfactor
p_d = daily subsurface drainage subfactor
p_r = daily ponding subfactor
P - USLE support practice factor
P_{10y24h} = 10 year-24 precipitation amount (length)
q = overland flow (runoff) rate [volume/(width·time)]
q_0 = 0, discharge rate at x = 0 [mass/(unit width·time)]
r = daily erosivity (erosivity units)
r_{10y24h} = storm erosivity associated with 10 year-24 precipitation amount P_{10y24h} (erosivity units)
R – USLE erosivity factor (erosivity units)
RUSLE – revised universal soil loss equation
$[(s/0.0896)/(3s^{0.8}+0.56)]$ = rill erosion steepness effect to interrill erosion steepness ratio
s = steepness along overland flow path
S - slope steepness factor for rill-interrill erosion, also USLE slope steepness factor
S_i = slope steepness factor for interrill erosion

T = transport capacity for a sediment class [mass/(width·time)]
T_c = sediment transport capacity [mass/(width·time)]
T_{cl} = sediment transport capacity at the lower end of segment [mass/(width·time)]
T_{cu} = sediment transport capacity at the upper end segment
T_t = total sediment transport capacity for all sediment classes [mass/(width·time)]
$T_{c(b)}$ = location where deposition begins within segment [mass/(width·time)]
V_f = sediment fall velocity for a sediment class (length/time)
USLE – universal soil loss equation
x = distance from origin of overland flow path (length)
x_b = location where deposition begins within segment (length)
x_e = location where deposition ends within a segment (length)
x_{ud} = location of upper edge of deposition in a segment in which deposition occurs (length)

α_d = a deposition coefficient
α_{mx} = the maximum monthly erosivity density at the location (erosivity units/length)
δ = scaling factor used to compute daily sediment load
ΔG_r = sediment amount produced by rill erosion within a segment (mass/width)
Δx = length of the distance step used in the numerical integration to compute deposition (length)
β = ratio of rill to interrill erosion for unit plot length
ζ = degree that increased hydraulic resistance (roughness) reduces sediment transport capacity
K = the number of crop stages
λ – USLE slope length (length)
λ_o = overland flow path length (length)
λ_u = length of unit plot (length)
σ = excess rainfall rate (rainfall rate - infiltration rate) (length/time)
ψ_k = fraction (mass) of sediment in a sediment class
$\omega_{1,k}$ = fraction (mass) of total sediment load leaving first segment in a sediment class

indices
b= location where deposition begins within sgment
i = daily
i = segment along overland flow path
j = storm
k = crop stage
k = sediment class
m = year
1 and 2 = subscripts for upper end of distance step and subscript 2 for lower end of distance step in numerical integration of deposition equation

3. Climate (weather), Runoff, and Hydraulics

The major weather variables used by RUSLE2 are monthly erosivity, precipitation, and temperature and the 10 year-24 hour precipitation amount. Erosivity values are an index of erosive rainfall at a location for causing rill and interrill erosion. Erosivity is a major variable in the equations used to compute detachment (e.g., see Section **2.1**). Precipitation and temperature influence the loss of biomass on and in the soil and how that loss varies among locations (e.g., see **Section 10.4.1**). Precipitation and temperature also affect the temporal distribution of soil erodibility and how that distribution varies by location (see **Section 4.5**). The 10 year-24 hour precipitation amount is a representative (index) storm that is used to compute the effect of ponding on erosivity, deposition on concave overland flow path profiles, deposition by dense vegetation strips, and the effectiveness of contouring (e.g., see **Section 7**). These computations are made using runoff and flow hydraulics based equations.

3.1. Disaggregation of monthly values into daily values

RUSLE2 uses daily values for erosivity, precipitation, and temperature to compute daily erosion (see **Section 2.1**). The RUSLE2 disaggregation procedure converts (disaggregates) the input monthly erosivity, precipitation, temperature, and soil erodibility values into daily values.

3.1.1. Basic disaggregation procedure

The same basic disaggregation procedure is used for monthly temperature, soil erodibility, precipitation, and erosivity. The procedure assumes that daily values vary linearly within each month according to a two-piece linear equation. A requirement is that the average of the daily values in a month equals the input monthly value.

The daily value at the beginning of a month is assumed to equal the mean of the monthly values for the current and immediately preceding months and the daily value at the end of the month equals the mean of the monthly values for the current and next months as illustrated in Figure 3.1. That is:

$$Y_b = (M_j + M_{j-1})/2 \qquad [3.1]$$

and

$$Y_e = (M_{j+1} + M_j)/2 \qquad [3.2]$$

where: M = the monthly value, Y_b = the daily value at the beginning of the *jth* month, Y_e = the daily value at the end of the month, and the index j refers to the month.

Figure 3.1 illustrates an example of increasing monthly values. The same equations apply to both increasing and decreasing values. A second set of equations apply for local maximums and local maximums illustrated in Figure 3.2.

3.1.1.1. Increasing or decreasing monthly values

The third major value is the time t_c where the two linear lines in Figure 3.1 equal the monthly value M_j. The value for t_c is determined so that the total area under the two linear lines equals the monthly value M_j. The area under the two lines is given by:

$$M_j = t_c(Y_b + M_j)/2 + (1 - t_c)(M_j + Y_e)/2 \quad [3.3]$$

A value for t_c is determined by rearranging equation 3.3 as:

$$t_c = [M_j - (Y_e + M_j)/2]/[(Y_b + M_j)/2 - (Y_e + M_J)/2] \quad [3.4]$$

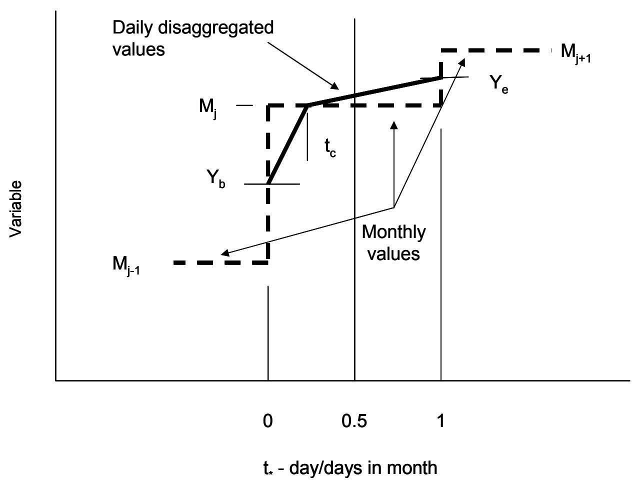


Figure 3.1. Illustration of two linear equations used to disaggregate monthly values into daily values for increasing or decreasing monthly values.

The equation used to compute daily values for times less than t_c is given by:

$$y_k = (k/D_j)[(M_j - Y_b)/t_c] + Y_b \quad [3.5]$$

where: y_k = the daily value, D_j = the number of days in the month, and k = the day of the month. The equation to compute daily values for times greater than t_c is given by:

$$y_k = (1 - k/D_j)[(M_j - Y_e)/(1 - t_c)] + Y_e \quad [3.6]$$

3.1.1.2. Local maxima and minima

Figure 3.2 illustrates a local maxima. The equations apply both to local maximums and minimums. The daily value at the beginning and end of the monthly are computed using equations 3.1 and 3.2. The total area under the two lines must equal the monthly value as:

$$M_j = (Y_b + Y_p)t_p/2 + (Y_p + Y_e)(1 - t_p)/2 \quad [3.7]$$

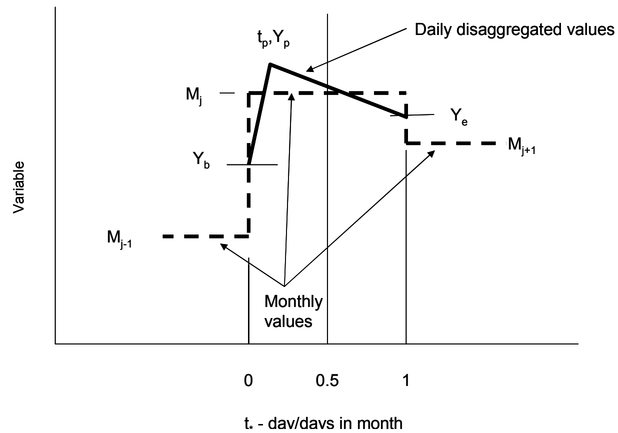


Figure 3.2. Illustration of two linear equations used to disaggregate monthly values for a local maxima or minima.

where: Y_p = the maximum value during the month that occurs at time t_p. Equation 3.7 is rearranged so that a value for the maximum value Y_p can be computed from:

$$Y_p = 2M_j + t_p(Y_e - Y_b) - Y_e \quad [3.8]$$

The equation for the time of the peak t_p is given by:

$$t_p = 1 - (M_j - Y_b)/(2M_j - Y_b - Y_e) \quad [3.9]$$

The equation for daily values for times less than the time of the peak is given by:

$$y_k = (k/D_j)(Y_p - Y_b)/t_p + Y_b \quad [3.10]$$

and the equation for times after the time to peak is given by:

$$y_k = [(Y_p - Y_e)/(1 - t_p)](1 - k/D_j) + Y_e \quad [3.11]$$

3.1.2. Disaggregation procedure for temperature and erodibility

The disaggregation procedure is applied directly as described in **Section 3.1.1** for temperature and soil erodibility. Figure 3.3 illustrates disaggregation of monthly temperature values into daily values for Columbia, MO. Notice that the date of the minimum daily temperature occurs in the third week of January as expected.

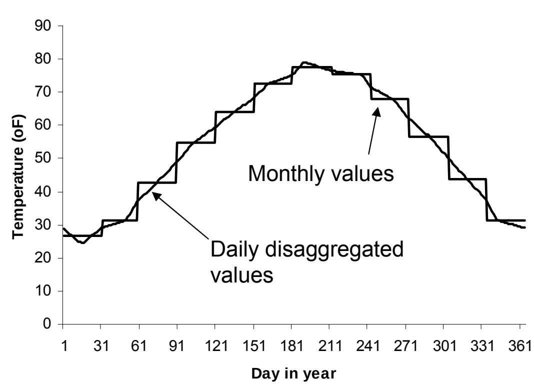


Figure 3.3. Daily temperature values obtained by disaggregating monthly temperature values.

3.1.3. Disaggregation procedure for precipitation and erosivity

When the disaggregation procedure is applied to monthly precipitation or erosivity, the mean monthly value is divided by number of days in the month to obtain a mean daily value. The disaggregation procedure is applied to the mean daily value in each month. Daily precipitation and erosivity values

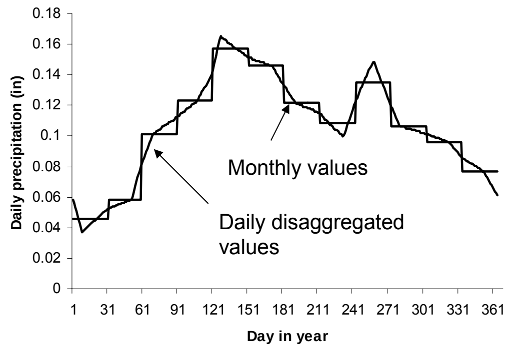


Figure 3.4. Daily precipitation values obtained from disaggregating monthly precipitation values at Columbia, MO.

must be checked for negative values in very low rainfall areas like Yuma, AZ. Daily precipitation and erosivity values are set to zero when negative values are computed. Setting these values to zero results in the sum of the disaggregated daily values being slightly greater than the monthly values in the months when the negative values occur. This adjustment has an insignificant effect on computed erosion values. Figure 3.4 shows daily disaggregated precipitation values for Columbia, MO.

3.2. Climate (weather) variables

The four input weather variables for RUSLE2 are monthly erosivity, precipitation, and temperature and the 10 year-24 hour precipitation amount. Selection of values for these variables is described in the RUSLE2 User's Reference Guide. This section describes underlying concepts, principles, and equations for processing weather data to develop input values consistent with RUSLE2 procedures and RUSLE2's purpose as a guide to conservation and erosion control planning.

3.2.1. Erosivity

RUSLE2 disaggregates average monthly erosivity values to obtain average daily erosivity values (see **Section 3.1**). Although monthly erosivity values can be input into RUSLE2 in three ways, the recommended procedure for the Continental US is to input average monthly values for erosivity density.[27] Erosivity density, which is the ratio of monthly erosivity to monthly precipitation, is multiplied by monthly precipitation to obtain monthly erosivity values. The first step in developing average monthly erosivity density value is to compute erosivity values for individual storms using measured weather data.

3.2.1.1. Storm erosivity

Erosivity, the product of the storm's energy and its maximum 30 minute intensity, for an individual storm is computed as (Wischmeier and Smith,1978):

$$R_s = EI_{30} \qquad [3.12]$$

where: R_s = storm erosivity, E = storm energy, and I_{30} = maximum 30-minute intensity. Maximum 30 minute intensity is the average intensity over the continuous 30 minutes in

[27] RUSLE2 can uses monthly erosivity values (1) computed by multiplying monthly erosivity density and precipitation values (see **Section 3.2.1.4.1**), (2) input directly, and (3) determined from input values for annual erosivity and the biweekly temporal distribution of erosivity.

the storm with the most rainfall. Storm energy is computed using (Renard et al., 1997):

$$E = \sum_{k=1}^{m} e_k \Delta V_k \qquad [3.13]$$

where: E = storm energy, e = unit energy (energy content per unit area per unit rainfall depth) in the *kth* period, and ΔV = the depth of rainfall in the *kth* period, n = index for periods during the rainstorm where rainfall intensity is considered uniform, and m = the number of periods in the rainstorm. Unit energy is computed from (Brown and Foster, 1987; McGergor et al., 1993; Renard et al., 1997):

$$e_k = 0.29[1 - 0.72 \exp(-0.082 i_k)] \qquad [3.14]$$

where: e_k = the unit energy [MJ/(mm·ha)] for the *kth* period and i_k = rainfall intensity (mm/h) for the *kth* period.[28]

Data for storms less than 0.5 inch (12 mm), non-rainfall precipitation events, and extreme storm erosivity events with a return period greater than 50 years are excluded in the computation of storm erosivity in RUSLE2.

3.2.1.2. Determining average annual erosivity values from measured precipitation data

Data from 15-minute precipitation gages that provide rainfall intensity values are required to compute storm erosivity values using equations 3.12-3.14. Modern data from 1960 through 1989 (1960-1999 in several cases) were analyzed to determine rainstorm erosivity and precipitation values at approximately ?? 15-minute precipitation gage locations across the Continental US. Erosivity values computed for the qualifying storms (i.e., rain events where amount was 0.5 inch or greater) were summed over the record length and divided by the years of record to determine an average annual erosivity value for each 15-minute precipitation station.

The plan was to develop an average annual erosivity contour map based on values computed from measured data at as many 15-minute precipitation gage locations as possible. Initial maps had many "bull's eyes" and irregular spatial trends rather than smooth trends required for RUSLE2. Data analysis showed that short and differing record lengths among locations greatly contributed to undesired spatial variability. The analysis also showed that the record length should be at least 18 years for directly computing average annual erosivity from measured 15-minute precipitation gage data. Even then the spatial variability among precipitation gage locations was too great.

3.2.1.3. Need for consistency in conservation and erosion control planning

Consistency in computed erosion estimates (hence, consistency in erosivity values)

---

[28] See Foster et al. (1981) and AH703 (Renard et al., 1997) for a discussion of RUSLE2 units and how to convert between customary US units and SI units.

between locations within geographic regions and between regions is just as important as the absolute erosion estimates computed with RUSLE2. Clients perceive inconsistency and variability in erosion estimates for no apparent reason to be unfair, especially when the results negatively affect them. The probability distribution (return periods) of storms in a measured precipitation record used to compute erosivity values should be the consistent among locations. To illustrate, the average annual erosivity values between Wink, Texas and Pecos, Texas, towns in West Texas, computed from measured 15-minute precipitation data differed by a factor of two for no obvious reason. Inspection of the data showed that a 600-year return period storm caused the much larger average annual erosivity at one location. The benefits or costs incurred by clients impacted by RUSLE2 should not be determined by the “luck of the draw” based on where they happen to be located. Furthermore, extreme events, such as a 100-, 200-, and 600-year storms, in the last 30 years are a very poor indicator of events likely to occur in the next 30 years. An average annual record that excludes extreme events is the best predictor of the immediate future for conservation planning where the objective is to protect the soil as a resource. However, other erosion prediction applications such as protecting highly sensitive water bodies and designing sediment storage in reservoirs may well require a different consideration of extreme events and a different set of input erosivity values than those developed for RUSLE2. Most erosion control practices are not designed or expected to withstand extreme events because in most cases failure does not cause catastrophic damages and the practices can be reinstalled without great costs.

Therefore, all storms with a return greater than 50 years were deleted from the measured data used in the RUSLE2 analysis to develop erosivity values.

3.2.1.4. Erosivity approach to developing erosivity values

3.2.1.4.1. Erosivity density analysis

The RUSLE2 erosivity density approach for determining monthly erosivity values was developed in consideration of RUSLE2’s consistency requirements for conservation planning and to maximize the information that could be extracted from the 15-minute precipitation data. RUSLE2 multiplies input values for average monthly erosivity density by input values for average monthly precipitation to compute monthly erosivity values as:

$$R_m = \alpha_m P_{d(m)} \qquad [3.15]$$

where: R_m = average monthly erosivity, α_m = average monthly erosivity density, $P_{d(m)}$ = average monthly precipitation determined from daily precipitation gage data, and m = an index for the month. Erosivity density refers to the erosivity content per unit precipitation. Erosivity density is computed from measured 15-minute precipitation data as:

$$\alpha = \frac{\sum_{i=1}^{n} I_{30(i)} \left(\sum_{j=1}^{J} e_{j(i)} \Delta V_{j(i)} \right)}{\sum_{i=1}^{n} P_{15(i)}} \qquad [3.16]$$

where: all values were determined from 15-minute precipitation gage data including precipitation amount P_{15}, i = the index for storm in a month, n = total number of storms in a given month for the period of record, j = index for each 15-minute period during a storm, and J = number of 15-minute periods during a storm. Unit energy e_j for each *jth* period is computed from the average intensity for each 15-minute period in the storm (i.e., $i_j = \Delta V_j/15$ minutes). Storm erosivity EI_{30} is computed with equation 3.16 using 15-minute precipitation data were multiplied by a 1.04 factor to account for the fact that intensity values from the 15-minute precipitation data are slightly lower than those computed with breakpoint rainfall (Hollinger et al., 2002). Breakpoint rainfall data where the data are divided into non-uniform periods where constant rainfall intensity can be assumed is the preferred data rather than 15-minute precipitation data for computing storm erosivity.[29]

Approximations can be made in Equation 3.16 to aid the interpretation of erosivity density. Unit energy e does not vary greatly with intensity such that storm energy can be approximated with aP_{15} (Foster et al., 1982). By assuming a representative $\bar{I}_{30}$ for the month, erosivity density is approximated by:

$$\alpha \approx \frac{\bar{I}_{30} a \sum_{i=1}^{n} P_i}{\sum_{i=1}^{n} P_i} \qquad [3.17]$$

where: $\bar{I}_{30}$ = the representative maximum 30-minute intensity for the month. Equation 3.17 in turn reduces to:

$$\alpha \approx a\bar{I}_{30} \qquad [3.18]$$

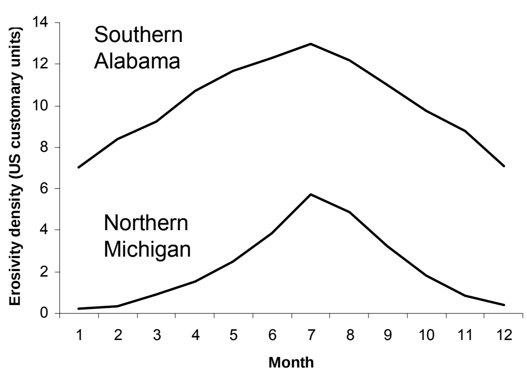


Figure 3.5. Erosivity density values for two locations.

Equation 3.18 shows that erosivity density varies directly with 30-minute rainfall intensity. As Figure 3.5 shows, erosivity density is much higher in Southern Alabama than in Northern Michigan. In both locations, erosivity density is higher in the summer months than in the winter months, which according to equation 3.18, is caused by rainfall intensity varying with season. Rainfall intensity is greater in the summer than in the winter, resulting in erosivity being greater in the summer than in the winter for a given amount of

[29] The storm data including computed storm erosivity values were provided by the Illinois State Water Survey. The analysis of erosivity data was a joint effort between the Illinois State Water Survey, the USDA-ARS and NRCS, and the University of Tennesseee.

rainfall. Also, most of the precipitation in Northern Michigan in the winter is snow and, therefore, is not included in the rainfall erosivity index.[30]

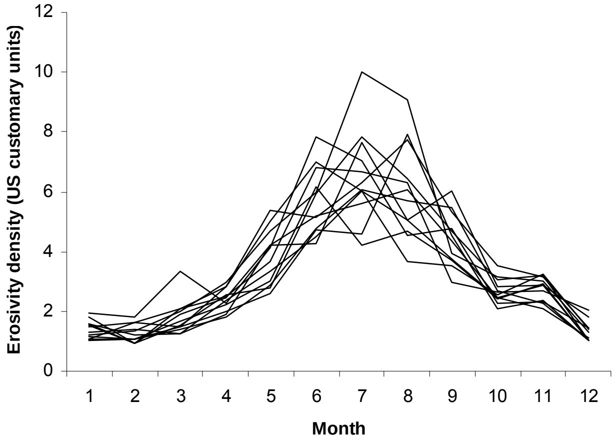


Figure 3.6. Spatial and temporal variability in erosivity density for locations in Southwestern Indiana.

Spatial and temporal variation in the erosivity density values computed from the 15-minute precipitation data was a major problem. Erosivity density values computed directly from the 15-minute precipitation data, as illustrated in Figure 3.6 for 15-minute gage locations in the southwest quadrant of Indiana, do not provide the smooth temporal and spatial trends required for RUSLE2 as a conservation and erosion control planning tool. Spatially averaging the erosivity density values by quadrant in Indiana smoothed the erosivity density values, both temporally and spatially, across Indiana as illustrated in Figure 3.7.

Geographic information systems (GIS) techniques, including kriging were used to spatially average the erosivity density values computed from 15-minute precipitation data measured at the various gage locations. The procedure is similar to a spatial, moving average fitting technique and produced results similar to that illustrated in Figure 3.7.[31] Before kriging was applied, the monthly erosivity density values computed from the measured data in a relatively small region, such as a quadrant of Indiana, were inspected and analyzed for outliers. Monthly erosivity density values that departed from the mean in this local region by more than two times the standard deviation were considered outliers. Rather than excluding the entire dataset for a location (i.e., deleting the location from the entire

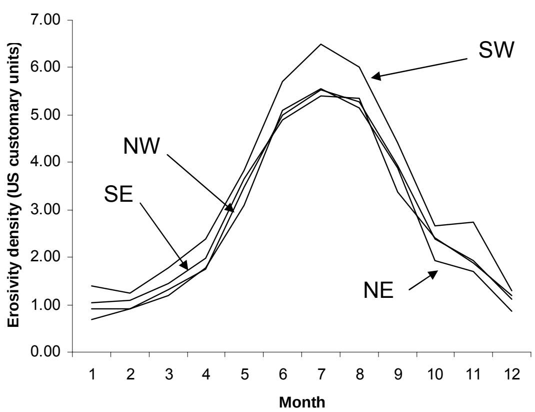


Figure 3.7. Erosivity density values spatially averaged for the four quadrants in Indiana.

[30] The storm precipitation and erosivity values used in this analysis were provided by the Illinois State Water Survey and the USA-Natural Resources Conservation Service Water and Climate Center. These values are computed from measured weather data collected by the National ?? and Atmospheric Administration. See (Hollinger et al., 2002) for additional information.
[31] The GIS and kriging analysis was conducted by the Department of Biosystems Engineering and Environmental Science, University of Tennessee, Knoxville.

data set), the outlier data point was adjusted to be consistent with other monthly erosivity density values at the location. Adjusting individual monthly data points kept the number of locations in the dataset as large as possible. In most cases, the same outliers at a location identified by the statistical test could also be identified by inspection. Outliers were monthly erosivity density value outside the smooth trend obtained by averaging the data points in the local region as was done in Figure 3.7. This process of identifying and adjusting outliers typically involved two or three iterations.

A compromise was made in the number of nearest neighbors used in the kriging (??spelling) analysis. Using the 10 nearest neighbors worked well in the eastern US, but it did not work well along the eastern side of the Cascade Mountains in Washington and Oregon where erosivity density values decrease very rapidly with distance in this area. This rapid decrease necessitated using five rather than 10 nearest neighbors. This problem was also related to a very low density of 15-minute precipitation stations in the region. Using the five nearest neighbors also worked better than 10 nearest neighbors along coastlines and borders between Canada and Mexico where no precipitation data were available.

This procedure produced erosivity density values that varied smoothly over the Continental US, including mountainous regions. The hypothesis that erosivity density was not affected by mountainous terrain was tested in two ways. The first test involved fitting a linear equation to erosivity density values as a function of elevation at the 15-minute precipitation gage locations in a local region. The region had to relatively small, such as a quadrant of Utah, to avoid cross and spurious correlations. For example, the

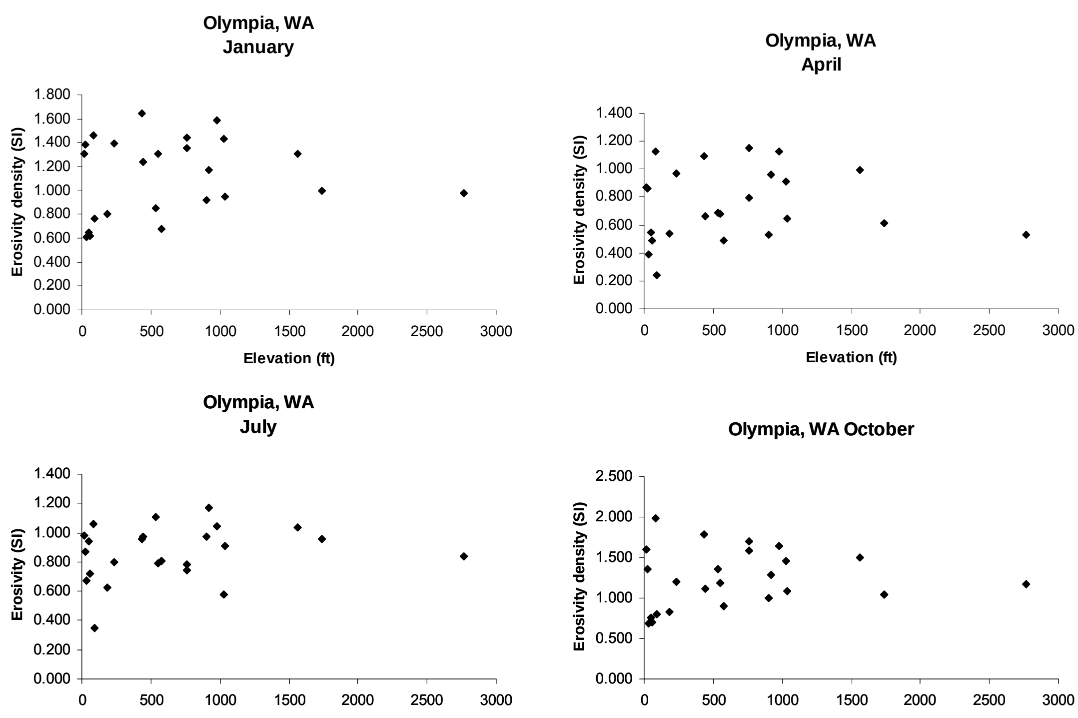


Figure 3.8. Variation of erosivity density with elevation in the Olympia, WA region.

linear equation could not be fitted to erosivity density values for the entire state of Montana. When erosivity density values for all of Montana were included in the analysis, erosivity density values appeared to be a function of elevation, but that correlation was spurious. Elevation decreases from west to east across Montana while erosivity density increases across Montana. The increase in erosivity density across Montana was not caused by elevation but by a west to east broad geographic increase in erosivity density.

Measured precipitation data from the 15-minute precipitation gages were available to compute erosivity density values for elevations up to about 10,000 ft. Statistical analysis were conducted for eleven local regions in mountainous areas throughout the western US and two local regions in the eastern US were conducted to determine if the hypothesis that erosivity density varied with elevation could be rejected. The analysis involved fitting a linear equation to the erosivity density values as a function of elevation. The data for three regions are shown in Figure 3.8-3.10. The results of the analysis was that the hypothesis that erosivity density values are independent of elevation could not be rejected. This test was not especially robust because of data variability. Elevation clearly affects erosivity density in the winter months because an increasing fraction of the precipitation occurs as snow at higher elevations. However, the assumption of no effect of elevation on erosivity density values in the summer months is considered acceptable.

Another test of the hypothesis that erosivity density values are independent of elevation

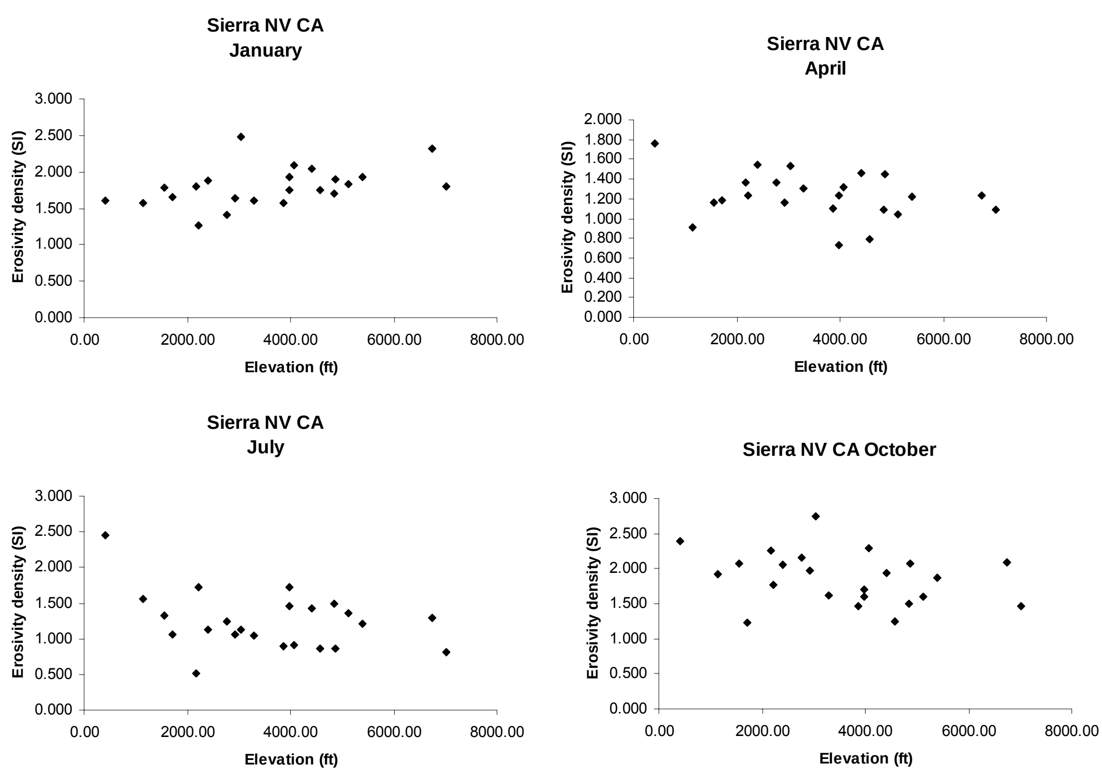


Figure 3.9. Variation of erosivity density with elevation in Sierra NV-CA region.

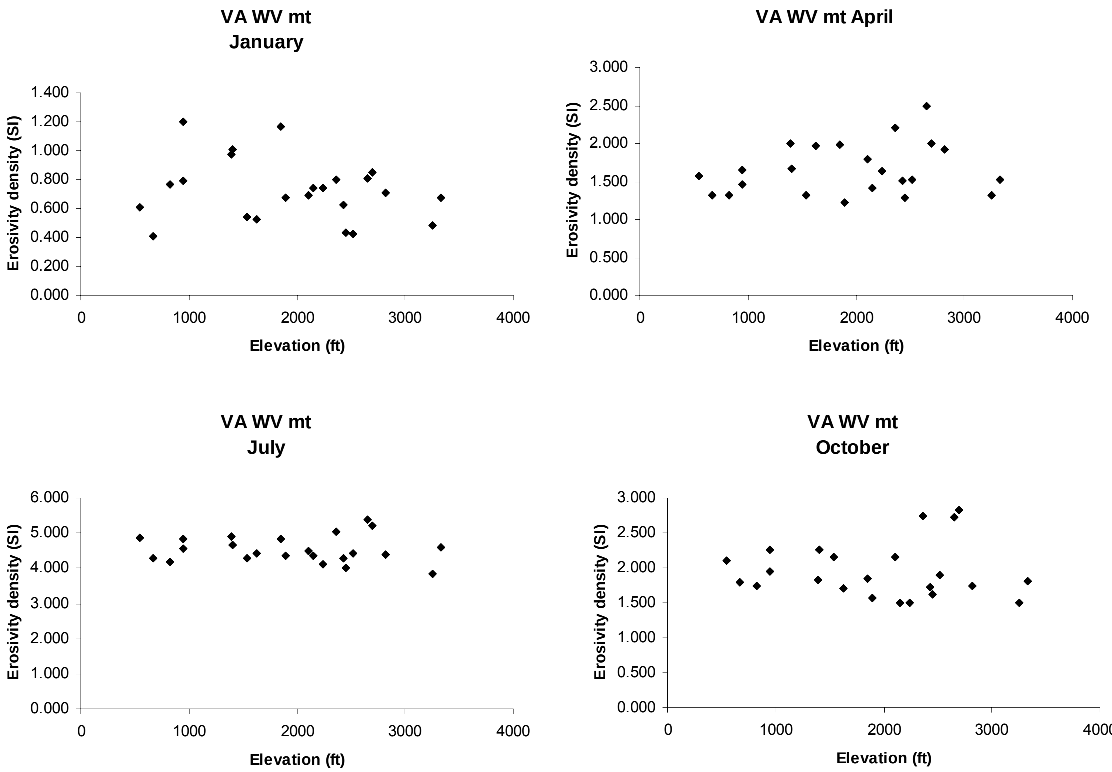


Figure 3.10. Variation of erosivity density with elevation in the West Virginia region.

was to inspect a map, shown in Figure 3.11, of average 30 minute intensity for all storms in the data set (Hollinger et al., 2002). Even though these data were extensively smoothed as a part of the contouring process, the map shows no effect of mountainous terrain in the Western US on maximum 30-minute intensity. Equation 3.18 shows that erosivity density is approximately proportional to maximum 30-minute rainfall intensity. Therefore, if 30-minute intensity is independent of elevation in mountainous regions, as indicated in Figure 3.11, then erosivity density is independent of elevation. This result means that the effect of mountainous terrain on erosivity can be fully captured in how terrain affects monthly precipitation. While these tests are not especially robust, the erosivity density approach is a major improvement over previously available erosivity values in AH703 (Renard et al., 1997) for the Western US.

3.2.1.4.2. Advantages of erosivity density approach

The erosivity density approach has major advantages. It produced consistent, smoothly varying erosivity density values across the US as desired for conservation and erosion control planning. The erosivity density approach uses data from daily precipitation gage stations, which are far more numerous than the 15-minute precipitation stations, to fill in erosivity values between the 15-minute precipitation gage locations where erosivity was computed from measured precipitation data. The erosivity maps for the Eastern US in AH282 (Wischmeier and Smith, 1965) and AH537 (Wischmeier and Smith, 1978) were based on approximately 2000 data points (see AH282). However, storm erosivity was computed from detailed intensity precipitation data comparable to the 15-mintue precipitation data at only 181 locations. An equation involving 2 year-6 hour precipitation amount and other variables was fitted to average annual erosivity values computed from the measured detailed precipitation data at the 181 locations (AH282, AH537). This equation was then used to estimate average annual erosivity values at the approximately 2000 locations used to draw the AH282 and AH537 erosivity maps for the Eastern US. The erosivity density approach using monthly precipitation measured by daily precipitation gages to compute erosivity at any particular location serves this function in RUSLE2.

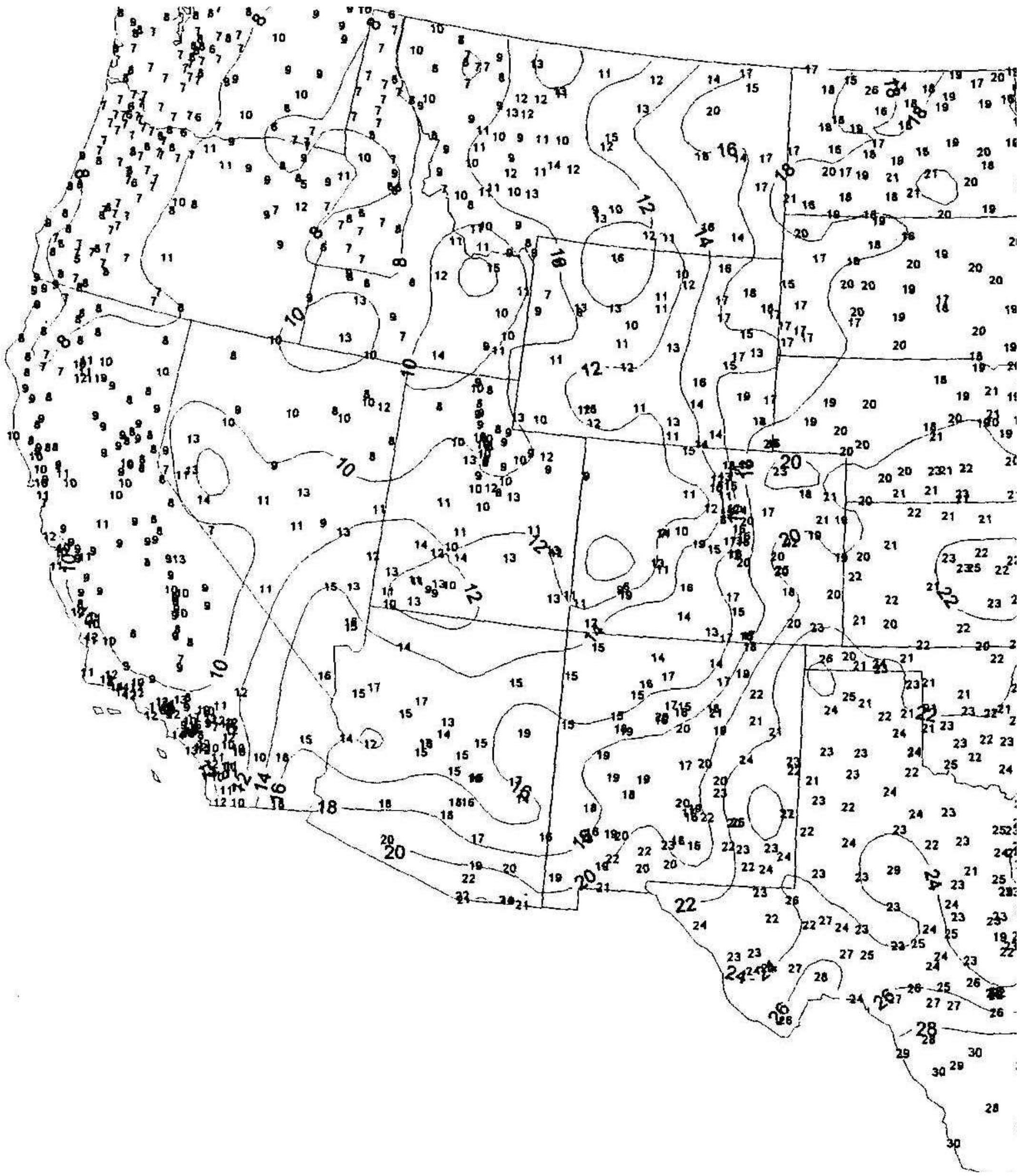


Figure 3.11. Average maximum 30 minute intensity computed for all storms. Source: Illinois State Water Survey (Hollinger et al., 2002).

The USLE and RUSLE1 use EI distribution zones in the US to describe the spatial variations in the temporal distribution of erosivity during the year. The temporal distribution of erosivity is assumed to be constant within a zone. Differences in temporal erosivity distributions between zones resulted in major differences in erosion estimates across certain zone boundaries. For example, Little Rock, Arkansas is very close to a EI zone boundary. The USLE and RUSLE1 compute a 25 percent change in erosion across the EI zone boundary at this location for a conventionally tilled corn cropping system. The impact of this step change is that a client should not be expected to change management practices unless estimated erosion changes by at least a 25 percent. RUSLE2's estimated erosion values vary smoothly across the US because RUSLE2 does not use such zones. See RUSLE2 User's Reference Guide for a discussion on how aggregating input weather data by counties affects estimated erosion across county boundaries.

Precipitation data measured by daily precipitation gages are much more stable and reliable and have much less missing data than precipitation data measured with the 15-mintue precipitation gages. That is, the quality of the 15-minute precipitation data is less than the quality of the daily precipitation data. The erosivity density approach computes a ratio in contrast to the standard approach that computes an absolute sum. The data requirements for computing a ratio of monthly erosivity to monthly precipitation amount are less demanding than for computing an absolute erosivity sum. An absolute sum is greatly affected by missing data, unless the missing data are so small that the missing values have little effect on the sum. In contrast, missing data have no effect on the ratio if the missing data are not biased. Although the missing 15-minute precipitation data were surely biased, problems caused by missing data and errors in reconstructing missing data are much less in the ratio erosivity density approach than in the absolute standard approach.

The erosivity density approach also reconciles differences in precipitation amounts measured by the daily and 15-minute precipitation gages. The Illinois State Water Survey provided precipitation data for 14 locations in West Texas and Eastern New Mexico where daily and 15-minutes precipitation gages were located sufficiently close so that annual precipitation measured by the two gages types could be compared. Overall, the annual precipitation measured by the 15-minute gages was 85 percent of that measured by the daily gages. The annual precipitation measured by the 15-minute gages was less than that measured by the daily gages for all 14 locations. The ratio of the precipitation amounts for the two gage types ranged from 0.76 to 0.94. This disparity between gage types affects erosivity density values much less than it does absolute erosivity values. The erosivity density approach computes monthly erosivity values, determined from 15-minute precipitation gage data, that are consistent with the monthly precipitation values, determined from daily precipitation gage data, used in RUSLE2.

A shorter record length and a record with more missing data can be used to compute erosivity density values than can be used to directly compute erosivity values with the standard method. Record length, including both number of years and number of storms, is especially critical in the Western US where spatial density of 15-minute precipitation gages is low, spatial and temporal variability is great, and records are often short with missing data. Twenty years was the minimum data record length considered to be acceptable for computing erosivity values for the Eastern US. That record length was actually too short using the standard procedure, but it was a compromise to include as many stations as possible. A data record length of 15 years was judged to be satisfactory for computing erosivity density values in the Eastern US. This conclusion was based on analysis of precipitation data collected by the USDA-Agricultural Research Service in Northern Mississippi in a research environment where data quality was very carefully maintained (McGregor et al. 1995). As Table 3.1 shows, a record length of 10 years was acceptable for these data using the erosivity density approach. Most important, the analysis showed that a shorter length of record could be used in the erosivity density approach than in the standard approach.

Table 3.1. Percent error in estimating monthly R from measured preciptiation data. Ratio refers to erosivity density approach. Abs refers to stanaard approach that computes absolute values.

record length	jan		feb		mar		apr		may		jun	
(yrs)	ratio	abs	ratio	abs	ratio	abs	ratio	abs	ratio	abs	ratio	abs
11	-21	-32	1	25	-5	3	-9	11	1	32	-10	-6
12	-21	-32	1	16	-4	-4	-5	6	-4	24	-8	-12
13	-12	-25	1	14	-8	-3	-5	2	-8	15	-8	-8
14	-9	-22	1	9	-1	0	-8	-3	-3	10	-7	-4
15	-2	-18	0	2	0	1	-6	0	0	4	-12	-2
16	-2	-11	3	3	2	0	-8	-3	-2	6	2	8
17	-7	-7	3	5	-3	-2	0	-1	-2	0	0	2
18	0	0	0	0	0	0	0	0	0	0	0	0

record length	jul		aug		sep		oct		nov		dec		ann		aver	
yrs	ratio	abs	ratio	abs	ratio	abs	ratio	abs	ratio	abs	ratio	abs	ratio	abs	ratio	abs
11	-4	17	10	19	7	-10	11	17	11	31	16	18	3	13	1	11
12	-5	8	4	27	4	-14	9	12	10	25	16	14	2	7	0	6
13	-6	10	4	18	0	-13	1	13	9	26	11	12	-1	6	-2	5
14	-8	9	1	13	-1	-16	5	9	6	22	10	5	0	3	-1	3
15	3	8	-3	5	-5	-9	6	16	5	19	7	5	1	3	-1	3
16	0	5	2	5	-3	13	3	11	3	11	3	4	2	5	1	4
17	0	0	0	-1	-3	6	2	4	1	5	0	-1	0	1	-1	1
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

The length of record in years and number of storms in the record are more important in the Western US than in the Eastern US. Figure 3.12 shows the effect of record length for a precipitation gage located in Beaver County, Utah. The example in Figure 3.12 is not very robust, but it represents typical conditions for the 15-minute precipitation data in the western US where the data record was short, the data was highly variable and contained relatively few storms, and number of the 15-minute gage locations was sparse. The erosivity density approach much more effectively uses the limited data in the Western US than does the standard procedure.

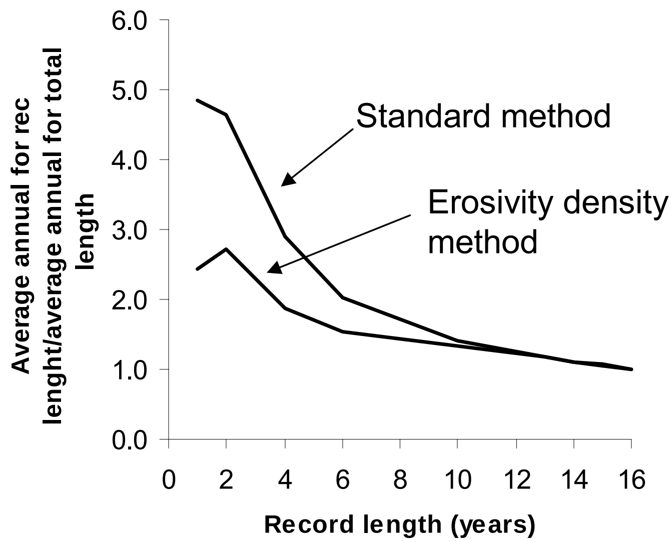


Figure 3.12. Effect of record length on variation of average annual values for erosivity and erosivity density for Beaver County, Utah.

Data for a gage location were not automatically discarded because of a short record length in the Western US in order to include as stations as possible. The overall curve of monthly erosivity density by month computed by averaging erosivity density values in a local region was examined (e.g., see Figures 3.6 and 3.7), and the data for the location were left in the analysis if the trend at the location matched the local regional trend. When the trends in a dataset at a location did not match the overall trend, the record length at the location was almost always short.

3.2.1.4.3. Comments on erosivity density approach

Precipitation amount is a very poor indicator of erosivity (Wischmeier, 1958; Foster et al., 1982). Measures of both rainfall intensity and amount are required in erosivity measures and indices. Monthly erosivity values computed using the erosivity density method have the immediate appearance of being solely a function of monthly precipitation amount. The erosivity density value for each month depends strongly on intensity as shown by equation 3.18. The erosivity density method also seems to conflict with the empirical result that storm erosivity is a nonlinear function of storm amount (Richardson et al., 1983). The empirical erosivity density values account for this nonlinearity. Nonlinear mathematical relationships can be linearized by dividing the solution space into sufficiently small intervals so that linear equations can be assumed within each interval. The erosivity density approach is a linearized procedure that captures the effect of both intensity and nonlinearity between storm erosivity and storm amount.

Care must be taken in developing and applying the erosivity approach in other situations, especially when it is used where only very limited precipitation data are available. The erosivity density method can be quite useful into these situations, but sufficient data must be available and analysis must be conducted to determine the variation of erosivity density values over the region where the method is being applied. Assuming constant erosivity density values over too large of a region can produce very erroneous results.

3.2.1.4.4. Alternative procedures for estimating erosivity involving precipitation amount

Lack of adequate precipitation data to derive RUSLE2 erosivity values is a major limitation in applying RUSLE2 in many countries. Erosivity values are estimated from storm, monthly, and annual precipitation amounts. Rainfall intensity is a critical element in erosivity indices and any estimation procedure must account for how intensity varies over space and time in relation to precipitation amount. The effect of intensity on erosivity varies by location and by month as Figure 3.5 and equation 3.18 indicate.

A procedure to estimate storm or daily erosivity from storm or daily precipitation, respectively, uses the equation (Richardson et al., 1983):

$$R_s = aP_s^b \qquad [3.19]$$

where: R_s = storm or daily erosivity, P_s = storm or daily precipitation amount, and a and b are coefficients that vary by location and month. Values for a and b are determined by empirically fitting equation 3.19 to observed data. The procedure requires sufficient data and analysis to determine values for a and b over space and by month or season. The Illinois State Water Survey (ISWS) attempted to apply this procedure to US data but concluded they had insufficient data to properly compute a and b values (Hollinger et al., 2002). Another problem was that they used a logarithmic transformation and linear regression in fitting equation 3.19 to the data rather than a nonlinear fitting procedure. The logarithmic transformation-linear regression procedure returns the mean of the logarithms of the observed values rather than the mean of the absolute observed values. Erosivity values that would be used in RUSLE2 produced by the ISWS procedure had a systematic error by being too low by about 10 percent. Use of equation 3.19 can work if the proper precautions are followed and sufficient data are available to determine values for a and b in equation 3.19 over space and time by month or season.

Another procedure is to compute storm erosivity using a design storm that has a particular intensity distribution (Cooley, 1980; Brown and Foster, 1987). The requirement for this procedure is that design storm intensity distributions vary over space and time. A few design storms are available that vary intensity distributions over space in the US, but no design storms seem to be available that vary intensity distributions by month or season.

A modified Fournier index is widely used to estimate erosivity where precipitation data are very limited. A value for the modified Fournier index is computed from (Renard and Freimund, 1994):

$$F = \frac{\sum_{m=1}^{12} P_m^2}{\sum_{m=1}^{12} P_m} \qquad \mathbf{[3.20]}$$

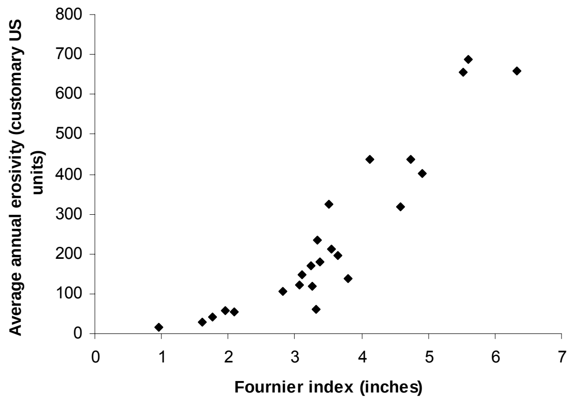


Figure 3.13. Relation of average erosivity to modified Fournier index for several US locations.

where: F = the modified Fournier index, P_m = average monthly precipitation, and m = index for each month. The usual procedure is to fit a linear equation involving average annual erosivity as a function of the modified Fournier index (Fournier, 1960). Values of the modified Fournier index were computed at the US locations listed in Table 3.1. Average annual erosivity values at these locations are plotted as a function of the modified Fournier index in Figure 3.13. These results show that the relation between average annual erosivity and the modified Fournier index is nonlinear rather than linear. Renard and Freimund (1994) also found that the relationship of average annual erosivity to the modified Fournier index was nonlinear where erosivity varied with the index raised to the 1.85 power for US data that are comparable to data represented in Figure 3.13. That equation is given by:

Table 3.2. Locations where modified Fournier index computed
Minneapolis, MN
Des Monies, IA
Columbia, MO
Oklahoma City. OK
Bryan, TX
Oxford, MS
Mobile, AL
Atlanta, GA
Norfolk, VA
Boston, MA
Scotfsbluff, NE
Houston, TX
Gulfport, MS
Miami, FL
Montgomery, AL
Denver, CO
Bismark, SD
Tombstone, AZ
Lincoln, NE
Lafayette, IN
San Francisco, CA
Bakesfield, CA
Jackson, MI
Pittsburg, PA

$$R = aF^{1.85} \qquad [3.21]$$

where: R = average annual erosivity. When this equation form is fitted to the data represented by Table 3.2, the exponent is 2.24. The difference in these exponent values is caused by differences in datasets and fitting procedures.

Another concern with the modified Fournier index is whether the square of monthly precipitation in equation 3.20 is the appropriate value for the exponent. A modified Fournier index with a generalized value for the exponent would be computed as:

$$F_{r2} = \frac{\sum_{m=1}^{12} P_m^b}{\sum_{m=1}^{12} P_m} \qquad [3.22]$$

$$R = aF_{r2} \qquad [3.23]$$

where: F_{r2} = the modified Fournier index where a value for the exponent b is determined by fitting equations 3.22 and 3.23 to observed data. In this formulation, the relationship between average annual erosivity and the generalized modified Fournier index is linear as shown in equation 3.23. The value for the exponent b most likely varies with the dataset. A value of 3.02 was obtained when equations 3.22 and 3.23 were fitted to the data represented in Table 3.2. Figure 3.14 shows a comparison between the values computed by equations 3.20 and 3.21 and equations 3.22 and 3.23. The values computed by equation 3.21 are slightly better than the values computed with equations 3.22 and 3.23. Using equations 3.20 and 3.21 or equations 3.22 and 3.23 is an improvement over fitting a linear equation to the standard modified Fournier index with the square exponent.

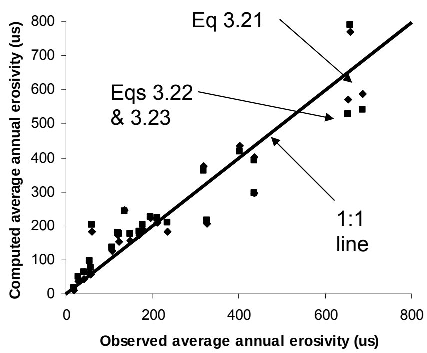


Figure 3.14 Comparison of alternate ways of using a modified Fournier index to estimate average annual erosivity.

The best approach for fitting either equations 3.20 or 3.21 or equations 3.22 and 3.23 is to divide the data into subsets by geographic region where the relationship between precipitation amount and intensity is constant over the region. A separate equation is fitted to the sub-dataset for each region. If the regions are too large, the variation in the relationship of intensity to precipitation amount over geographic space will be too large. Otherwise, the error in estimated erosivity will be very large. For example, the range in average annual erosivity in Figure 3.13 is from about 50 to 325 (us units) for a modified Fournier index value of about 3.5 inches. Obviously this great difference in erosivity for a particular value of the modified Fournier index results in very large errors in estimated erosion.

The implicit assumption in the modified Fournier procedure is that the monthly precipitation distribution coincides with the monthly intensity distribution. That is, the monthly precipitation distribution must coincide with the monthly erosivity density distribution. These distributions coincide well at Minneapolis, Minnesota but not at Oxford, Mississippi. The effect of the coincidence of the distributions on the monthly erosivity distribution is illustrated in Figure 3.15. The monthly erosivity distribution computed from the Fournier index, assuming a square power as in equation 3.20, compares reasonably well with the observed distribution at Minneapolis but compares very poorly at Oxford. Therefore, if the Fournier index is used to estimate monthly erosivity for the USLE, RUSLE1, or RUSLE2, the monthly erosivity density distribution must correspond closely to the monthly precipitation distribution.

Another procedure to estimate erosivity from monthly or annual precipitation amounts is to empirically fit equations involving these variables to observed data (Renard and Freimund, 1994). These procedures work satisfactorily only if the spatial and temporal variations in the relationship between precipitation amount and intensity are taken into account. For example, average annual erosivity ranged from 88 (US units) to 470 (us units) for an average annual precipitation of 39 inches in the data analyzed by Renard and

Freimund (1994). This variation in average annual erosivity for a particular average annual precipitation is much too great to be useful in erosion prediction used for conservation and erosion control planning. The data should be divided into subsets according to the relation of intensity to precipitation amount.

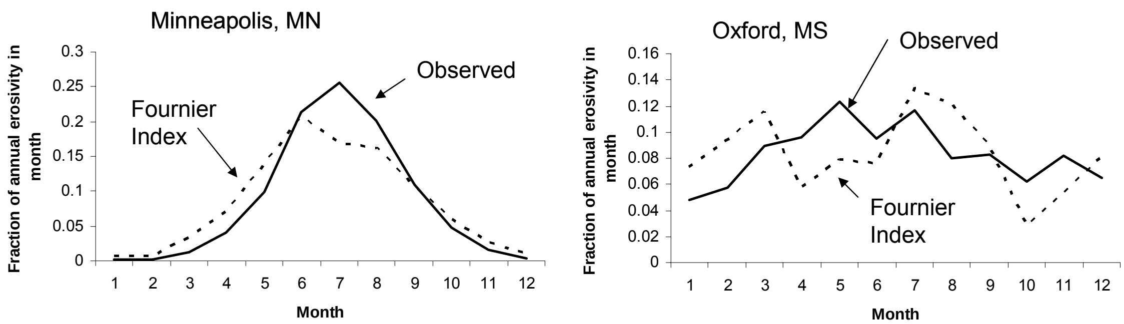


Figure 3.15. Comparison of monthly erosivity distributions computed with the modified Fournier index with observed monthly erosivity distributions.

Any method used to estimate erosivity from precipitation amount MUST take into account how the relationship between precipitation and intensity varies over space and time.

3.2.2. Precipitation

RUSLE2 uses average monthly precipitation values as input values for precipitation. RUSLE2 uses the disaggregation procedure described in **Section 3.1** to disaggregate average monthly precipitation values into daily values. A consistent and sufficient record length should be used to determine average monthly precipitation values from measured data. A 22-year record length was used to develop erosivity values for the USLE (Wischmeier and Smith, 1958, 1962, 1978) because climate was thought to vary in a 22-year cycle. The modern accepted record length seems to be 30 years for hydrologic modeling (ref). The USDI-Weather Bureau (?) has assembled 30-year data records for the locations where daily precipitation was measured. These data have been reviewed to correct erroneous and missing data. In addition, the USDA-NRCS, Weather Bureau, and other agencies used the PRISM (Daly et al., 1997) computer program that extrapolates the measured data at each weather station to compute monthly precipitation values across the US on a 4 km grid. This mathematical procedure adjusts measured values for the effect of elevation, proximity to a coastline, and other variable that spatially affect precipitation. Users should contact their USDA-NRCS state office for precipitation data to use in RUSLE2.

The data available from the NRCS, referred to as the PRISM data, were analyzed to ensure that the probability distribution of the data is uniform for all locations. For example, extreme precipitation summer precipitation events can be highly localized. The PRISM data should be reviewed to ensure that the return periods for the precipitation input data are uniform among locations where RUSLE2 is being applied so that a land user is not unfairly affected by the happenstance of extreme precipitation occurring at their location and not at other locations (See RUSLE2 User's Reference Guide). In general, events having a return period greater than 50 years should be excluded.

3.2.3. Temperature

RUSLE2 uses average monthly values for input temperature values. RUSLE2 uses the disaggregation procedure described in **Section 3.1** to compute average daily temperature values from average monthly input values. The time period used to obtain monthly precipitation values should be the same as that used to obtain average monthly temperature values so that precipitation and temperature input values will be consistent. The most recent 30 years is an acceptable period over which to obtain average monthly temperature values. However, the data should be reviewed to ensure that the data record does not contain unusually extreme events that would have extraordinary effect on RUSLE2's computations. Extreme events in the temperature observed data do seem be as nearly severe as in the precipitation record.

The best source of temperature values for use in RUSLE2 is from the USDA-NRCS. Their data have been produced with the PRISM program that takes into account how elevation and other variables affect temperature. Like precipitation, the USDA-NRCS PRISM temperature values are available on a 4 km grid across the US.

3.2.4. 10 year-24 hour precipitation

RUSLE2 uses the precipitation amount for a 24-hour event that has a 10-year return period as a representative storm to compute the effect of ponding on rainfall erosivity, runoff's sediment transport capacity, and the location along an overland flow path length that contouring fails (e.g., see **Section 3.4.3**). The fundamental structure of RUSLE2 computes daily erosion for unit plot conditions (see **Section 2.1**), which in turn is multiplied by non-dimensional ratios to account for effects of topography, cover-management, and support practices. A single storm is used to compute values for these non-dimensional ratios that involve ponding and runoff. The RUSLE2 intent is to capture main effects related to runoff as they vary with location, soil, and cover-management. RUSLE2 starts with accepted USLE values and uses runoff computations to adjust the ratio values up or down as runoff departs from a base condition. An advantage of this approach is the ratio values vary less temporally than erosivity, which allows a single precipitation event to be used to compute runoff. Most of the temporal variation is capture by the temporal varying erosivity. Other temporal differences are captured by computing daily runoff for the representative storm as cover-management variables change temporally. The 10 year-24 hour precipitation was chosen to make the runoff computations because most of the rill-interrill erosion at a site is caused by moderate to large rainfall events (Wischmeier and Smith, 1958, 1978).

The 10-year EI storm was used for the same purpose in RUSLE1 [Foster et al., 1997; AH703 (Renard et al., 1997)]. The procedure in RUSLE1 was to compute a precipitation amount for the 10 year-EI storm using an equation that was derived empirically by fitting an equation that computed erosivity as a function of precipitation amount (Richardson et al., 1983). The RUSLE1 procedure worked satisfactory for the eastern US but not for the western US, especially in the Northwest Wheat and Range Region (NWRR). Winter precipitation causes most of the erosion in the NWRR. This precipitation occurs at a very low intensity, which has low unit energy whereas most of the erosion in the eastern US is caused by summer precipitation at high unit energy. Directly using the 10 year-24 hour precipitation values more accurately computes runoff for RUSLE2 purposes than computing runoff from a precipitation value computed from an erosivity-precipitation equation empirically derived from eastern US data as was done in RUSLE1.

An erosivity value is needed for the 10 year-24 hour precipitation amount. This erosivity value should reflect the 10 year-24 hour precipitation amount and unit energy at the location. The equation used in RUSLE2 to compute the erosivity for the 10 year-24 hour precipitation amount is:

$$EI_{10y24h} = 2\alpha_m P_{10y24h} \qquad [3.24]$$

where: EI_{10y24h} = the storm erosivity associated with the 10 year-24 hour precipitation amount, α_m = the maximum monthly erosivity density at the location, and P_{10y24h} = the 10 year-24 hour precipitation amount. Equation 3.24 is consistent with the procedure used to compute monthly erosivity using monthly precipitation amount and monthly erosivity density (see **Section 3.2.1.4.1**). The implicit assumption is that the 10 year-24 hour precipitation event occurs in the month having the maximum erosivity density. A procedure that uses the erosivity density from the month with the maximum precipitation was evaluated. That procedure gave inconsistent results because of spatial variability in the month with the maximum precipitation. The month having the maximum precipitation varies greatly within a relatively small region, which in turn results in relatively large variations in the monthly erosivity density values used in equation 3.24. The 2 coefficient in equation 3.24 was obtained by calibrating equation 3.24 to observed values for the 10-year EI from modern precipitation data in the Eastern US (Hollinger et al., 2002).

The main role of using the 10 year-24 hour precipitation event in RUSLE2 and the 10 year EI in RUSLE1 was to compute the variation in the effectiveness of support practices, especially contouring and strip cropping, across the US. The 10-year EI map published in AH703 (Renard et al., 1997) shows numerous narrow ridges and valleys for the 10-year EI contours. Those narrow ridges and valleys were judged to represent unexplained variability in the measured data used to compute 10-year EI values rather than trends in precipitation important in support practice effectiveness. The smooth trends in the widely accepted maps of the 10 year-24 hour precipitation for the eastern US were judged to much more accurately represent precipitation trends important in support practice effectiveness.

3.2.5. Req

In the Northwest Wheat and Range Region (NWRR), erosion per unit erosivity is much greater during the winter months than during the summer months and much greater than for the Eastern US. A unique set of conditions in the NWRR related to thawing soil that is highly saturated produces a very highly erodible condition (McCool et al. 1995). The approach used in RUSLE2 computes erosion using standard soil erodibility values (see **Section 4.1**) and adjusted erosivity, i.e., Req for the effective (equivalent) average annual erosivity. Also, a special monthly erosivity distribution is used to distribute the annual Req erosivity over each month.

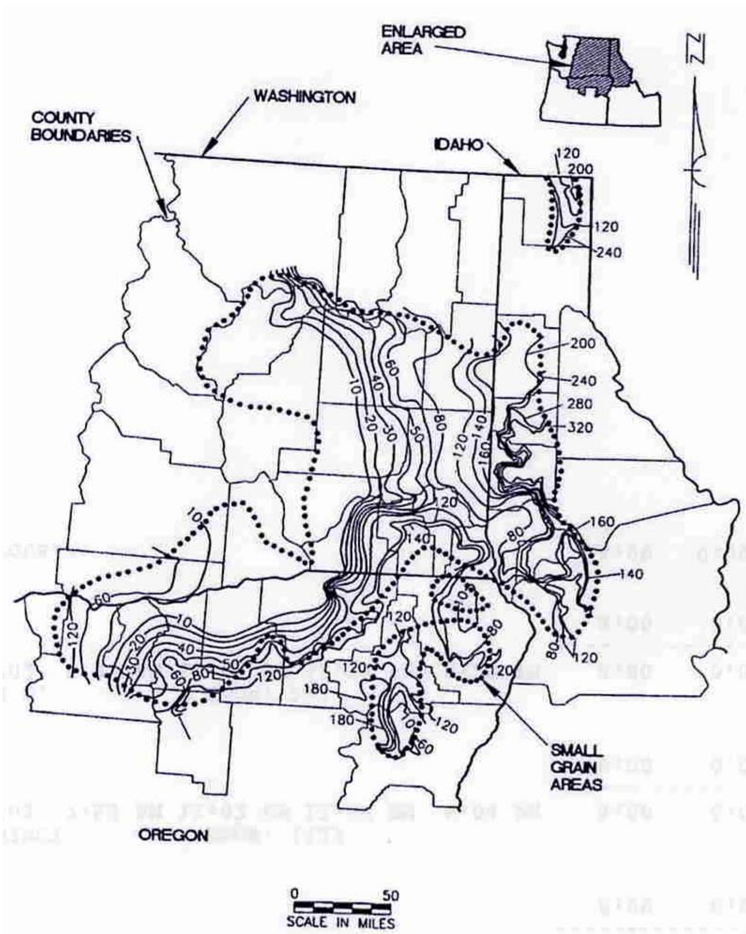


Figure 3.16. Area in Oregon, Washington, and Oregon where RUSLE2 Req procedure works best. Ignore contour lines.

The principal source of data for determining Req has been from research erosion plots operated by the USDA-ARS at Pullman, WA and Pendleton, OR. The procedure is to measure erosion on plots having the unit plot cover-management condition (see **Section 2.1** and **Footnote 2**) and to adjust measured erosion values for the effect of length and steepness to account for differences between the actual plots and unit plots. The adjusted average annual erosion value is divided by the standard soil erodibility value to produce an Req value. The distribution of measured erosion on unit plot conditions by month is used to obtain an Req erosivity distribution.

The RUSLE2 Req procedure works well for the region shown in Figure 3.16, which is mainly northeastern Oregon, eastern Washington and northeastern Idaho. The Req effect occurs in other parts of the Western US, but the Req relationships for these regions have not been well determined. RUSLE2 compute Req as a function of average annual precipitation based on conditions across eastern Washington. Whether that relationship applies in other regions where the precipitation and temperature differs from that in eastern Washington is a concern. Certainly the monthly distribution for Req surely differs in other regions where the monthly distribution of precipitation differs from that in eastern Washington. The Req distribution for eastern Washington should not be used at other locations without making adjustments for differences in monthly precipitation and temperature distributions.

Another consideration is that winter temperatures are so low at some locations that soil freezing significantly decreases soil erodibility. Also, snow covers the soil at high elevations to prevent winter erosion. Another factor is erosion by snowmelt in late winter and early spring, but RUSLE2 is not designed to estimate erosion by snowmelt. Erosion research at Morris, Minnesota showed that only about seven percent of the erosion occurred by snowmelt (Knisel, 1980). Thawing and recently thawed soil can be highly erodible in late winter and early spring in all locations, including the eastern US. Even though soil erodibility can be greatly increased for a short time, less than three weeks, not much erosion occur if little erosivity occurs during this period, which is the case in Minnesota. A similar effect occurs in the mid-South region. This effect is partially captured in the temporal soil erodibility equation for the mid-south US and similar regions (see **Section 4.5**).

The Req effect is described in detail in the **RUSLE2 User's Reference Guide**. Additional information can be obtained by contacting D.K. McCool, USDA-ARS, Pullman, WA, and by reviewing his scientific publications.

3.3. Runoff

RUSLE2 uses the 10 year-24 hour representative storm to compute runoff depth, which is subsequently used as an index to compute deposition, erosion control effectiveness of support practices, and effect of water depth (ponding) on erosion (see **Sections 2.3.3, and 3.4.5**). This procedure captures runoff's main effects but not every detail effect. For example, RUSLE2 uses this approach to estimate how contouring effectiveness differs between the northern and southern US.

Both runoff amount and rate are important for computing erosion. RUSLE2's equations for runoff hydraulics (see **Section 3.4**) are based on runoff rate. RUSLE2 computes a daily sediment load to erosivity ratio, which RUSLE2 multiplies by daily erosivity to estimate daily erosion, deposition, and sediment load (see **Section 2.3.9**). The RUSLE2 assumption is that excess rainfall rate (depth/time) equals runoff depth, which is the major determinant of excess rainfall rate. The 10 year-24 hour precipitation amount is used each day to compute daily runoff depth as cover-management conditions temporally vary. The resulting runoff values are indices of how runoff varies by location as a function of soil and cover-management.

3.3.1. Computation of runoff

RUSLE2 uses the NRCS curve number method to compute runoff depth as a function of precipitation amount and curve number (Haan et al., 1994). Curve number values vary with cover-management, hydrologic soil group, and antecedent soil moisture. A moderate antecedent soil moisture condition is used in RUSLE2.

3.3.1.1. NRCS curve number method

The NRCS curve number equation computes runoff depth as:

$$Q = \frac{(P - 0.2S)^2}{P + 0.8S} \qquad [3.25]$$

where: Q = runoff depth, P = precipitation depth, and S = a variable computed with:

$$S = 1000 / N - 10 \qquad [3.26]$$

where: N = curve number and inches are the units for P, Q, and S.

A requirement for equation 3.25 is that precipitation depth P is greater than 0.2S. Equation 3.25 was modified so that RUSLE2 computes decreasing runoff rate with distance along the overland flow path where a segment has a much higher infiltration rate than do upslope segments. The modified equation computes the additional precipitation amount that would be needed to just produce runoff for the precipitation depth P as:

$$P_a = P - 0.2\left[\left(\frac{1000}{N}\right) - 10\right] \qquad [3.27]$$

where: P_a = the additional precipitation (inches).

Excess rainfall rate σ (inches/hour) in equation 2.18 is set equal to Q (inches) in equation 3.25 or to P_a (inches) in equation 3.27 (see **Section 2.3.5**).

3.3.1.2. Curve number as function of cover-management variables

RUSLE2 uses equations that are functions of cover-management variables to compute curve number N values. Curve number values vary daily as cover-management variables change temporally.

3.3.1.2.1. Standard conditions – no Req, no non-erodibile cover, no irrigation, no adjustment made for subsurface drainage

Curve number N represents the effect of cover-management on runoff. Cover-management affects runoff in several ways. For example, improved soil management, which is represented in RUSLE2 by increased soil biomass, decreases runoff. Mechanical soil disturbance like tillage reduces runoff on soils having no biomass in comparison to the soils not disturbed for several years. Soil biomass and soil consolidation interact to affect runoff. Soil consolidation increases runoff when soil biomass is very low, typical of construction sites not recently mechanically disturbed. Conversely, soil consolidation decreases runoff when soil biomass is very high, typical of undisturbed, high production pasture. Increased soil surface roughness and ground cover decrease runoff depending on soil biomass levels. Curve numbers and how they are affected by cover-management are also a function of soil properties as represented by hydrologic soil group. For example, cover-management decreases runoff more on soils having a high infiltration potential, hydrologic soil group A, than on soils having a low infiltration potential, hydrologic soil group D.

RUSLE2 curve number equations were calibrated to curve number values commonly used by NRCS (Haan et al., 1994). Indices in these empirical equations reflect how cover-management is known to affect infiltration and runoff.

The main RUSLE2 equation used to compute curve number values is:

$$N = [N_{u100} - s_u(1 - s_c)] f_B \exp(b_D B_s) \qquad [3.28]$$

where: N = curve number used in equations 3.25 and 3.27 to compute runoff, N_{u100} = a curve number value that represents the effect of ground cover and soil roughness on curve number on a soil recently mechanically disturbed (i.e., s_c = 1), s_u = the change in curve number per unit change in the soil consolidation subfactor (see **Section 6.6**), f_B = a fraction, which along with the term $\exp(b_D B_s)$, describes the main effect of soil biomass and its interaction with soil consolidation on curve number, b_D = a coefficient that is a function of the soil consolidation subfactor s_c, and B_s = soil biomass. Soil biomass B_s is the sum of buried residue averaged over the residue accounting depth (see **Section 6.2**) and the live and dead root biomass averaged over the upper 10 inch soil depth (see **Section 6.2.1**). Units for B_s are biomass on a dry basis/(land area·unit soil depth). The accounting depth for buried residue decreases from 3 inches to 1 inch as the soil consolidation subfactor c_s decreases from 1 to 0.45 (see Section **6.6**).

The curve number N_{u100} is determined by starting with a base curve number for a recently mechanically tilled soil and adjusts curve number downward for increases in ground cover and adjusted soil surface roughness r_a greater than 0.24 inch, which is the base roughness value assumed for unit plot conditions (see **Section 2.1** and **Footnote 2**). Curve number values increase when adjusted roughness is less than 0.24 inch, which represents a condition where runoff is greater than from the unit plot condition. The adjusted soil surface roughness is used in equation 6.26 to compute a soil surface roughness subfactor value (see **Section 6.3**). The equations used to compute N_{u100}, which do not consider any effect of soil biomass or soil consolidation on curve number, are given by:

$$N_{u100} = N_{s100} + a_{cu}(f_g/100) + a_{ru}\{1 - \exp[-1.7(r_a - 0.24)]\} \qquad r_a > 0.24 \text{ in} \qquad [3.29]$$

$$N_{u100} = N_{s100} + a_{cl}(f_g/100) + a_{rl}[(0.24 - r_a)/0.24] \qquad r_a \leq 0.24 \text{ in} \qquad [3.30]$$

where: N_{u100} = a curve number for a recently mechanically disturbed soil (i.e., s_c = 1) with no soil biomass, N_{s100} = a starting curve number value for unit plot conditions that are recently mechanically disturbed, adjusted soil surface roughness r_a = 0.24 in, and no soil biomass, a_{cu} = a coefficient for the effect of ground cover when surface roughness is greater than 0.24 inches, a_{cl} = a coefficient for the effect of ground cover when surface roughness is less than 0.24 inches, f_g = ground cover (percent), a_{ru} = a coefficient for the effect of soil surface roughness when roughness is greater than 0.24 inches, a_{rl} = a coefficient for the effect of adjusted soil surface roughness when the adjusted soil surface roughness is less than 0.24 inches, and r_a = adjusted soil surface roughness index (inches) (see **Section 6.3**). Values for starting curve number N_{s100} and the coefficients a_c and a_r, which vary with hydrologic soil group, are given in Table 3.3.

Table 3.3. Curve number and coefficient values used in standard RUSLE2 curve number equations (not Req)

Hydrologic soil group	N_{s100}	N_{uB}	N_{lB}	N_{u45}	N_{lb45}	b_B (in ac/lbs$_m$)	a_{cu}	a_{cl}	a_{ru}	a_{rl}	a_{45}
A	87.0	87.0	53.0	94.0	70.0	0.00219	-12.0	-6.5	-12.0	6.5	-0.12
B	92.0	92.0	68.0	98.0	82.0	0.00174	-12.0	-6.5	-12.0	6.5	-0.12
C	93.0	93.0	75.0	98.6	84.6	0.00200	-7.0	-5.0	-7.0	5.0	-0.07
D	94.0	94.0	79.0	98.7	88.4	0.00153	-5.0	-3.0	-5.0	4.0	-0.05

The main effect of soil consolidation is represented in the terms involving s_u, which is the rate of change in the curve number per unit change in the soil consolidation subfactor s_c. The equation for s_u is given by:

$$s_u = (N_{u45} - N_{u100})/0.55 \qquad [3.31]$$

where: 0.55 = the range in the soil consolidation subfactor c_s from 1 for a recently mechanically disturbed soil to 0.45 for a fully consolidated soil. Values for the curve number N_{u45}, given in Table 3.3, are for a fully consolidated soil with no ground cover. .

The fraction f_B represents the main effect of soil biomass on curve number. A value for f_B is computed with:

$$f_B = [(N_{uB} - N_{lB})\exp(-b_B B_s) + N_{lB}]/N_{uB} \qquad [3.32]$$

where: N_{uB} = the curve number value when no biomass is present in the soil and the soil has been recently mechanically disturbed, N_{lB} = the curve number for a very high soil biomass (i.e., when $\exp(-b_B B_s)$ is near zero) and the soil has been recently mechanically disturbed, and b_B = a decay coefficient that represents how the curve number decreases exponentially as a function of soil biomass. Curve number values for N_{uB} and N_{lB} are given in Table 3.3. The effect of soil biomass on curve number is assumed to be greater in soils having a low infiltration potential, i.e., hydrologic soil group A, than soils having high infiltration potential, i.e., hydrologic soil group D. Values for the decay coefficient b_B, are also given in Table 3.3.

The term $\exp(b_D B_s)$ in equation 3.28 represents how the interaction between soil biomass and soil consolidation affect curve number values. A value for the coefficient b_D is computed from:

$$b_D = \ln(N_l / N_u)/1750 \qquad [3.33]$$

where: N_l and N_u = lower and upper curve numbers, respectively, that represent the difference in curve numbers for a soil with no soil biomass and one with a high soil biomass of 1750 lbs_m/(acre·in) value. The value for N_u is computed from:

$$N_u = N_{u100} - s_u(1 - s_c) \qquad [3.34]$$

A value for the lower curve number that is comparable to the upper curve number N_u is computed as:

$$N_l = N_{l100} - s_l(1 - s_c) \qquad [3.35]$$

where: $N_{l100} = N_{u100}$ and s_l is computed from:

$$s_l = (N_{l100} - N_{l45})/0.55 \qquad [3.36]$$

The curve number N_{l45} is adjusted for ground cover is computed as:

$$N_{l45} = N_{lb45}(1 + a_{45} f_g / 100) \qquad [3.37]$$

where: a_{45} = a coefficient having values given in Table 3.3. Soil surface roughness is assumed not to affect curve number for a fully consolidated soil with high soil biomass. Values for the base curve number N_{lb45} for a fully consolidated soil at high soil biomass with no ground cover are also given in Table 3.3.

3.3.1.2.2. Req conditions, no irrigation, no adjustment made for subsurface drainage

The procedure described in Section 3.3.1.2.1 is also used to compute runoff for Req conditions, but different runoff curve number and coefficient values are used. A major effect in the Req zone is that infiltration is very low during the winter unless residue cover, soil biomass, and soil surface roughness is very high. The soil becomes highly saturated resulting in a very high portion of the precipitation becoming runoff during the winter period. High residue cover, soil biomass, and surface roughness seem to keep open macro-pores for significantly increased infiltration. The values given in Table 3.4 are used during by RUSLE2 for the winter Req period to compute runoff while the values given in Table 3.3 can be used for the summer months.

Table 3.4. Curve number and coefficient values used in RUSLE2 curve number equations for Req conditions

Hydrologic soil group	N_{s100}	N_{uB}	N_{lB}	N_{u45}	N_{lbb45}	b_B (in ac/lbs$_m$)	a_{cu}	a_{cl}	a_{ru}	a_{rl}	a_{45}
A	92.0	92.0	22.0	94.0	70.0	0.00024	-12.0	-6.5	-25	2.0	-0.12
B	97.0	97.0	58.0	98.0	82.0	0.00020	-12.0	-6.5	-25	2.0	-0.12
C	98.0	98.0	73.0	98.6	84.6	0.00025	-7.0	-5.0	-15	2.0	-0.07
D	98.0	98.0	78.0	98.7	88.4	0.00020	-5.0	-3.0	-10	2.0	-0.05

3.3.1.2.3. Effect of non-erodible cover on runoff

RUSLE2 assumes no detachment for the portion of the soil surface covered by non-erodible cover. However, RUSLE2 assumes that non-erodible cover can be permeable. An input value is the fraction of the non-erodible cover that is fully permeable so that infiltration is controlled by the underlying soil. All of the precipitation is assumed to become runoff for the remaining portion of the non-erodible cover. The overall effective curve number for this condition is computed by RUSLE2 as:

$$N = N_b(1 - f_n) + f_n[N_b f_p + 100(1 - f_p)] \qquad [3.38]$$

where: N = overall, effective curve number used in equation 3.25 or 3.27 to compute runoff, f_n = fraction of the soil surface covered by non-erodible cover, f_p = fraction of the non-erodible cover that is permeable, N_b = the curve number for the portion of the soil not covered by the non-erodible cover, and 100 = the curve number for the non-permeable portion of the non-erodible cover. A 100 curve number means that all of the precipitation becomes runoff.

3.3.1.2.4. Effect of subsurface drainage on runoff

The RUSLE2 procedure for adjusting for subsurface drainage is to select a hydrologic soil group that describes runoff potential for the undrained condition and one that describes runoff potential for the drained condition (see **Sections 7.4** and RUSLE2 User's Reference Guide). RUSLE2 uses the hydrologic soil group assigned to the drained and undrained soil conditions to compute runoff using the values in either Table 3.3 or 3.4.

An input for RUSLE2 is the portion of the area represented by the overland flow path that is subsurface drained. RUSLE2 uses that input to compute an effective curve number value used for the entire overland flow path. The effective curve number is computed with:

$$N = N_d f_d + N_{ud}(1 - f_d) \qquad [3.39]$$

where: N = effective curve number used in equation 3.25 or 3.27 to compute runoff, N_d = curve number for the drained condition, N_{ud} = the curve number for the undrained condition, and f_d = the fraction of the area represented by an overland flow path that is drained.

3.3.1.2.5. Effect of irrigation on runoff

RUSLE2 computes the effect of irrigation on erosion when rainfall occurs. RUSLE2 does not compute erosion caused by the applied water. RUSLE2 computes increased erosion on irrigated areas because of increased soil moisture (see **Section 7.5**). However, RUSLE2 does not compute increased runoff caused by irrigation.

3.4. Hydraulics

RUSLE2 uses shear stress as the hydraulic variable to compute sediment transport capacity and locations where contouring fails. Runoff's total shear stress is applied to surface soil particles, ground cover, soil surface roughness elements, and stems of live and standing dead vegetation. Total shear stress is computed with (Chow, 1959):

$$\tau_t = \gamma y s \qquad [3.40]$$

where: τ_t = total shear stress, γ = weight density of water (62.4 lb_f/ft^3), y = flow depth, and s = overland flow path steepness. Flow depth is computed with the Manning equation as (Chow, 1959):

$$y = \left(\frac{qn_t}{1.49 s^{1/2}}\right)^{3/5} \qquad [3.41]$$

where: q = discharge rate, n_t = total Manning's n (index for hydraulic roughness-resistance), and the 1.49 is used when US customary units are used.

3.4.1. Concept of grain and form roughness

The total shear stress can be divided into two parts (Graf, 1971), the part referred to as grain roughness shear stress that acts on surface soil particles and the part referred to as from roughness shear stress that acts on ground cover, stems of live and dead standing vegetation, and soil surface roughness elements. Grain roughness shear stress is assumed to be responsible for sediment transport while form roughness shear stress is assumed to be responsible for contouring failure (Foster, 1982; Foster et al., 1982).

3.4.2. Grain roughness shear stress for computing sediment transport capacity

RUSLE2 uses Equation 2.17 to compute sediment transport capacity. That equation is based on the assumption that sediment transport capacity can be computed as:

$$T_c = K_T \tau_g^{3/2} \qquad [3.42]$$

where: τ_g = grain roughness shear stress. By using the concept that flow depth can be divided into parts associated with grain and form roughness, equations 3.41 and 3.42 can be combined with a Manning's n for grain roughness to give equation 2.17 where the coefficient ζ is given by (Foster et al., 1982):

$$\zeta = 0.0008 n_t^{-1.5} \qquad [3.43]$$

where: the coefficient ζ has absorbed γ and the Manning's n_g value for grain roughness, which is assumed to be 0.01.[32] Total Manning's n_t is computed by RUSLE2 as a function of soil surface roughness, ground cover, live vegetation biomass, and standing residue biomass (see **Section 3.4.6**).

3.4.3. Grain roughness shear stress for computing contouring failure

3.4.3.1. Main equations

RUSLE2 computes grain roughness shear stress as a function of discharge rate as:

$$\tau_g = a_f q^{0.85714} s / n_t^{1.2857} \qquad [3.44]$$

where: τ_g = grain roughness shear stress and a_f =a coefficient that includes γ in equation 3.40, 1.49 in equation 3.41, and other empirical coefficients. RUSLE2 assumes contouring failure where grain roughness shear stress computed with equation 3.44 exceeds a critical shear stress. A value for critical shear stress for contouring failure was determined by calibrating equation 3.44 to critical slope length values given in AH537 (Wischmeier and Smith, 1978). The resulting critical shear stress for contour failure is 3619 when US customary units are used in the equations. The value for a_f in equation 3.44 is absorbed in the critical shear stress value along with conversion factors that would be used to convert excess rainfall rate to ft/sec rather than using inches/hour. Grain roughness shear stress for contouring failure is computed with:

$$\tau_g = q_i^{0.85714} s / n_t^{1.2857} \qquad [3.45]$$

where: the discharge rate q_i is computed using excess rainfall rate (σ_i) in inches/hour rather than ft/sec as $q_i = x\sigma_i$ and x = distance along overland flow path. The critical slope length values beyond which contouring failure is assumed were based on judgment of soil conservation technical specialists and were not determined by research. These values were developed at a 1956 workshop (Wischmeier and Smith, 1978) and therefore represented observations from research studies and field observations from the early 1930's to the mid 1950's The base condition used in calibrating the critical shear stress for contouring failure represents those conditions rather than modern conditions. The assumed base condition is conventionally tilled, low yield (50 bu/ac) continuous corn at Columbia, Missouri. The operations assumed for this cropping system included a

---

[32] This equation is based on US customary units of ft^3/sec per ft width for discharge rate (q), ft for flow depth (y), and lbs_f/ft^2 for shear stress (τ).

moldboard plow in the spring for primary tillage, two secondary tillage operations to prepare the seedbed, row planter to seed the crop, row cultivation to control weeds, and harvest. Table 3.5 shows a comparison between the values computed with RUSLE2 and those given in AH537 (Wischmeier and Smith, 1978). The values compare well except at very flat steepness where RUSLE2 values are much longer than those given in AH537. The values computed by RUSLE2 are considered acceptable.

Table 3.5. Critical slope lengths

Slope steepness (%)	Critical slope length (ft)	
	AH537	RUSLE2
1.5	400	>1000
4.0	300	384
7.0	200	200
10.5	120	125
14.5	80	86
18.5	60	66
23.0	50	51

RUSLE2 sets the contouring subfactor value to 1 for those portions of the overland flow path where grain roughness shear stress exceeds the critical shear stress for contouring failure (see **Section 7.1**). No adjustments are made in the cover-management subfactors used to compute detachment in equation 2.10. RUSLE2 also computes the location where runoff shear stress acting on grain roughness equals the critical shear stress for contour failure. That equation is:

$$q_c = 13900 n_t^{1.5} / s^{1.1667} \qquad [3.46]$$

where: q_c = the discharge rate (where excess rainfall rate in equation 2.18 is in units of in/hr) at which contouring fails. The location of this discharge rate can be determined from equation 2.18.

RUSLE2 computes where contouring fails along overland flow paths as a function of location (i.e., as reflected by the $P_{10y\text{-}24h}$ precipitation amount), runoff, soil infiltration potential, overland flow path steepness, and cover-management conditions. For example, RUSLE2 computed critical slope length values are a function of crop yield. Increased crop yield increases critical slope length. The increased biomass improves soil properties that increase infiltration and reduce runoff, increases soil surface roughness, and increases ground cover provided by crop residue. For example, the critical slope length increases from 103 to 151 ft for an increase in corn yield from 50 to 115 bu/ac in a grain corn-silage corn-alfalfa hay- alfalfa hay-alfalfa hay crop rotation for an overland flow path on a silt loam soil at 20 percent steepness at LaCrosse, Wisconsin. Tillage systems that leaves increased surface soil roughness and surface crop residue cover also increase RUSLE2 computed critical slope length as illustrated in Table 3.6.

Table 3.6. RUSLE2 computed critical slope lengths for three tillage systems for continuous 50 bu/ac corn.

Slope steepness (%)	RUSLE2 computed critical slope length (ft)		
	Conv till	Mulch till	No-till
1.5	>1000	>1000	>1000
4.0	384	594	837
7.0	200	310	436
10.5	125	194	273
14.5	86	134	188
18.5	66	101	143
23.0	51	79	112

RUSLE2 does not compute contouring failure as a function of how soil properties affect critical shear stress for contouring failure. This capability is desirable, but sufficient empirical data are not available to develop the required critical shear stress values as a function of soil properties. Contouring failure in RUSLE2 is assumed not to be a function of ridge height or grade along the ridges-furrows. Clearly contouring failure is a function of ridge height because ridge height affects storage of runoff water and the likelihood of ridge breakover especially in low areas. However, accurately describing flow hydraulics and water storage on a specific field site is very difficult because of imperceptible variations of row grade and ridge heights along the ridges-furrows. Although RUSLE2 has these shortcomings, it was developed to guide for conservation planning, and in that context, RUSLE2 is a major improvement over the USLE and RUSLE1.

3.4.3.2. Grain roughness shear stress below a high hydraulic roughness segment

RUSLE2 assumes a gradual rather than a step decrease in total hydraulic roughness where total hydraulic roughness decreases from one overland flow path segment to the next segment. Consequently, the grain roughness shear stress increases gradually rather than abruptly between segments. An example is runoff exiting from dense vegetation onto a relatively smooth, bare soil surface. The dense vegetation spreads the runoff so that the flow has a laterally uniform depth as it exits the vegetation. Grain roughness shear stress is assumed to be less when flow depth is laterally uniform than when concentrated in rills. A distance is required below the dense vegetation for the runoff to become concentrated in rills with increased grain roughness shear stress.

This concept is implemented in RUSLE2 by assuming that the effective total hydraulic roughness decreases exponentially below a segment having a high total hydraulic roughness. The equation for the effective total Manning's n_t in the transitional region is:

$$n_{et} = n_l + (n_u - n_l)\exp[-0.065(x - x_u)] \qquad [3.47]$$

where: n_{et} = effective Manning's n_t in the transitional zone, n_l = the total Manning's n_t in the lower segment, Manning's n_u = the Manning n_t in the upper segment, x = distance along the overland flow path (ft), and x_u = the distance to the upper end of the lower segment (ft). Figure 3.17 shows the RUSLE2 computed decrease in Manning's n_t below a hay strip in a typical strip cropping system used in LaCrosse, Wisconsin and evaluated in research studies (Hays and Attoe, 1957; Hays et al., 1949). Also, other erosion from strip cropping systems were also studied at other locations (Borst et al., 1945; Hill et al.,. 1944; Hood and Bartholomew, 1956; Smith et al. 1945). RUSLE2 gives similar

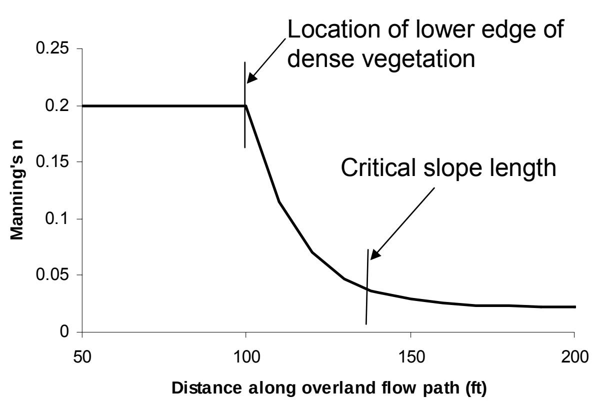


Figure 3.17. Decrease in Manning's n_t along overland flow path below a segment having a high Manning's n_t.

results for these systems as shown in AH703 (Renard et al., 1997; Foster et al., 1997).

The reduction in grain roughness shear stress by runoff spreading reduces the portion of an overland flow path where grain roughness shear stress can exceed critical shear stress for contouring failure. The result is that contour strip cropping increases computed critical slope length (i.e., the location where contouring fails). The assumption that contour strip cropping increases critical slope length has long been accepted and used in conservation planning [e.g., see AH282 (Wischmeier and Smith, 1965) and AH537 (Wischmeier and Smith, 1978)]. In AH537, the critical slope length (referred as slope length limits in AH537) is doubled for contour strip cropping without regard to cover-management condition such as type, quality, and density of vegetation on each overland flow path segment. However, the AH537 contouring factor values for contour strip cropping do vary with cover-management condition.

Data from research in Wisconsin (Hays and Attoe,1957; Hays et al., 1949) were the best available in the 1950's to guide development of critical slope length concepts and values by erosion scientist and soil conservation specialists for use in the USLE (AH282, AH537). The RUSLE1 developers judged that critical slope length with strip cropping was 1.5 times the critical slope length without strip cropping [AH703 (Renard et al., 1997)]. A major RUSLE2 improvement is that RUSLE2 computes how location (i.e., $P_{10y\text{-}24h}$ precipitation), runoff, overland flow path steepness, cover-management conditions, number of strips, and relative placement of strips along an overland flow path affect critical slope length. The RUSLE2 procedure is far more comprehensive that previous USLE and RUSLE1 procedures.

The 0.065 ft^{-1} value in equation 3.47 was selected to give critical slope length values considered appropriate for the LaCrosse, Wisconsin experimental contour strip cropping (Hays et al., 1949). For example, RUSLE2 computes a critical slope length of 103 ft on a 20 percent steep overland flow path for the crop rotation used in the contour stripping studies without the crops being arranged in strips. That is, cover-management along the overland flow path is uniform at any particular time although cover-management temporally changes during the crop rotation. The crop rotation is a year of grain corn and a year of silage corn conventionally tilled with a moldboard plow, and three years of alfalfa hay fall seeded immediately after the silage corn is harvested. The assumed corn yield is 50 bu/acre, a typical yield in the 1930's and 1940's. The RUSLE2 computed critical slope length is 191 ft when the crops are arranged in a four strip contour strip cropping system.

The RUSLE2 computed critical slope length is a function of number of strips along the overland flow path. For example, the RUSLE2 computed critical slope length is 153 ft for the LaCrosse, Wisconsin crop rotation placed in two rather than four strips. Strip width is 50 ft for the four-strip system on a 200 ft overland flow path length while it is 100 ft for the two-strip system. As Figure 3.17 shows, about 38 ft is required for total effective hydraulic roughness computed with equation 3.47 to decrease to where grain roughness shear stress exceeds the critical shear stress for contouring failure. Strip width should be no wider than 38 ft, according to Figure 3.17 for these conditions, to prevent grain roughness shear stress from exceeding the critical shear stress for contour failure. The 100 ft strip width in the two-strip contouring strip cropping system greatly exceeds 38 ft. In contrast, the 50 ft wide strip in the four-strip contour strip cropping system is sufficiently narrow that the grain roughness shear stress only exceeds critical shear stress for contouring failure over the last 9 ft of the overland flow path length.

3.4.3.3. Determining location where contouring failure occurs

RUSLE2 uses rules to determine where the grain roughness shear stress exceeds critical shear stress for contouring failure within an overland flow path segment.

3.4.3.3.1. Discharge rate increases within segment

If discharge rate increases within a segment and grain roughness shear stress at both the upper and lower ends of the segment is less than the critical shear stress for contouring failure, contouring failure does not occur within the segment. If grain roughness shear stress exceeds the critical shear stress for contouring failure at both the upper and lower ends of the segment, contouring failure occurs over the entire segment. However, if grain roughness shear stress at the upper end of the segment is less than the critical shear stress for contouring failure, and grain roughness shear stress at the lower end of the segment exceeds critical shear stress for contouring failure, contouring failure occurs over the lower portion of the segment beginning at the location where grain roughness shear stress equals the critical shear stress for contouring failure. This location is computed with equations 2.18 and 3.46.

3.4.3.3.2. Discharge rate decreases within segment

If discharge rate decreases within a segment and grain roughness shear stress at both the upper and lower ends of the segment is less than the critical shear stress for contouring failure, contouring failure does not occur within the segment.

If grain roughness shear stress at the upper end of the segment is less than the critical shear stress for contouring failure but exceeds critical shear stress for contouring failure at the lower end of the segment, contouring failure occurs over the lower portion of the segment beginning at the location where grain roughness shear stress equals the critical shear stress for contouring failure. This location is computed with equations 2.18 and 3.46.

If grain roughness shear exceeds the critical shear stress for contouring failure at both the upper and lower ends of the segment, the possibility exists for contouring failure on upper and lower portions of the segment without contouring failure in the middle portion of the segment. RUSLE2 determines where the grain roughness shear stress is a maximum within the segment and if that shear stress is greater than the critical shear stress for contouring failure, then contouring failure occurs over the entire segment. If the minimum grain roughness shear stress within the segment is less than the critical shear stress for contouring failure, then grain roughness shear stress equals the critical shear stress at two locations within the segment. These locations are determined with equations 2.18 and 3.46.

If grain roughness shear stress is less than the critical shear stress for contouring failure at both the upper and lower ends of the segment, the possibility exists that grain roughness shear stress increases to a value greater than the critical shear stress for contouring failure within the segment and then decreases to below this critical shear stress above the lower end of the segment. Contouring failure occurs on a middle portion within the segment. This check can be made by computing the maximum grain roughness shear stress within the segment, and if it exceeds the critical shear stress for contouring failure, this condition exists. The portion where contouring fails lies in the middle of the segment between the two locations where grain roughness shear stress equals the critical shear stress for contouring failure, which are determined from equations 2.18 and 3.46.

3.4.3.4. Runoff rate used to compute contouring failure

To compute contouring failure, RUSLE2 computes a daily runoff rate that varies with both cover-management and the probability of an intense storm occurring when contouring is susceptible to failure. The daily precipitation amount used to compute contouring failure is assumed to vary linearly with the temporal daily erosivity distribution (see **Sections 3.1 and 3.2.1**) with the maximum daily precipitation occurring on same day that the maximum daily erosivity occurs. This daily precipitation amount is computed as:

$$P_{cf} = (f_{R,j} / f_{R,mx}) P_{10y,24h} \qquad [3.48]$$

where: P_{cf} = the daily precipitation amount used to compute contouring failure, $f_{R,j}$ = the fraction of the annual erosivity that occurs on the *jth* day, and $f_{R,mx}$ = the fraction of the annual erosivity that occurs on the day when maximum daily erosivity occurs.

3.4.4. Backwater

Backwater occurs at locations on an overland path where total hydraulic roughness makes a step increase, such as at the upper edge of a dense vegetation strip. This backwater is especially important because most of the deposition caused by dense vegetation strips occurs in the backwater (Dabney et al., 1995; Flanagan et al., 1989; Foster et al., 1980; Hayes et al., 1984; McGregor, K.C. et al., 1999). Ignoring backwater length would cause RUSLE2 to greatly underestimate deposition when computing deposition caused by narrow, dense vegetation strips.

The Manning equation is used in RUSLE2 to compute flow depth at the upper edge of segments where Manning's n_t makes a step increases. An effective backwater length is computed from this flow depth assuming that the backwater is level. The combined equation for computing backwater length is:

$$\Delta x_b = 3.44[n_t q_b /(1.49 s_l^{0.5})]^{0.6} / s_u \qquad [3.49]$$

where: Δx_b = the backwater length (ft), q_b = discharge rate (ft^2/s) at the upper edge of the segment having the high total Manning's n_t, s_l = the **sine** of the slope angle of the segment having the high Manning's n, and s_u = the **tangent** of the slope angle of the immediate upslope segment. The 3.44 value in equation 3.49 was determined by calibration. The coefficient was adjusted until RUSLE2 computed the observed sediment yield from plots having a dense 1.5 ft wide dense stiff grass hedge below conventionally tilled cotton on a 5 percent steepness at Holly Springs, Mississippi (McGregor, K.C. et al., 1999). The RUSLE2 computed backwater length was compared to measured backwater values and locations of deposited sediment above the stiff grass hedge. Although the upper edge of deposition moves upslope as deposited sediment accumulates (Dabney et al., 1995), this dynamic effect is not considered in RUSLE2. The RUSLE2 computed backwater length is an index that captures the effects of location through the 10 year-24 hour precipitation amount, runoff, hydraulic roughness, and overland flow path steepness. The maximum computed backwater length is limited to 15 ft to prevent RUSLE2 from computing excessively long backwater lengths on relatively flat overland flow paths. Also, RUSLE2 assumes a 3 ft minimum for special cases like fabric filter fence on construction sites (see **Section 7.2**). RUSLE2 adds the computed backwater length to the upper edge of the segment having the high total Manning's n_t and decreases the length of the immediate upslope segment by the same amount.

3.4.5. Ponding

Water deeper than about 3 mm reduces raindrop impact erosivity (Mutchler, C.K., 1970; Mutchler and Murphree, Jr., 1985; Mutchler and Young. 1975). The judgment of soil conservation specialists is that water depth reduces erosion on flat overland flow paths in high erosivity locations, such as the lower Mississippi Delta [AH703 (Renard et al., 1997)]. Erosivity (R) values along the Gulf Coast Region were reduced to consider this effect in the USLE (e.g., compare erosivity values between [AH282 (Wischmeier and Smith, 1965) and AH537 (Wischmeier and Smith, 1978)]. RUSLE1 uses a ponding subfactor that reduces effective erosivity based on flow depth if ridges are not present. Water depth (ponding) was assumed to have no effect on erosivity in RUSLE1 when ridges are present. However, in RUSLE2, the ponding effect is assumed to reduce erosivity regardless of the presence or absence of ridges.

The 10 year-24 hour precipitation amount is used to compute a runoff amount using equation 3.25. A normalized flow depth is computed using the Manning equation as:

$$y_n = (v_r / 3.03)^{0.6} (0.01 / s)^{0.3} \qquad [3.50]$$

where: y_n = the normalized flow depth, v_r = the runoff amount expressed as a depth (inches), 3.03 = a reference runoff depth (inches) selected to represent runoff and 0.01 = a reference overland flow path steepness to represent typical of cotton production in the Mississippi Delta where the water depth effect is highly most important and the effect has been studied in research (Mutchler et al., 1982; Mutchler and McGregor, 1983; Mutchler and Murphree, 1985; McCool et al., 1987). This normalized flow depth is then used to compute a ponding subfactor value using:

$$p_r = \exp[-0.49(y_n - 1] \qquad \text{if } p_r < 0.4, p_r = 0.4 \qquad [3.51]$$

where: p_r = the ponding subfactor for the effect of water depth on raindrop impact erosivity. The minimum value for the ponding subfactor is 0.4. The 0.49 value in equation 3.51 was chosen by calibration to represent the judgment of erosion scientists and soil conservationists regarding the ponding effect [AH537 (Wischmeier and Smith, 1978), AH703 (Renard et al., 1997)]. Example values for the average annual ponding factor are given in Table 3.7 where daily ponding values have been weighted by the temporal erosivity distribution (see **Sections 3.1** and **3.2.1**).

Table 3.7. Example values for the ponding subfactor

Location, 0.5% steepness	Value	Steepness (%), at Jackson, MS	Value
New Orleans, LA	0.58	0.001	0.45
Baton Rouge, LA	0.63	0.005	0.73
Jackson, MS	0.73	0.01	0.85
Memphis, TN	0.82	0.02	0.96
Columbia, MO	0.86	0.04	1.00

3.4.6. Manning's n_t as a function of cover-management and row grade

RUSLE2 computes total Manning's n_t values as a function of soil surface roughness, ground cover, live vegetation, and standing residue using:

$$n_t = 0.11[1 - \exp(-0.6r_n)] + [0.075 f_g / \exp(0.35r_n)] + n_v + n_s \qquad \text{if } n_{tc} < 0.01, n_{tc} = 0.01 \qquad [3.52]$$

$$r_n = r_a \quad \text{if } r_n > 5, r_n = 5 \qquad \text{inches} \qquad [3.53]$$

where: n_t = total Manning's n_t, $r_n = r_a$ = adjusted roughness index value (inches) used to compute roughness subfactor values (see **Section 6.3**), f_g = net ground cover (fraction) (see **Section 6.2**), n_v = Manning's n contributed by live vegetation (see **Section 9.2.4**), and n_s = the Manning's n contributed by standing residue (see **Section 10.4.3**). Equation 3.52 was derived from multiple data sets where overland flow velocity was measured for a wide variety of conditions. Manning's n values derived from these measurements have been compiled and used in numerous models including CREAMS, RUSLE1, and scientific articles (Foster et al., 1980; Foster, 1982; Foster et al., 1982; Foster et al., 1997; Gilley and Finkner, 1991; Gilley and Kottwitz, 1994; Gilley and Kottwitz, 1995).

Equation 3.52 represents form and grain roughness combined rather than representing them as two separate terms. The condition on n_t in equation 3.52 is to prevent total Manning's n_t from being less than the grain roughness Manning's n of 0.01.

The ground cover and soil surface roughness combination term in equation 3.52 reduces the effect of ground cover on hydraulic roughness as soil surface roughness increases. Ground cover in depressions is inundated by ponded water and deposited sediment so that ground cover has reduced effect on runoff hydraulics as soil surface roughness increases.

The condition that adjusted roughness not be greater than 5 inches is primarily because no research data were available at high roughness values to derive equation 3.52. Actually the high soil surface roughness condition has little effect on computed Manning's n_t values. For example, the first term in equation 3.52 is 0.105 for r_a = 5 inches and 0.11 for r_a = 10 or more inches.

Net ground cover is (1 – the fraction of soil surface not covered by ground cover). Net ground cover takes into account surface residue overlapping rock cover and live ground cover overlapping both surface residue and rock cover.

Table 3.8. Retardance classes used in RUSLE2

Class	Retardance index
no retardance (wide plant spacing in strip-row)	0
low retardance (corn)	1
moderate low (soybeans, cotton)	2
moderate (dense wheat)	3
moderate high (legume hay before mowing)	4
high (legume-grass hay before mowing)	5
very high (dense sod)	6
extreme (stiff grass hedge, silt fence)	7

The maximum Manning's n value for vegetation in rows perpendicular to the overland flow path (i.e., on the contour) is computed with:

$$n_{mvc} = 0.017154 R_c + 3.82 \times 10^{-5} R_c^5 \quad \textbf{[3.54]}$$

where: n_{mvc} = the Manning's n for live vegetation in rows on the contour at it maximum canopy cover and R_c = vegetation retardance at maximum canopy cover for vegetation in rows on the contour, which is a measure of how much vegetation and porous barriers like fabric fences slow runoff. Input retardance values are chosen to represent the combined hydraulic roughness of the vegetation in rows and bare soil between the rows for vegetation at its maximum growth in the RUSLE2 vegetation description.[33] Using these input retardance values listed in Table 3.8, RUSLE2 computes a retardance value based on vegetation production (yield) level (see **Section 9.3.1**). The Manning's n_{mvc} represents the effect of stems and any vegetation component, besides live ground cover, that slows runoff. Live ground cover values in the RUSLE2 vegetation description are used to represent the effect of leaves and similar plants components touching the soil surface and slowing runoff.

[33] Assignment of retardance values considers the geometrical arrangement of the rows of the vegetation. For example, retardance for small grain represents the net retardance for multiple grain rows whereas the retardance for a narrows stiff grass hedge considers only a single row of the vegetation. In the case of the stiff grass hedge, the overland flow path is divided into segments to represent the bare soil separately from the vegetation in a situation where backwater created by the dense vegetation has an important effect on deposition.

The hydraulic roughness for a vegetation's rows oriented parallel to the overland flow path (up and down hill) differs from the hydraulic roughness for the vegetation's rows on the contour. RUSLE2 computes a value for the Manning's n_{mvud} for vegetation in rows parallel to the overland flow path by multiplying the contour vegetation Manning's n_{mvc} by a factor based on the user entered row width. Values for this factor are given in Table 3.9. The **No rows (broadcast)** input means that the vegetation is randomly spaced in both directions so that no row orientation exists. Manning's n is the same in all directions. The **Vegetation on ridges** represents vegetation rows so widely spaced or the vegetation being on ridges so that the vegetation stems have no effect on hydraulic roughness.

Depending on row grade (steepness along the vegetation rows), vegetation Manning's n varies between the Manning's n for vegetation rows on the contour and the Manning's n for the vegetation rows oriented up and down hill. The RUSLE2 equation used to compute vegetation Manning's n for intermediate row orientations is:

$$n_{rg} = n_{ud} + (n_c - n_{ud})[1 - (s_r / s_l)^{1/2}] \qquad [3.55]$$

where: n_{rg} = vegetation Manning's n for the row grade s_r, , n_c = vegetation Manning's n for rows on the contour (perpendicular to the overland flow path), n_{ud} = vegetation for Manning's n for rows up and down slope (parallel to overland flow path), s_r = row grade, and s_l = overland flow path steepness.

RUSLE2 assumes that vegetation Manning's n varies temporally as the vegetation's effective fall height varies (see **Section 6.1**). The equation used to compute vegetation Manning's n values through time is:

$$n_v = n_{mv}(h_f / h_m)^{0.3} \qquad [3.56]$$

where: n_{mv} = the vegetation Manning's n at maximum growth in the vegetation description, h_f = the daily fall height for a particular vegetation description and h_m = the maximum daily fall height for the vegetation description (see **Section 9**).

Table 3.9. Factor values used to multiply Manning's vegetation n on contour to obtain Manning's n value for orientation parallel to overland flow path

Row width	Factor
Vegetation on ridges	0.063
Wide row	0.125
Moderate row spacing	0.250
Narrow row spacing	0.500
Very narrow row spacing	0.750
No rows (broadcast)	1.000

When live vegetation is killed in RUSLE2, it becomes standing residue that continues to provide hydraulic roughness. The hydraulic roughness caused by standing residue is assumed to vary through time as:

$$n_s = n_k(B_s / B_k) \qquad [3.57]$$

where: n_s = Manning's n for standing residue, n_k = Manning's n for the standing residue on the day that the live vegetation is killed, B_s = standing residue biomass (dry matter basis), and B_k = the live vegetation biomass (dry matter basis) on the day that the vegetation is killed (see **Section 9.2.3.4.3**).

List of symbols

a = coefficient in approximation for storm energy directly proportional to storm precipitation amount (force-length)/(area·length)
a = coefficient in equation that computes storm or daily erosivity from storm or daily precipitation ($R_s = aP_s^b$)
a = coefficient in equation used to average annual erosivity from Fournier index F($R = aF^{1.85}$)
a = coefficient in equation used to average annual erosivity from Fournier index F_{r2} $R=aF_{r2}$
a_{cl} = a coefficient for the effect of ground cover when surface roughness is less than 0.24 inches
a_{cu} = a coefficient for the effect of ground cover when surface roughness is greater than 0.24 inches
a_f = coefficient used to compute grain roughness shear stress
a_{rl} = a coefficient for the effect of adjusted soil surface roughness when the adjusted soil surface roughness is less than 0.24 inches
a_{ru} = a coefficient for the effect of soil surface roughness when roughness is greater than 0.24 inches
a_{45} = coefficient used to compute curve number as affected by cover-management
b= exponent in equation that computes storm or daily erosivity from storm or daily precipitation ($R_s = aP_s^b$)
b = exponent used to compute erosivity from Fournier index F_{r2}
b_B = a decay coefficient that represents how the curve number decreases exponentially as a function of soil biomass
b_D = a coefficient that is a function of the soil consolidation subfactor s_c (mass/area·length)$^{-1}$
$b_D = \ln(N_l / N_u)/1750$
B_k = live vegetation biomass on day that vegetation is killed (mass/area)
B_s = soil biomass per unit depth computes as sum of buried residue biomass averaged over the residue accounting depth and live and dead root biomass averaged over the upper 10 inch soil depth (mass/area·length)
B_s = standing residue biomass (mass/area)
D = number of days in the month
e = unit energy (energy content per unit area per unit rainfall depth) [force-distance/(area·length)
E = storm energy (force-distance/area)
EI_{10y24h} = the storm erosivity associated with the 10 year-24 hour precipitation amount (erosivity units)
EI_{30} = storm erosivity (erosivity units)
f_B = a fraction, which along with the term $\exp(b_D B_s)$, describes the main effect of soil biomass and its interaction with soil consolidation on curve number
$f_B = [(N_{uB} - N_{lB})\exp(-b_B B_s) + N_{lB}]/N_{uB}$
f_d = fraction of area represented by an overland flow path that is drained

f_g = net ground cover (portion of soil surface covered)
f_n = portion of the soil surface covered by non-erodible cover (fraction)
f_p = portion of the non-erodible cover that is permeable (fraction)
$f_{R,j}$ = fraction of the annual erosivity that occurs on *jth* day
$f_{R,mx}$ = fraction of the annual erosivity that occurs on day when maximum daily erosivity occurs
F = the modified Fournier index
F_{r2} = the modified Fournier index used to compute erosivity month precipitation to b power
h_f = daily fall height for a particular vegetation description (length)
h_m = maximum daily fall height for the vegetation description (length)
i = rainfall intensity for a period during rainstorm (length/time)
I_{30} = maximum 30-minute intensity (length/time)
$\bar{I}_{30}$ = representative maximum 30 minute intensity for month (length/time)
J = number of 15 minute periods in a storm
M = monthly value of climate variable being disaggregated
n_c = vegetation Manning's n for rows (strips) on the contour (perpendicular to the overland flow path)
n_{et} = effective Manning's n_t in the transitional zone below a high hydraulic resistance segment
n_g = grain roughness Manning's n
n_k = Manning's n for standing residue on day that live vegetation is killed
n_l = total Manning's n_t in segment downslope of high hydraulic resistance segment
n_{mv} = vegetation Manning's n at maximum growth in the vegetation description
n_{mvc} = Manning's n for live vegetation in rows (strips) on the contour at maximum canopy cover
n_{mvud} = Manning's n for vegetation in rows parallel to the overland flow path
n_{rg} = vegetation Manning's n for row grade s_r
n_s = Manning's n contributed by standing residue
n_t = total Manning's n
n_u = Manning n_t in upper high hydraulic resistance segment
n_{ud} = vegetation for Manning's n for rows up and down slope (parallel to overland flow path)
n_v = Manning's n contributed by live vegetation
N = curve number used to compute runoff
N_b = curve number for the portion of the soil not covered by the non-erodible cover
N_d = curve number for the drained condition
N_l = upper curve numbers that represents difference in curve numbers for a soil with no soil biomass and one with a high soil biomass of 1750 lbs_m/(acre·in) value
N_{lb45} = base curve number for fully consolidated soil at high soil biomass with no ground cover
N_{lB} = the curve number for a very high soil biomass (i.e., when $\exp(-b_B B_s)$ is near zero) and the soil has been recently mechanically disturbed
N_{l45} = curve number adjusted for ground cover as $N_{l45} = N_{lb45}(1 + a_{45} f_g / 100)$
N_{l100} = ??
N_{s100} = a starting curve number value for unit plot conditions that are recently

mechanically disturbed, adjusted soil surface roughness r_a = 0.24 in, and no soil biomass
N_u = upper curve numbers that represents difference in curve numbers for a soil with no soil biomass and one with a high soil biomass of 1750 lbs_m/(acre·in) value
N_{uB} = curve number value when no biomass is present in the soil and the soil has been recently mechanically disturbed
N_{ud} = curve number for the undrained condition
N_{u100} = curve number value that represents the effect of ground cover and soil roughness on curve number on a soil recently mechanically disturbed (i.e., s_c = 1) with no soil biomass
p_r = daily ponding subfactor
P = precipitation depth (length)
P_a = additional precipitation depth required so that zero runoff would be computed when infiltration greater than precipitation (length)
P_{cf} = daily precipitation amount used to compute contouring failure (length)
P_d = average monthly precipitation from daily precipitation gage data (length)
P_m = average monthly precipitation (length)
P_s = storm or daily precipitation amount (length)
P_{10y24h} = the 10 year-24 hour precipitation amount (length)
P_{15} = precipitation amount determined from 15-minute precipitation gage data (length)
q = discharge rate (volume/width·time)
q_b = discharge rate at upper edge of segment having high total Manning's n_t (volume/width·time)
q_c = discharge rate (where excess rainfall rate is in units of in/hr) at which contouring fails (volume/width·time)
q_i = discharge rate computed using excess rainfall rate in inches/hour rather than ft/sec as $q_i = x\sigma_i$
Q = runoff depth (length)
r_a = adjusted soil surface roughness index (length)
r_n = adjusted soil surface roughness index (length)
R = average annual erosivity (erosivity units)
R_c = vegetation retardance at maximum canopy cover for vegetation in rows (strips) on contour, which is a measure of how much vegetation and porous barriers like fabric fences slow runoff
R_m = average monthly erosivity (erosivity units)
R_s = storm erosivity (erosivity units)
s = overland flow path steepness
s_c = soil consolidation subfactor
$s_l = (N_{l100} - N_{l45})/0.55$
s_l = overland flow path steepness
s_l = **sine** of slope angle of segment having high hydraulic resistance
s_r = row grade
s_u = change in curve number per unit change in the soil consolidation
s_u = **tangent** of slope angle of immediate segment upslope of high hydraulic resistance segment
S = a variable computed with $S = 1000/N - 10$
t_c = time during month that disaggregated value equals monthly value

t_p = time during month of peak or minimum of climate variable being disaggregated
x = distance along overland flow path (length)
x_u = the distance to the upper end of segment immediately downslope of high hydraulic resistance segment (length)
y = daily value of climate variable being disaggregated
y = flow depth (length)
v_r = runoff amount used to compute ponding subfactor (length)
y_n = normalized flow depth used to compute ponding subfactor
Y_b = daily value of climate variable being disaggregated at beginning of month
Y_e = daily value at end of month
Y_p = maximum value of climate variable being disaggregated when peak or minimum occurs within month

α_m = average monthly erosivity density (erosivity units/length)
α_m = maximum monthly erosivity density
Δx_b = the backwater length (length)
ΔV = rainfall depth during a period in a rainstorm (length)
γ = weight density of water (force/volume)
σ_i = excess rainfall rate in inches/hour (length/time)
τ_g = grain roughness shear stress (force/area)
τ_t = total shear stress (force/area)
ζ = coefficient $\zeta = 0.0008 n_t^{-1.5}$ has absorbed γ and the Manning's

Indices
i – storm
j - day
j - month
j – 15 minute period in a storm
m - month
k – day
k – period during a rainstorm
m – number of period during a rainstorm
n – period during rainstorm

4. Soil

4.1. Erodibility

The major RUSLE2 soil variable is the soil erodibility factor. A value for the soil erodibility factor for soils that have their soil horizons in place and have not been disturbed other than for cultivation can be selected from the USDA-NRCS soil survey database. However, soil erodibility values are not available for all soils, especially highly disturbed soils where the original soil layers have been mixed. RUSLE2 includes two sets of equations, referred to as the standard soil erodibility nomograph and the RUSLE2 modified soil erodibility nomograph, which can be used to estimate soil erodibility factor values for most situations (See RUSLE2 User's Reference Guide).

The soil erodibility factor in RUSLE2 is a measure of soil erodibility under unit plot conditions. These conditions empirically measure soil erodibility where the effects of cover-management are removed so that the measured erosion represents how inherent soil properties and local climate affect soil erodibility as defined in RUSLE2. The RUSLE2 soil erodibility factor is not an inherent soil property like soil texture. It is defined in terms of the erosivity variable used in RUSLE2 and, therefore, should not be used in other erosion prediction technologies that use a different erosivity factor than the RUSLE2 erosivity factor.

The RUSLE2 soil erodibility factor, which is the same as the USLE and RUSLE1 soil erodibility factor (Wischmeier and Smith, 1965 and 1978; Römkens et al,, 1997), is a measure of erosion per unit erosivity EI for unit plot conditions. Consequently, the RUSLE2 soil erodibility factor is a function of local climate because erosion per unit erosivity is greater where runoff is increased per unit erosivity. For example, if the same soil properties were to occur in two locations, the RUSLE2 soil erodibility factor would be increased in locations where frequent, high, intense rainfall occurs that produces increased runoff per unit precipitation. Unfortunately, the soil erodibility nomograph commonly used to estimate soil erodibility factor values, including those in RUSLE2, is not a function of climate variables.

4.1.1. Standard soil erodibility nomograph

The standard soil erodibility nomograph (Wischmeier et al., 1971) was derived from data produced by applying simulated rainfall to about 55 agricultural soils, primarily in Indiana (Wischmeier. and Mannering, 1969). Although these soils represented a range of inherent soil properties, the standard nomograph best fits medium textured soils.

The equation for the standard soil erodibility nomograph is:

$$K = (k_t k_o + k_s + k_p)/100 \qquad [4.1]$$

where: K = soil erodibility factor, k_t = texture subfactor, k_o = organic matter subfactor, k_s

= soil structure subfactor, and k_p =soil profile permeability subfactor.

4.1.1.1. Texture subfactor

The soil texture subfactor equation is given by (Wischmeier et al., 1971):

$$k_{tb} = 2.1[(P_{sl} + P_{vfs})(100 - P_{cl})]^{1.14} / 10000 \quad [4.2]$$

$$k_t = k_{tb} \qquad P_{sl} + P_{vfs} \le 68\% \quad [4.3]$$

where: P_{sl} = percent silt, P_{vfs} = percent very fine sand based on the total soil primary particles and not just the portion of the sand content, and P_{cl} = percent clay. Although equation 4.2 was derived using regression analysis, Wischmeier et al. (1971) used judgment to graphically draw the k_t relationship for P_{sl} + P_{vfs} percentage above 68 percent. The RUSLE2 equations fitted to the Wischmeier et al. (1971) graphical curves is.

$$K_{t68} = 2.1[68(100 - P_{cl})]^{1.14} / 1000 \quad [4.4]$$

$$k_t = k_{tb} - [0.67(k_{tb} - k_{t68})^{0.82}] \qquad P_{sl} + P_{vfs} > 68\% \quad [4.5]$$

4.1.1.2. Organic matter subfactor

The equation for the soil erodibility nomograph organic matter subfactor is:

$$k_o = (12 - O_m) \quad [4.6]$$

where: O_m = percent inherent soil organic matter. Inherent organic matter is the organic matter content of the soil in unit plot conditions. The experimental plots used to develop the soil erodibility nomograph were not in unit plot condition (Wischmeier and Mannering, 1969). Above ground biomass was removed but the plots were not maintained in a tilled fallow condition for more than a few months. Soil organic matter had not reached inherent soil organic matter levels for unit plot conditions, which resulted in measured soil organic matter being higher than it would have been in unit plot conditions. However, measured erosion values were adjusted to remove land use residual effects from previous cover-management conditions (see **Section 6** and RUSLE2 User's Reference Guide).

The organic matter relationship in the soil erodibility nomograph should not be used to evaluate how biomass additions and organic farming practices affect rill and interrill erosion. Those effects are considered in RUSLE2's cover-management relationships (see **Section 6**). Furthermore, the experimental conditions used to derive the soil erodibility nomograph were very dissimilar to organic matter conditions associated with organic farming or application of manure, biological waste, or other biological soil amendments.

4.1.1.3. Soil structure subfactor

The soil erodibility nomograph soil structure subfactor refers to how the arrangements of soil primary particles in aggregates and the arrangement of aggregates in the soil affect erosion under unit plot conditions. Four structural classes are used in the nomograph. These classes are 1-very fine granular, 2-fine granular, 3-medium or coarse granular, and 4-blocky, platy, or massive. These classes are defined in the USDA-NRCS soil survey manual. The classes used to derive the soil erodibility nomograph were those in use in the mid-1960's when the experiments were conducted, which should be used to assign RUSLE2 values for soil structure.

The equation for the soil erodibility nomograph soil structure subfactor is:

$$k_s = 3.25(S_s - 2) \qquad \text{if } (k_t k_o + k_s) \geq 7 \qquad [4.7]$$

$$k_t k_o + k_s = 7 \qquad \text{if } (k_t k_o + k_s) < 7 \qquad [4.8]$$

where: S_s = the soil structure class. The graphical soil structure relationship in the soil erodibility nomograph has a slight "knee" close the origin of the subfactor (Wischmeier et al., 1971), which is represented with equation 4.8.

4.1.1.4. Soil profile permeability subfactor

The soil permeability subfactor is a measure of the potential of the soil profile in unit plot conditions for generating runoff. Six permeability classes that range from 1-rapid (very low runoff potential) to 6-very slow (very high runoff potential) are used to rate the soil profile for infiltrating precipitation and reducing runoff. The USDA-NRCS soil survey definitions for soil profile permeability used in the mid-1960's should be used to assign a soil permeability class in applying the soil erodibility nomograph. The assigned permeability class should not be based on a permeability measurement of the surface soil layer. The permeability rating should take into account the presence of restricting layers such as rock, claypan, or fragipan. Also, the rating should also take into account landscape position. For example, the permeability for a sandy soil underlain by a restricting layer might be moderate for the soil at the top of a hillslope but be very slow if the soil is at the bottom of the hillslope. The permeability rating should take into account the presence of rock fragments in the soil profile permeability rating should not reflect current or past cover-management on runoff; it is a rating for the soil in unit plot condition (see **Section 4.6** and RUSLE2 User's Reference Guide). The assigned permeability class can also be used to reflect how local climate affects the RUSLE2 soil erodibility factor.

The equation for the permeability subfactor is given by:

$$k_p = 2.5(P_r - 3) \qquad [4.9]$$

where: P_r = the soil profile permeability rating.

4.1.2. RUSLE2 modified soil erodibility nomograph

A review of soil erodibility factor values computed with the standard soil erodibility nomograph did not show the expected range or trend for very high sand soils and very high clay soils typical of highly disturbed lands, such as reclaimed mined land and construction sites . The soil structure subfactor did not provide the expected trend in soil erodibility values as a function of soil structure. Soil erodibility is expected to decrease as soil structure changes from very fine granular to blocky, platy, or massive because of the role of clay as a bonding agent and its effect on soil structure.

The unexpected trend in the soil structure subfactor most likely resulted from the empirical derivation of the standard soil erodibility nomograph from a relatively small database where the soils were predominantly medium texture. Consequently, the data points were not uniformly distributed among the major variables that affect soil erodibility. Furthermore, all of the nomograph variables are correlated with each other, which can result in empirical equations derived from a small database not reflecting proper trends for how major variables affect soil erodibility. For example, soil structure is related to soil texture. The soil structure subfactor in the standard soil erodibility nomograph may well represent an interactive effect rather than a main effect in the particular dataset used to derive the standard soil erodibility nomograph.

After reviewing measured erosion data from high clay soils typical of construction sites (Römkens et al., 1975; Römkens et al., 1977; Roth et al., 1974), the judgment was made to modify the soil structure subfactor in the standard nomograph. The modification results in the RUSLE2 modified nomograph computing soil erodibility values that decrease as soil structure goes from fine granular to blocky, platy, and massive and decrease as soil structure goes from fine granular to coarse granular. Soil erodibility factor values computed with the RUSLE2 modified soil erodibility nomograph are smaller than those computed with the standard nomograph for high clay and high sand soils.

4.1.2.1. Soil structure subfactor

The soil structure subfactor equation used in the RUSLE2 modified soil erodibility nomograph is given by:

$$k_s = 3.25(2 - S_s) \qquad [4.10]$$

The difference between this equation and the comparable equation, equation 4.7, in the standard soil erodibility nomograph is the algebraic sign on the variables in the second term in equations 4.7 and 4.10. A nice feature of both the standard and the RUSLE2 modified nomographs is that they use equations referenced to a midpoint. The equations compute values about the midpoint well established by the experimental data. The midpoint for the soil structure subfactor is the fine granular structure. Both soil erodibility nomographs give the same soil erodibility factor values for the fine granular soil structure, but the two nomographs give different trends for departures from this midpoint soil structure.

4.1.2.2. Other subfactors in RUSLE2 modified soil erodibility nomograph

All other subfactors in the RUSLE2 modified soil erodibility nomograph are the same as those used in the standard nomograph.

4.1.3. Special soil erodibility cases

Special cases, described in the RUSLE2 User's Reference Guide, exist where neither RUSLE2 soil erodibility nomograph applies. Equations are available in AH703 (Renard et al., 1997) and elsewhere (El-Swaify and Dangler, 1976; Mutchler et al., 1976; Young and Mutchler. 1977; Roth et al., 1974) to estimate soil erodibility for some of these special conditions. However, these equations were not included in RUSLE2 even though some of them were included in RUSLE1 [AH703(Renard et al., 1997)]. The equations were judged to give poor results or to use variables that were not properly defined or could not be easily measured for input in typical RUSLE2 applications. Soil erodibility values can be user determined outside of RUSLE2 and entered in RUSLE2.

4.2. Rill to interrill soil erodibility

RUSLE2 computes a ratio of rill to interrill erosion used to compute a slope length exponent in equation 2.10 (e.g., see **Section 2.1.3**) and a **b** value in the subfactor equation for the ground cover effect on erosion (see **Section 6.2**). The RUSLE2 equation used to compute a value for the rill to interrill soil erodibility ratio is:

$$K_r / K_i = (P_{sd}/100)[(1-\exp(-0.05P_{sd})] + 2.7(P_{sl}/100)^{2.5}[1-\exp(-0.05P_{sl})] + 0.35(P_{cl}/100)[1-\exp(-0.05P_{cl})] \quad [4.12]$$

where: K_r/K_i = the rill to interrill soil erodibility ratio and all soil texture values are in percent. Rill to interrill soil erodibility ratio values computed with equation 4.12 are shown in Table 4.1 at the central point of the textural classes.

Equation 4.12, like many RUSLE2 equations, is based on computing variations about a mid or central point that is well established by experimental data. As shown in table 4.1, equation 4.12 gives a value of 1 for the reference silt loam soil. Equation 4.12 computes values that vary about one as soil texture deviates from silt loam. Although soil erodibility data from the Water Erosion Prediction Project (WEPP) were reviewed as the basis for deriving equation 4.12 (Elliot et al., 1989; Laflen et al., 1991), the equation was derived based on judgment. For example, increased clay content is assumed to reduce rill erosion much more rapidly than it reduces interrill erosion. Clay is bonding agent that is assumed to have a greater effect on rill erosion than on interrill erosion. Conversely, soils very high in silt are assumed to have increased rill erosion relative to interrill

Table 4.1. Rill to interrill soil erodibility ratio as a function of soil texture	
Soil textural class	Rill to interrill soil erodibility ratio
Clay	0.36
Clay loam	0.50
Loam	0.65
Loamy sand	0.82
Sand	0.89
Sandy clay	0.61
Sandy clay loam	0.65
Sandy loam	0.7
Silt	1.91
Silt loam	1.04
Silty clay	0.53
Silty clay loam	0.73

erosion. Soils high in sand are expected in two ways. Increased rill erosion is expected because of clay content that reduces soil cohesiveness that increases rill erosion more than interrill erosion. However, offsetting that increase is decreased runoff that is assumed would result to reduce rill erosion more than interrill erosion because rill erosion is directly related to runoff. Overall, the rill to interrill soil erodibility ratio is assumed to be reduced for soils high in sand but not as much as for soils high in clay.

Equation 4.12 quantifies concepts and advice that users were expected to consider in RUSLE1 for selecting LS and ground cover effect relationships [(AH703 (Renard et al., 1997)]. Equation 4.12 is considered to be a significant improvement over RUSLE1procedures.

4. 3. Very fine sand

Soil texture is the single most important variable in estimating soil erodibility. In many cases, the standard soil texture such as clay loam, silt loam, or sandy loam based on the USDA classification may be known or can be estimated. However, as Wischmeier et al. (1971) found, this standard classification does not work as well as including the very fine sand fraction with the silt fraction. Unfortunately, although the sand, silt, and clay content may be known for a soil, information on the very fine sand fraction may not be available. A mechanical analysis of the soil is required to determine the very fine sand fraction. The following RUSLE2 equation was developed to estimate the very fine sand fraction from sand, silt, and clay content:

$$P_{vfs} = (0.74 - 0.62 P_{sd} / 100) P_{sd} \qquad [4.11]$$

where: P_{vfs} and P_{sd} are in percent. Regression analysis was used to fit equation 4.11 to the USDA-NRCS soil survey data for Lancaster County, Nebraska.

4.4. Spatial soil erodibility variability

Even when soil properties are identical, RUSLE2 soil erodibility factor values vary with location because of climatic differences among locations. For example, erosion is greater per unit rainfall erosivity in locations such as the southern US, where frequent, high, and intense rainfall occurs, than in the northern Great Plains. Average annual soil erodibility factor values are also related to the temporal distribution of erosive precipitation that varies among locations.

The RUSLE2 soil erodibility nomographs do not take these factors into consideration. The data used to derive the soil erodibility nomographs were produced by uniform intensity simulated rainfall applied in a sequence of three events. The first simulated storm was 60 minutes of rainfall at 2.5 in/hr on dry soil conditions. The second storm was 30 minutes of rainfall at 2.5 in/hr approximately 24 hour later. The third storm was also 30 minutes long at 2.5 in/hr that occurred approximately 15 minutes after the second storm. When Wischmeier et al. (1971) developed the standard soil erodibility nomograph, they weighted measured erosion values produced by each simulated storm to compute an average annual soil erodibility factor value. This sequence of storms reflects the likelihood of a storm on dry conditions than on wet conditions.

This weighting procedure was assumed to apply at all locations, which is probably satisfactory for conservation planning on cropland in the eastern US. However, major questions arise about applying the soil erodibility nomograph to the western US where the precipitation patterns and rainfall amounts and intensities differ significantly from that used to derive the soil erodibility nomograph.

Although questions can be raised about the applicability of the soil erodibility nomograph for these and other reasons, the RUSLE2 assumption is that the nomographs provide soil erodibility values suitable for conservation and erosion control planning. Some of the nomograph issues are not significant with respect to conservation planning when uncertainty in the RUSLE2 soil erosion estimates are considered (See Section 17, RUSLE2 User's Reference Guide) because other factors have a must greater effect on rill-interrill erosion than does the soil erodibility factor. However, the issue of soil erodibility being a function of rainfall amounts, intensities, and temporal patterns are mathematically important when using RUSLE2 to estimate rill-interrill from rainfall on irrigated lands (see **Section 7.5**).

4.5. Temporal soil erodibility factor values

Along with factors for slope length, cover-management, and supporting practices, the RUSLE2 soil erodibility factor temporally varies (Mutchler and Carter, 1983). Erosion is significantly increased if peak soil erodibility occurs, for example, when cover-management conditions are most susceptible to erosion. An equation is needed to compute daily soil erodibility so that daily erosion can be computed to improve the mathematical accuracy of the RUSLE2 (see **Section 2.1**).

RUSLE2's temporal soil erodibility is high for thawing soil and for the immediate period after the soil has thawed because the soil's susceptibility to detachment is increased (Van Klaveren and McCool, 1998.). Also, soil erodibility is high when soil moisture is high, which increases runoff per unit rainfall and hence erosion per unit erosivity. Erosion on the unit plot per unit erosivity is soil erodibility in RUSLE2. Runoff per unit rainfall is increased on the unit plot, and hence rill erosion is increased, when rainfall is frequent and soil evaporation is low. Soil erodibility may also be related to biological activity in the soil, which is a function of soil moisture and temperature (Vigil and Sparks, 2004).[34]

[34] The RUSLE2 soil erodibility factor is solely related to unit plot conditions. Soil erodibility is also influenced by cover-management conditions but those effects, such as related to soil moisture and runoff, are considered in cover-management variables (see **Section 6**).

Although the reasons for soil erodibility temporally varying are partially known, adequate equations for temporal soil erodibility are lacking. Temporal soil erodibility variability seems well defined at Morris, Minnesota and Holly Springs, Mississippi (Mutchler and Carter, 1983), but not at other locations. A complicating factor is the timing of plot maintenance with highly erosive rains. The unit plots used to experimentally determine soil erodibility factor values are periodically tilled to break the soil crust and to control weeds. Erosion per unit erosivity, hence RUSLE2's soil erodibility factor, can be very high if a highly erosive rain occurs immediately after plot tillage.

The RUSLE1 temporal soil erodibility equations were reexamined and found to work poorly at most of the 11 locations where temporal soil erodibility data are available. Also, the equations performed very poorly in Minnesota and northern Iowa where computed temporal soil erodibility factor values varied too much with slight differences in weather between adjacent counties. Furthermore, the empirically derived RUSLE1 temporal soil erodibility equations are not applicable in the Western US. Consequently, a new temporal soil erodibility equation was derived for RUSLE2 using data collected at the locations listed in Table 4.2. The record length for these data is about 10 years.

Table 4.2. Locations where unit plot conditions were used to determine monthly soil erodibility factor values

Location
Tifton, GA
Watkinsville, GA
Holly Springs, MS
Bethany, MO
Independence, IA
Beaconsfield, IA
Castana, IA
Clarinda, IA
Morris, MN
LaCrosse, WI
Presque Isle, ME

Temporal soil erodibility values grouped by geographic area are shown in Figure 4.1. A similar pattern in the temporal erodibility values by location was expected for each geographic area, especially for the four Iowa locations. The patterns are similar for the two northern Midwestern US and Northern Maine locations where almost no rill-interrill erosion occurs during the winter. The patterns are mostly similar for the two Georgia locations but differ significantly from the pattern at Holly Springs, Mississippi. The difference in patterns, especially among the Iowa locations, indicates that other variables besides weather, such as timing of plot maintenance with erosive rains, affect temporal soil erodibility.

With the exception of the southern locations, the data do not capture the increased soil erodibility in late winter and early spring during and immediately after soil thawing. The very few data available points for these conditions are not usable because of very large variability. In many cases, measurements were not made during in late winter and early spring because measuring equipment was difficult to operate during cold weather. Also, increased soil erodibility during the thawing and recently thawed period seems to be related to a unique set of conditions that do not occur every year.

Regardless of these limitations, a temporal soil erodibility equation seemed advisable for

RUSLE2. This equation was empirically derived from these data for RUSLE2.

4.5.1. Basic assumptions

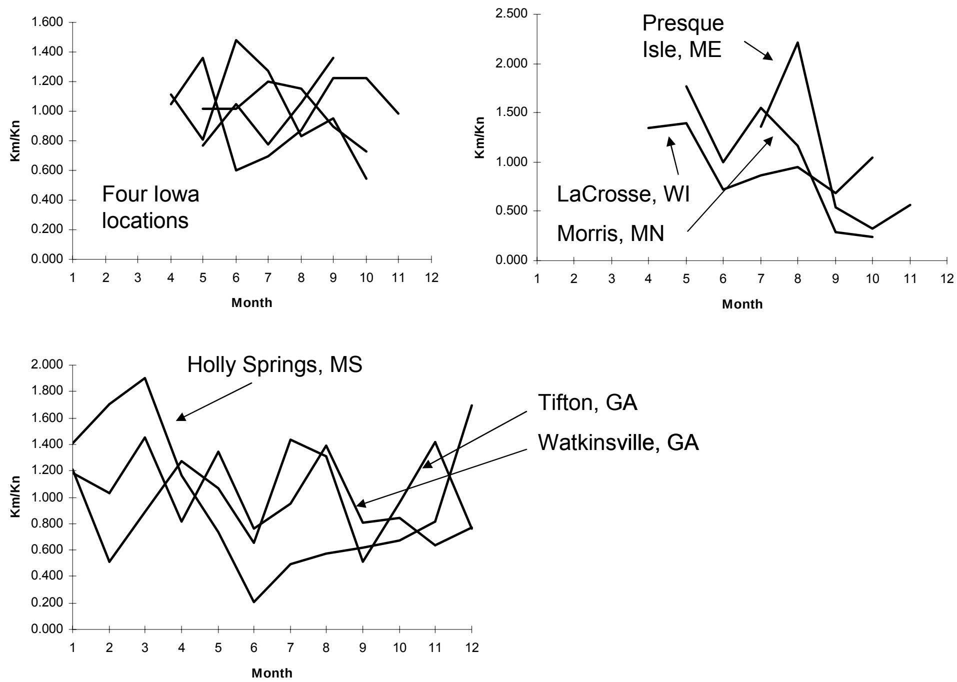


Figure 4.1. Monthly variation in soil erodibility at several locations.

The RUSLE2 assumption is that the soil erodibility value entered in RUSLE2, whether user entered or computed with either of the RUSLE2 soil erodibility nomographs, represents average soil erodibility for a summer period. This summer period as defined in RUSLE2 for temporal soil erodibility purposes is when average daily temperature exceeds 40 oF. Analysis of soil erodibility data at Pullman, WA indicates that a better definition is the time between when average daily temperature reaches 45 oF early in the year to when it decreases to 35 oF late in the year. RUSLE2 does not vary the base soil erodibility value by location (see **Section 4.1**), but users can enter soil erodibility values to represent how base soil erodibility values differ as weather patterns vary but soil properties are the same among locations.

The major assumption used to derive the RUSLE2 temporal soil erodibility equation is that monthly precipitation and temperature can be used as indices to estimate the temporal variability in soil erodibility during the RUSLE2 summer period.

4.5.2. Temporal soil erodibility for the summer period

Average values for the ratio of monthly soil erodibility to average soil erodibility were computed for the data collected the locations listed in Table 4.2. Average soil erodibility was computed as the total erosion for the period of record divided by total erosivity, excluding storms less than 0.5 inches (see **Section 3.2.1**). The period of record at all locations closely corresponded to the RUSLE2 summer definition except at the southern US locations because the plots were not operated during the winter as can be seen in Figure 4.1.

The resulting equation from fitting the data is:

$$K_j / K_n = 0.704 - 0.336 T_j / T_s + 0.632 P_j / P_s \qquad [4.12]$$

where: K_j = average daily soil erodibility factor value for the *jth* day, K_n = soil erodibility value from the RUSLE2 soil erodibility nomographs or user entered into RUSLE2, T_j = average daily temperature for the *jth* day (oF), T_s = the average temperature for the RUSLE2 summer period defined above, P_j = the average daily precipitation, and P_s = the average precipitation for the RUSLE2 summer period. This equation follows the expected trends of increased soil erodibility when precipitation is high and decreased soil erodibility when temperature is high. Equation 4.12 does not describe increased soil erodibility during or immediately after soil thawing.

The fit of equation 4.12 to the observed data at three locations is shown in Figure 4.2, which also represents the fit at the other locations. Equation 4.12 is a major improvement over the RUSLE1 equations as can be seen by inspection and by comparing the sum of squares of differences between observed and computed values. However, the fit of equation 4.12 is only slightly better than assuming a time invariant soil erodibility factor value for the summer period.

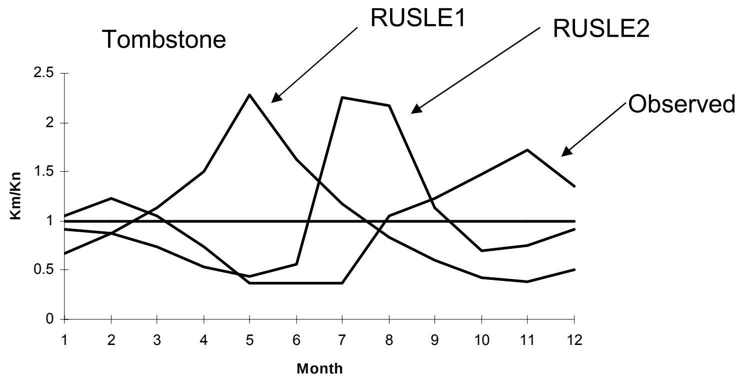


Figure 4.3. Fit of temporal erodibility equations to data from simulated rainfall on rangeland plots at Tombstone, Arizona.

Computed values from equation 4.12 are shown in Figure 4.3 for Tombstone, Arizona and compared to values computed with the RUSLE1 equations and observed values. Very clearly, equation 4.12 performs much better than the RUSLE1 equations, which illustrates why a time invariant soil erodibility factor value should be assumed when applying RUSLE1 to the western US. The observed values shown in Figure 4.3 were obtained by applying rainfall each month with a rainfall simulator.[35] The observed values are not directly comparable to soil erodibility values produced by natural precipitation because of temporal differences between natural precipitation and the uniform precipitation of the simulated rainfall. Nevertheless, the fit of equation 4.12 to the observed Tombstone, Arizona data is comparable to the fit of equation 4.12 to soil erodibility values produced by natural rainfall in the eastern US.

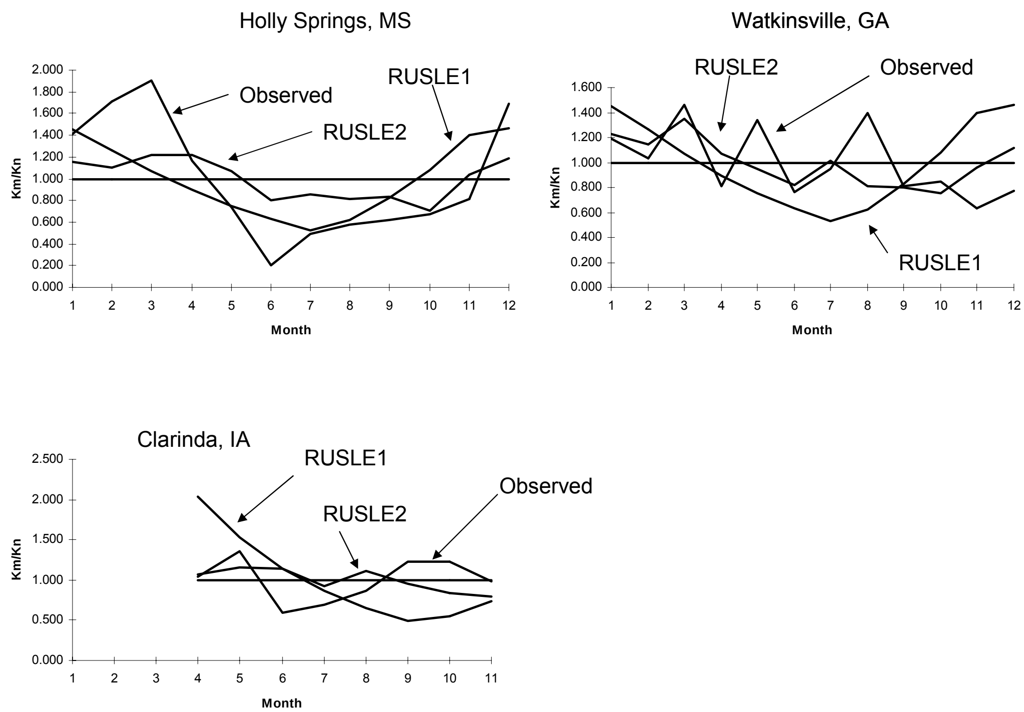


Figure 4.2. Fit of RUSLE2 temporal erodibility equation (equation 4.12), RUSLE1 equation, and constant value to observed data.

---

[35] These experiments were conducted by K. G. Renard and J. R. Simanton, USDA-Agricultural Research Service, Tucson, Arizona.

Therefore, the recommendation is that the RUSLE2 temporal soil erodibility equation be used for all locations in the US except for Req periods (see **Section 3.2.5** and RUSLE2 User's Reference Guide).

4.5.2. Temporal soil erodibility for the winter period

Equation 4.12 is used to compute temporal RUSLE2 soil erodibility factor values in the winter period as well as the summer period, except when average daily temperature is less than 30 oF. The RUSLE2 temporal soil erodibility equation for average daily temperature less than 30 oF is:

$$K_j / K_n = (K_{s,j} / K_n)\exp[-0.2(30 - T_j)] \qquad [4.13]$$

where: $K_{s,j}$ = the soil erodibility factor value computed with equation 4.12 on the *jth* day, Tj = the average daily temperature on the *jth* day (oF), and 30 = the average daily temperature at which soil erodibility is reduced because of soil freezing (oF). The *exp* term in equation 4.13 computes a value less than 0.05 when average daily temperature is less than15 oF. The exponential decay term in equation 4.13 takes into account the fact that temperature in some years on a given day will not be less than freezing even though average daily temperature is below freezing. Also, the temperature used in equation 4.13 is air temperature rather than soil temperature.

Equation 4.13 does not compute increased erosion during and immediately after soil thawing.

4.5.3. Temporal soil erodibility for the Req regions

Winter erosion processes differ greatly from summer erosion processes in the Northwest Wheat and Range Region (NWRR) and other areas in the Western US (McCool et al., 1995). Soil erodibility is very high during the winter in these regions, resulting in very high erosion. This winter effect is accounted for in RUSLE2 by assuming an equivalent erosivity known as Req. Equation 4.12 can be used to estimate temporal erodibility for the summer period defined as the time between the day when average daily temperature reaches 45 oF early in the year and decreases to 35 oF late in the year. Equation 4.13 does not apply where Req effects are assumed to occur (see **Section 3.2.5** and RUSLE2 User's Reference Guide).

4.6. Effect of rock on soil erodibility

Rock on and in the soil affects rill-interrill erosion. RUSLE2 treats rock on the soil surface as ground cover (see **Section 6.2**). Rock in the soil is assumed to affect runoff and this effect on erosion is represented by choosing a soil erodibility factor value based on how rock in the soil profile is assumed to affect runoff under unit plot conditions. User entered soil erodibility values should reflect how rock in the soil profile affects erosion but not account for any effect of rock on the soil surface.

The permeability class input should reflect how rock in the soil profile affects runoff when a RUSLE2 soil erodibility nomograph is used to compute a soil erodibility factor value. Although RUSLE2 includes the RUSLE1 soil erodibility nomograph equations used to estimate how rock in the soil profile affect soil erodibility (Römkens et al., 1997), these equations should not be used in RUSLE2, especially for construction sites and reclaimed surface mine lands. Toy, T.J. and G.R. Foster (1998) describes how to adjust input values to the RUSLE2 modified soil erodibility nomograph to estimate the effect of large rock fragments in the soil on soil erodibility.

A value for soil surface cover provided by rock that is a natural part of the soil can be entered in RUSLE2's soil input. RUSLE2 assumes that this rock cover is not be affected by mechanical soil disturbing operations. Rock cover can also be represented in RUSLE2 as an operation that adds surface cover, but RUSLE2 handles this rock cover differently from how it handles rock cover entered in the soil input. Rock cover represented as surface cover added by an operation is affected by soil disturbing operations and RUSLE2 treats this rock as an organic material. Special inputs are required when rock cover is represented in this way (see **Section 10.1** and RUSLE2 User's Reference Guide).

The USDA-NRCS soil survey database includes soil erodibility factor values that have been adjusted for rock cover on the soil surface. **NRCS soil erodibility factors values adjusted for rock surface cover must not be used in RUSLE2.** The ground cover subfactor relationship used by NRCS to adjust for rock surface cover differs from the comparable RUSLE2 relationship (see **Section 6.2.1**). The surface cover relationship used by the NRCS is the USLE mulch cover subfactor [AH537 (Wischmeier and Smith, 1978)], which has an approximate 0.026 **b** value whereas the approximate RUSLE2 **b** value is 0.035. The error in estimated erosion from this difference for a 20 percent rock cover is 20 percent. Also, RUSLE2 uses a net ground cover that takes into account surface residue and live ground cover overlapping rock surface cover. This overlap is not taken into account when NRCS soil erodibility factor values adjusted for rock surface cover are used, which can result in serious errors because the ground (mulch) cover relationships are highly non-linear (see RUSLE2 User's Reference Guide). The error in estimated erosion from neglecting the overlap for a 50 percent residue cover and a 20 percent rock cover is 30 percent even when if the proper **b** value had been used in the NRCS adjustment.

4.7. Sediment characteristics

RUSLE2 computes deposition and enrichment ratio as a function of sediment characteristics (see **Sections 2.3.3** and **4.7.6**). Diameter, specific gravity, distribution among sediment particle classes, and composition of sediment particle classes are the RUSLE2 variables used to describe sediment characteristics. RUSLE2 uses only soil texture and inherent soil organic matter content to compute values for sediment characteristics at the point of detachment although soil management affects these sediment characteristics. Sufficient information was not available to develop equations for the effect of soil management on sediment characteristics at the point of detachment.

The RUSLE2 equations used to compute sediment characteristics at the point of detachment are described by (Foster et al., 1985). The RUSLE2 intent in representing sediment characteristics is to capture main effects rather than to precisely represent all variables that affect sediment characteristics at the point of detachment. Also, more detail, such as more than five sediment particle classes, than is used in RUSLE2 equations is desired for computing deposition. However, the desired information is not easily available for most applications of RUSLE2 as a conservation planning tool in local field offices. The RUSLE2 approach is far better than assuming that sediment characteristics at the point of detachment are the same as the characteristics of dispersed samples of the soil subject to detachment. A critically important point is that sediment is eroded as a mixture of aggregates and primarily particles. Assuming that sediment is composed entirely of primary particles produces serious errors when computing deposition. RUSLE2 computes how deposition changes sediment characteristics so that the characteristics of sediment leaving an overland flow path, terrace/diversion channels, and small impoundments can be quite different from the characteristics of the soil being eroded, especially where RUSLE2 computes a high degree of deposition.

4.7.1. Definition of sediment particle classes

Five sediment particle classes are used to represent the sediment produced by detachment for each soil along an overland flow path. The five classes are primary clay, primary silt, small aggregate, large aggregate, and primary sand. Sediment from cohesive soils is eroded as a mixture of primary particles (small mineral particles that the soil can be divided into) and aggregates (conglomerates of primary particles) (Foster et al., 1985). Also, the sediment distribution for many cohesive soils is bimodal, having a peak in the silt-size range and a peak in the sand-size range (Meyer et al., 1980). The two aggregate sediment particle classes represent these two peaks in the sediment distribution. The three primary sediment particle classes represent primary particles in the sediment while the two aggregate classes represent aggregates in the sediment.

4.7.2. Density of sediment particle classes

Densities, expressed as specific gravity, of the sediment particle classes are given in Table 4.3. The slightly reduced density for the primary clay class relative to the primary silt and sand classes is because of the platy nature of clay particles. The difference is of no consequence in RUSLE2. The significantly reduced densities of the aggregate classes from the primary particle classes reflect how aggregates are conglomerates of primary particles with internal open spaces in them that are partially or fully filled with water. Sediment particle density is especially important for sediment sizes larger than 0.1 mm because density seems to affect deposition by overland flow as much as size (Lu et al., 1988; Neibling and Foster, 1982). A smaller density is

Table 4.3. Densities of sediment particle classes

Particle class	Density (specific gravity)
Primary clay	2.60
Primary silt	2.65
Small aggregate	1.80
Large aggregate	1.60
Primary sand	2.65

assigned to the large aggregate class than to the small aggregate class because density decreases as aggregate size increases (Foster et al., 1985).

4.7.3. Diameter of sediment particle classes

The diameter of the sediment particle classes is given in Table 4.4. The diameter of each primary particle class is fixed. However, the diameter for each aggregate sediment particle class varies with soil clay content, which reflects the role of clay as a bonding agent.

Table 4.4. Diameter of sediment particle classes.

Particle class	Diameter		
	Symbol	Size (mm)	Condition
Primary clay	$d_{se,cl}$	0.002	
Primary silt	$d_{se,sl}$	0.010	
Small aggregate	$d_{se,sa}$	0.030	$P_{cl} < 25$
	$d_{se,sa}$	$0.2*(P_{cl}/100-0.25)+0.03$	$P_{cl} < 25 < P_{cl} <60$
	$d_{se,sa}$	0.100	$P_{cl} > 60$
Large aggregate	$d_{se,la}$	0.300	$P_{cl} < 15$
	$d_{se,la}$	$2*P_{cl}/100$	$P_{cl} > 15$
Primary sand	$d_{se,sd}$	0.300	

The diameter of each aggregate class is a function of soil clay content for certain ranges of clay content. RUSLE2 adds aggregate sediment particle classes as necessary along the overland flow path where soil clay differs by segment to represent unique particle classes having different diameters. The same primary sediment particle classes are used for all soils along an overland flow path because the diameters of these classes do not vary with soil.

4.7.4. Distribution of sediment mass among particle classes at point of detachment

As shown in Table 4.5, the distribution of sediment mass among the sediment particle classes at the point of detachment depends mainly on the soil's clay content. Seventy four percent of the clay in the sediment at the point of detachment is in the aggregate sediment particle classes while only 26 percent is in the primary clay sediment particle class.

Table 4.5. Distribtuion of sediment mass among particle particle classes				
Particle class	Fraction			
	Symbol		Condition	Comment
Primary clay	F_{cl}	$0.26*P_{cl}$		
Primary silt	F_{sl}	$P_{sl}/100-F_{sa}$		
Small aggregate	F_{sa}	$1.8*P_{cl}/100$	$P_{cl} < 25$	
	F_{sa}	$0.45-0.6*(P_{cl}/100-0.25)$	$P_{cl} < 25 < P_{cl} < 50$	If $F_{sl} < 0$, $F_{sl} = 0.0001$ and
	F_{sa}	$0.6*P_{cl}/100$	$P_{cl} > 50$	$F_{sa} = P_{sl}/100 - F_{sl}$
Large aggregate	F_{la}	$1-F_{cl}-F_{sl}-F_{sa}-F_{sd}$		If $F_{la} < 0$, each fraction is multiplied by the same fraction to give $F_{la} = 0.0001$
Primary sand	F_{sd}	$(P_{sd}/100)*(1-P_{cl}/100)^5$		

Soil clay content determines the fraction of the sediment mass that is in the small aggregate sediment particle class at the point of detachment. The fraction of the sediment in the primary silt class at the point of detachment is the soil's silt content less the silt fraction computed to be in the small aggregate class. The fraction of sediment mass in the small aggregate class at the point of detachment can not be larger than the silt content in the soil.

Both clay and sand content in the soil determine the fraction of the sediment mass that is in the primary sand sediment particle class at the point of detachment. The role of soil clay content in determining this fraction increases rapidly as soil clay content increases. The fraction of sediment mass in the large aggregate sediment particle class at the point of detachment is computed as 1 minus the sum of the fractions of the other four sediment particle classes. The fractions for the other four classes are adjusted when the fraction of the large aggregate sediment particle class is computed as being less than zero.

4.7.5. Composition of each sediment particle class

Detachment in RUSLE2 is assumed to be non-selective. Consequently, the sediment's primary particle composition at the point of detachment is the same of the composition of the surface soil subject to detachment.

4.7.5.1. Primary clay sediment particle class

The primary sediment particle is composed of primary clay and the organic matter associated with the clay.[36] The RUSLE2 assumption is that the ratio of organic matter to

[36] The terms clay, silt, and sand sometimes refer to particle sizes. However, as used herein, clay, silt, and

clay on a mass basis is the same for all sediment particle classes where clay is present. That ratio is given by:

$$r_{om,cl} = P_{om} / P_{cl} \qquad [4.14]$$

where: $r_{om,cl}$ = the fraction (mass) of the primary clay sediment particle class that is composed of organic matter and P_{om} = 100 times the ratio of mass of organic matter in the soil to the mass of soil mineral particles. The fraction of the primary clay sediment particle class that is composed of organic equals $r_{om,cl}$.

4.7.5.2. Primary silt sediment particle class

The primary silt sediment particle class is composed solely of silt. This particle class contains no organic matter because the class contains no clay.

4.7.5.3. Small aggregate sediment particle class

The small aggregate sediment particle class is composed of clay, silt, and organic matter. This particle class contains no sand by definition. The size of the small aggregate particle class is too small to contain any sand except very fine sand. However, the RUSLE2 assumption is that this particle class does not contain even very fine sand. The distribution of the clay and silt is assumed to equal the proportion of clay and silt in the soil subject to detachment. That is,

$$f_{cl,sa} = P_{cl} /(P_{cl} + P_{sl}) \qquad [4.15]$$

where: $f_{cl.sa}$ = the fraction (mass) of the small aggregate that is composed of clay. The fraction of the small aggregate that is composed of silt is given by:

$$f_{sl,sa} = Pl_{si} /(P_{cl+} + P_{sl}) \qquad [4.16]$$

where: $f_{sl,sa}$ = the fraction (mass) of the small aggregate that is composed of silt. The fraction of the small aggregate that is composed of organic matter is given by:

$$f_{om,sa} = r_{om,cl} \, f_{cl,sa} \qquad [4.17]$$

where: $f_{om,sa}$ = fraction of the small aggregate sediment class composed of organic matter.

4.7.5.4. Large aggregate sediment particle class

The large aggregate sediment particle class is assumed to be composed of clay, silt, sand, and organic matter. The total of each constituent among the sediment particles classes must equal the constituent's amount in the soil. The mass of a constituent, except organic

---

sand refer to mineral particles in the clay, silt, and sand sizes.

matter, in the large aggregate is computed as the total minus the sum of that constituent in the other sediment particle classes That is:

$$f_{cl,la} = (P_{cl}/100 - F_{cl} - f_{cl,sa}F_{sa})/F_{la} \quad [4.18]$$

$$f_{sl,la} = (P_{si}/100 - F_{si} - f_{sl,sa}F_{sa})/F_{la} \quad [4.19]$$

$$f_{sd,la} = (P_{sd} - F_{sa})/F_{la} \quad [4.20]$$

Equations 4.18-4.20 directly result from the RUSLE2 assumption that detachment is a non-selective process, which requires that the distribution of the constituents in the sediment at the point of detachment be the same as that in the soil subject to detachment. A check is made of the clay content in the large aggregate sediment particle class. Because clay and the organic matter associated with it are assumed to be bonding agents for the two aggregate classes, clay must be sufficient in the large aggregate class to give those particles stability. To meet this requirement, the RUSLE2 assumption is that the clay content in the large aggregate class must be at least half of the soil's clay content. If the clay content in the large aggregate particle class computed with equation 4.18 is less than half the soil's clay content, the fraction F_{sa} of the small aggregate sediment particle class is reduced to meet this requirement.

The fraction of the organic matter in the large aggregate sediment particle class is given by:

$$f_{om,la} = f_{cl,la}r_{om,cl} \quad [4.21]$$

4.7.5.5. Primary sand sediment particle class

The primary sand class is solely composed of sand. It contains no organic matter because it contains no clay.

4.7.6. Specific surface area

Each constituent of clay, silt, sand, and organic is assigned a specific surface area so that RUSLE2 can compute an enrichment ratio based on specific area of the soil subject to detachment and the computed sediment yield from the overland flow path, terrace/diversion channel, or small impoundment, represented in a RUSLE2 computation. Specific surface is the total surface area of the soil or sediment per unit mass. The specific surface areas used in RUSLE2 are given in Table 4.6, which were used in the CREAMS model (Foster et al.1980; Foster et al., 1981). As Table 4.6 shows, most of the surface area is associated with organic matter and clay with almost no specific surface area associated with sand. Because organic matter is directly associated with the clay, the specific surface of both the soil and the sediment is directly related to clay content in each.

Specific surface area of the soil subject to detachment and the sediment leaving the RUSLE2 flow path is used to compute an enrichment ratio as:

$$E_r = S_{sed} / S_{soil} \qquad [4.22]$$

where: E_r = enrichment ratio, S_{sed} = the specific surface area of the sediment and S_{soil} = the specific surface area of the soil. The enrichment ratio is a measure of the degree that RUSLE2 computes that deposition enriches the sediment in fine particles, especially clay. Deposition is a selective process that first deposits particles that are coarse and dense, which have a low specific surface area, leaving the sediment enriched in fine particles that have a high specific surface area. The enrichment ratio increases as the degree of deposition increases. A sediment delivery ratio can be computed as the ratio of sediment yield at the end of the RUSLE2 flow path divided by the total amount of sediment produced by detachment. Enrichment ratio increases as the sediment delivery ratio decreases. A low sediment delivery ratio represents a high degree of deposition. Enrichment ratio is a relative term and not an absolute term. A high enrichment ratio means that the specific area of the sediment is greater than that of the soil that produced the sediment, but the specific surface area of the sediment may still be low if the soil being eroded has a high sand content and a low inherent organic matter content.

Table 4.6. Specific surface

Constituent	Specific surface area (m^2/g)
Clay	20
Silt	4
Sand	0.05
Organic matter	1000

The enrichment ratio computed by RUSLE2 is strongly affected by soil texture as shown in Table 4.7. Interestingly, the highest enrichment ratio is for a sand soil while the lowest enrichment ratio is for a high silt soil. Enrichment ratio values are moderate for high clay soils. These results are directly related to the sediment being a mixture of aggregates and primary particles, the role of clay as a bonding agent in determining size of the large the aggregates, and the distribution of sediment between the small aggregate and large aggregate sediment particle classes. An important point to remember when interpreting and using the RUSLE2 computed enrichment ratio values is that about 74 percent of the clay is in the small and large aggregate particle classes at the point of detachment. RUSLE2 computes that a moderate sized large aggregate class is deposited at a rate comparable to the primary sand sediment particle class. Because much of the clay is assumed to be in the large aggregate class, a significant amount of clay is deposited when the large aggregate class is deposited.

Table 4.7. RUSLE2 computed enrichment ratios for a filter strip

Soil textural class	Enrichment ratio
Clay	1.95
Clay loam	2.23
Loam	2.65
Loamy sand	7.56
Sand	11.50
Sandy clay	2.13
Sandy clay loam	3.07
Sandy loam	3.47
Silt	0.94
Silt loam	1.58
Silty clay	1.19
Silty clay loam	1.44

The enrichment ratio values computed by RUSLE2 are very different from those that would be computed if the sediment at the point of detachment was assumed to be composed entirely of primary particles. High sand soils have very low clay contents such that the portion of the sediment in the aggregates classes at the point of detachment is low. The aggregate classes, which contain most of the clay, have small diameters for high sand soils and are, therefore, less readily deposited. Consequently, the enrichment ratio for sediment from high sand soils is generally high as illustrated in Table 4.7. In contrast, the diameters of both the small and large aggregate classes, which contain most of the clay, are very large for the high clay soils. These aggregates classes are more readily deposited than the aggregate classes produced by high sand soils. The result is that a higher fraction of the clay in a high sand soil is left in the sediment after deposition than for a high clay soil.

Essentially no enrichment occurs with the high silt soil because of the very low clay content and a very high portion of the sediment at the point of detachment being in the primary silt class that is not readily deposited. Most of the clay is in the aggregate classes that are more readily deposited than the primary silt class where most the sediment is concentrated at the point of detachment.

Although specific surface area of clay varies significantly with clay mineralogy, RUSLE2 does not consider that effect. Also, RUSLE2 uses the inherent soil organic matter content under unit plot conditions in these computations. Soil organic matter content as influence by cover-management is a more appropriate measured than inherent soil organic matter content.

The enrichment ratio values computed by RUSLE2 represent an index. The enrichment ratio value indicates the concentration of sediment associated chemicals in the sediment relative to their concentration in the soil. Calibration should be used to empirically relate the concentration of chemicals on sediment to the RUSLE2 enrichment ratio values because the values computed by RUSLE2 are lower than expected (Knisel et al., 1980).

4.8. Time to soil consolidation

Soil consolidation refers to the soil becoming resistant to erosion over time after a mechanical soil disturbance and not to a mechanical increase in bulk density of the soil (see **Section 6.6**). RUSLE2 computes time to soil consolidation as function of annual precipitation using:

$$t_c = 20 \qquad P_a < 10 \qquad [4.23]$$

$$t_c = 26.5 - 0.65P_a + 0.5 \qquad 10 \le P_a \le 30 \qquad [4.24]$$

$$t_c = 7 \qquad 30 < P_a \qquad [4.25]$$

where: t_c = the time to soil consolidation in years and P_a = annual precipitation in inches. The equation that computes values for the soil consolidation subfactor uses the ratio of time since last mechanical soil disturbance to time to soil consolidation and computes subfactor values that asymptotically approach the 0.45 final value (see **Section 6.6.2**).

The time to soil consolidation is defined as the time for 95 percent of the reduction in the soil consolidation subfactor to occur. The time to soil consolidation occurs when the soil consolidation factor equals 0.4775, which is 95 percent of the decrease from 1 for the soil consolidation subfactor immediately after a mechanical soil disturbance to the final 0.45 value.

After a mechanical soil disturbance, the soil becomes resistance to detachment by the soil experiencing wetting and drying cycles in the presence of soil moisture and bonding agents including clay and organic matter (Foster et al., 1985). Mechanical compaction of the soil is assumed in RUSLE2 to have little effect on this increase in erosion resistance. The seven year time to soil consolidation is based on analysis of fallow plot data from Zanesville, Ohio (Borst et al., 1945), which are the only sufficient data available to empirically determine time to soil consolidation. This seven year is assumed to apply to all areas where annual precipitation is greater than 30 inches. The increase of time to soil consolidation based on average annual precipitation is an approximate way to capture the idea that soil consolidation occurs more slowly in the western US than in the eastern US because of reduced rainfall and rainfall occurrences. Equations 4.23 and 4.24 are based on judgment.

List of symbols

b = coefficient used to compute ground cover subfactor values
$d_{se,cl}$ = diameter of primary clay sediment class (length)
$d_{se,la}$= diameter of large aggregate sediment class (length)
$d_{se,sa}$= diameter of small aggregate sediment class (length)
$d_{se,sd}$ = diameter of primary sand sediment class (length)
$d_{se,sl}$ = diameter of primary silt sediment class (length)
E_r = enrichment ratio
$f_{cl.la}$ = mass portion of large aggregate sediment class composed of clay
$f_{om,la}$ = mass portion of large aggregate sediment class composed of organic matter
$f_{sl,la}$ = mass portion of large aggregate sediment class composed of silt
$f_{sd,la}$ = mass portion of large aggregate sediment class composed of sand
$f_{cl.sa}$ = mass portion of small aggregate sediment class composed of clay
$f_{sl,sa}$ = mass portion of small aggregate sediment class composed of silt
$f_{om,sa}$ = mass portion of the small aggregate sediment class composed of organic matter
F_{cl} = portion of sediment at point of detachment composed of primary clay sediment class
F_{la} = portion of sediment at point of detachment composed of large aggregate sediment class
F_{sa} = portion of sediment at point of detachment composed of small aggregate sediment class
F_{sl} = portion of sediment at point of detachment composed of primary silt sediment class
F_{sd} = portion of sediment at point of detachment composed of primary silt sediment class
k_o = organic matter subfactor in soil erodibility nomograph
k_p =soil profile permeability subfactor in soil erodibility nomograph
k_s = soil structure subfactor in soil erodibility nomograph
k_t = texture subfactor in soil erodibility nomograph
k_{tb} = base soil texture subfactor in soil erodibility nomograph
K = USLE soil erodibility factor
K_j = average daily soil erodibility factor value for the *jth* day
K_n = soil erodibility value from RUSLE2 soil erodibility nomographs or user entered
K_r/K_i = the rill to interrill soil erodibility ratio
$K_{s,j}$ = soil erodibility factor computed with soil erodibility equation for summer period on *jth* day
O_m = inherent soil organic matter (percent)
P_a = annual precipitation (length)
P_{cl} = portion of soil mass based on total soil primary particles composed of clay (percent)
P_j = average daily precipitation (length)
P_{om} = 100 times ratio of mass of organic matter in soil to mass of soil mineral particles
P_r = soil profile permeability rating used in soil erodibility nomograph
P_s = average precipitation for the RUSLE2 summer period (length)
P_{sd} = portion of soil mass based on total soil primary particles composed of sand (percent)
P_{sl} = portion of soil mass based on total soil primary particles composed of silt (percent)
P_{vfs} = portion of soil mass composed of very fine sand based on the total soil primary particles and not just the portion of the sand content (percent)

$r_{om,cl}$ = mass portion of the primary clay sediment class composed of organic matter
S_s = soil structure class used in soil erodibility nomograph
S_{sed} = the specific surface area of the sediment
S_{soil} = the specific surface area of the soil
t_c = time to soil consolidation (years)
T_j = average daily temperature (oF) for the *jth* day (temperature)
T_s = average temperature (oF) for the RUSLE2 summer period (temperature)

Indices
j - day

Topography

The purpose of this section is to describe some of the mathematical consequences of RUSLE2's equation structure rather than provide additional equations except for steepness factor and adjusting soil loss tolerance values for position along the overland flow path.

Equations that describe how topography affects rill-interrill erosion where the overland flow streamlines are parallel are described in **Section 2**. Those equations form RUSLE2's fundamental, underlying mathematical structure. Those equations accommodate spatial variability in soil, steepness, cover-management, and some support practices along the overland flow path. Those equations compute whether detachment or deposition occurs along the overland flow path. RUSLE2 computes its erosion and sediment load values using a numerical solution of the governing RUSLE2 equations written as a function of distance along the overland flow path. The numerical solution is a spatial integration of the governing equations. Furthermore, RUSLE2 performs a temporal integration of the governing equations, where the slope length exponent m in equation 2.10, along with soil erodibility and cover-management relationships change daily.

5.1. Converging- diverging streamlines on overland flow areas

The RUSLE2 assumption is that overland flow streamlines are parallel. Consequently, RUSLE2 does not estimate how converging or diverging overland flow affects rill-interrill erosion. An analysis based on a simple process-based erosion model showed that rill-interrill erosion with converging overland flow is about 7/6 times that where the streamlines are parallel (Toy and Foste, 2000). The same analysis showed that rill-interrill erosion with diverging overland flow is about 5/6 times that where the streamlines are parallel.

5.2. Topographic equations for overland flow having parallel streamlines on uniform overland flow paths

RUSLE2's numerical mathematical procedures are complex, which complicates comparisons with the basic USLE equation structure to evaluate RUSLE2 topographic relationships. A simplified form of the main RUSLE2 governing equation, equation 2.10, is written for a single day for a uniform overland flow path where neither soil, steepness, nor cover-management vary along the overland flow path to facilitate partial comparisons. On any day, the relation of erosion computed by RUSLE2 to overland flow path length for a uniform overland flow path is given by:

$$a_j = c_j(\lambda/\lambda_u)^{m_j} \qquad [5.1]$$

where: a_j = average erosion rate for the overland flow path length λ on the *jth* day, c_j = a coefficient that includes erosivity, soil, steepness, cover-management, and support practice factors, λ_u = length of the unit plot (72.6 ft, 22.1 m), and m_j = the slope length exponent on the *jth* day. This equation is derived from equation 2.10. The slope length exponent m_j is a function of the rill to interrill erosion ratio as shown by equation 2.12. The equation for rill to interrill erosion ratio is given by equation 2.13. RUSLE2 uses equation 2.13 to directly compute a rill to interrill ratio erosion whereas RUSLE1 requires users to make input selections to represent the factors considered in equation 2.13 [AH703, (Renard et al., 1997)]. The RUSLE2 rill to interrill erosion ratio varies daily whereas the RUSLE1 rill to interrill erosion ratio is time invariant. Overland flow path steepness is the only variable considered in adjusting the slope length exponent in the USLE [AH537 (Wischmeier and Smith, 1978)].

Although the rill to interrill erosion ratio varies with distance along the overland flow path (Foster and Meyer, 1975), RUSLE2 does not consider that effect because of the mathematical structure of equations 2.10 and 5.1. When the rill to interrill erosion ratio is made a function of distance, erosion computed for a uniform overland flow path is affected by subdividing the overland flow path into segments, which is an obvious error. Computed erosion on a uniform overland flow path should be independent of the number and length of segments used to represent an overland flow path when all segments are the same otherwise.

RUSLE2 computes local deposition[37] on a uniform overland flow path when interrill erosion rate is greater than the increase in transport capacity with distance along the overland flow path (i.e., $D_i > dT_c/dx$ where D_i = interrill erosion rate, T_c = runoff's sediment transport capacity, and x = distance). Deposition is computed with equation 2.16 and its companion equations. The computed net erosion does not vary with distance along the overland flow path, i.e., the slope length exponent m_j in equation 5.1 is zero (Renard and Foster, 1983; Meyer and Harmon, 1985).

Erosion values computed with equation 2.16 conflict with values computed by the empirical USLE. A RUSLE2 development principle is that RUSLE2 computed erosion values agree with USLE computed values (see **Section 1**). The conflict between equation 2.16 and the USLE equation forms was resolved by having RUSLE2 gives the USLE result. However, RUSLE2 uses equation 2.16 to compute characteristics of the sediment leaving the overland flow path when RUSLE2 determines that local deposition occurs. This example illustrates how RUSLE2 is a hybrid model that combines the empirical USLE equation with process-based erosion equations.

This procedure works well for local deposition except when the overland flow path is subdivided. Subdivision without changing any of the segments variables should not affect computed erosion and sediment values. However, subdivision affects the enrichment ratio values but not the erosion values when RUSLE2 computes local

---

[37] Local deposition is where sediment is deposited almost adjacent to the point of detachment such as in soil surface roughness depressions and in furrows between ridges. Remote deposition is where sediment is deposited a significant distance from the point detachment such as at the upper edge of dense vegetation strips and on the toe of concave-shaped overland flow path profiles.

deposition. The enrichment ratio value computed when a uniform overland flow path is not subdivided is the correct value.

RUSLE2 does use equation 2.16 and its companion equations to compute remote deposition. RUSLE2 has been constructed so that its remote deposition computations are independent of subdivision of the segment where the remote deposition occurs. However, if local deposition occurs on an upslope segment, subdivision of that segment very significantly affects computed enrichment ratio values, especially if the subdivision is near the upper end of the segment. The erosion values are only very slightly affected by subdivision of the upslope segment.

The error in the enrichment ratio values caused by subdividing the overland flow path is a RUSLE2 flaw. This flaw can not be eliminated because of differences in equation structure between the USLE and the process-based erosion equations. The error in enrichment ratio caused by overland flow path subdivision when local deposition is computed could have been prevented by developing RUSLE2 entirely from process-based erosion equations. However, that approach would have lost RUSLE2's power of giving the well-accepted, empirically derived USLE values. The RUSLE2 approach was to develop a hybrid model that combines the best of both the empirical USLE equation structure and the process-based equation structure. RUSLE2 was derived and evaluated to ensure that inconsistencies, which can not be totally eliminated, are acceptable for the purpose of conservation and erosion control planning. Fortunately, most RUSLE2 conservation planning applications assume a uniform overland flow path without subdivision.

5.3. Topographic equations for overland flow having parallel streamlines on non-uniform overland flow paths

RUSLE2 uses the equations described in **Section 2** to compute erosion and sediment load on non-uniform overland flow paths. The overland flow path is divided into segments where soil, steepness, or cover-management change along the overland flow path. The governing equations are numerically solved along the overland flow path starting at the upper end of the overland flow path where overland flow originates (see **Section 2.3**).

Each soil, steepness, and cover-management variable that changes between segments is treated as a step rather than a continuous change (see **Section 2.3.1**). Assuming step changes is appropriate for most cover-management changes, whereas continuous change is appropriate for changes in soil and steepness for overland flow paths on most natural landscapes.

Steepness is where a step change rather than a continuous change is significant. Steepness at the intersection of two segments could be treated as the average of the steepness of the two segments, which is appropriate for describing an overland flow path where steepness changes continuously along the overland flow path, such as a concave overland flow path profile. However, a continuous change in steepness is not appropriate for constructed slopes where steepness makes a step change, such as at the top of a land fill or at the toe of a hillslope cut. RUSLE2 assumes a step change in steepness to accommodate step changes in steepness common to constructed slopes. See the RUSLE2 User's Reference Guide on representing overland flow paths where the change in steepness is continuous along their length.

The effect of step changes in representing gradual soil changes along an overland flow path is minimized by dividing the overland flow path into several segments.

A concern in applying RUSLE2 to non-uniform overland flow paths is dealing with changes in infiltration caused by soil and cover-management changes along the overland flow path. RUSLE2 considers how changes in infiltration along an overland flow path affect contouring failure, sediment transport capacity, and deposition. RUSLE2 does not consider how changes in infiltration along an overland flow path affect detachment on a downslope segment. While interrill erosion on a particular segment is only affected by infiltration rate on that segment, rill erosion on a segment is affected by both the runoff generated on that segment and by the runoff that arrives from the upslope area of the overland flow path. This effect can be partially represented by adjusting the upslope overland flow path length to reflect runoff coming into a downslope segment. Although not possible in RUSLE2, the slope length exponent for the downslope segment should be adjusted as well.

Nevertheless, a conflict exists in RUSLE2 between the way that overland flow path distance is treated for computing runoff and the way that overland flow path distance is treated for computing detachment. An example situation is runoff from an upslope pasture draining onto a cultivated field where infiltration on the pasture area is much higher than on the cultivated area. If the actual overland flow length is entered, RUSLE2 computes detachment values that are too high on the cultivated area because runoff reaching the cultivated area will be much less than is implicitly assumed in RUSLE2. If an effective overland flow path length is entered to correctly compute detachment on the cultivated area, RUSLE2 computes runoff rates that are too low on the cultivated area and incorrectly computes detachment on the pasture area. See the RUSLE2 User's Reference Guide for recommendations for selecting overland flow path lengths where infiltration varies greatly along an overland flow path.

The resolution of this problem would have been to derive RUSLE2 based on process-erosion equations. Given that most RUSLE2 conservation planning applications involve uniform overland flow paths or overland flow paths where infiltration does not vary greatly along the path, RUSLE2 is considered to be satisfactory for most conservation planning applications.

5.4. Applying RUSLE2 to complex topography with converging and diverging overland flow

The RUSLE2 User's Reference Guide describes the proper procedure for applying RUSLE2 to complex topography. The effect of converging and diverging overland flow on RUSLE2 computed erosion is discussed in **Section 5.1**.

The USLE and RUSLE1 are used in GIS applications to compute erosion on topographically complex areas where overland flow converges and diverges. In these applications, overland flow path distance is considered equivalent to upslope drainage area (Desmet and Govers, 1996). This assumption is questionable as discussed in **Section 5.3**. The slope length exponent should be adjusted to represent how upslope drainage area affects the rill to interrill erosion ratio. Interrill erosion at a location is independent of upslope drainage area while rill erosion is directly related to upslope drainage area. Consequently, the slope exponent should be high when a large upslope drainage area is involved where overland flow has converged. However, making the slope length exponent a function of upslope drainage area means that erosion inappropriately becomes a function of how the drainage areas is divided into cells (see **Section 5.2**).

RUSLE2 is far more complex than the USLE or RUSLE1 regarding the rill to interrill erosion ratio. RUSLE2 should only be used in GIS applications for complex topography where distance along an overland flow path is assumed to be comparable to upslope drainage area **when infiltration rate spatially varies little and where convergence or divergence of overland flow is minimal** (see **Section 5.3**). A much better approach is to derive separate rill erosion, interrill erosion, and deposition equations using RUSLE2 assumptions, concepts, and equations for these processes. In that approach, a discharge rate can be properly computed from upslope drainage area. The discharge rate can be used to compute rill erosion, sediment transport capacity, deposition, and contouring failure. Interrill erosion is computed as independent of upslope drainage area.

Another common error in using the USLE and RUSLE1 in GIS applications that should also be avoided in using RUSLE2 is that excessively long overland flow path lengths are assumed. A major problem with USLE/RUSLE1/RUSLE2 GIS applications is inadequate resolution of topographic data, which results in excessively long overland flow paths and poor representation of steepness along the overland flow path (Toy and Foster, 2000). The maximum overland flow path length allowed in RUSLE2 is 1,000 ft (see RUSLE2 User's Reference Guide). In fact, overland flow has often been collected into concentrated flow areas within 200 ft on most farm fields, for example (Foster, 1985).

If RUSLE2 is to be used in GIS applications, provisions should be made for representing sediment transport capacity and deposition separate from the detachment computation. (Desmet and Govers, 1996) illustrates such an application.

5.5. Slope length exponent

5.5.1. Slope length exponent for standard (non-Req) conditions

The slope length exponent is the exponent m in equations 2.10 and 5.1. The RUSLE2 slope length exponent is a function of the rill to interrill erosion ratio just is it was in RUSLE1 [Foster and Meyer, 1975; McCool et al., 1989; AH703 (Renard et al., 1997)].

However, in contrast to RUSLE1 where the slope length exponent is time invariant, the RUSLE2 slope length exponent varies daily as cover-management conditions change. A value for the RUSLE2 slope length exponent for standard, non-Req conditions is computed daily using equations 2.12 and 2.13.

5.5.1. Slope length exponent for Req conditions

The erosion processes that occur during the winter Req conditions (see **Section 3.2.5** and RUSLE2 User's Reference Guide) differ from those that occur with standard rill-interrill erosion. Most of the erosion during Req conditions is by surface runoff. The empirically derived RUSLE2 soil length exponent for Req conditions is m = 0.046 [McCool et al., 1989, (AH703, (Renard et al., 1997)].[38] The slope length exponent for Req conditions is time invariant and does not vary with the rill to interrill erosion ratio.

The slope length exponent, equations 2.12 and 2.13, for standard, non-Req rill-interrill erosion can be used for the non-Req period (summer period) at those locations where Req effects during the winter. Standard rill-interrill erosion can be assumed for the summer months at Req locations. This summer period defined for RUSLE2 as the time between the day when average daily temperature becomes greater than 45 oF early in the year to the day average daily temperature falls to 35 oF late in the year (see **Section 4.5.1**).

5.6. Steepness effect on rill-interrill erosion

5.6.1. Steepness factor for standard (non-Req) conditions

Figure 5.1 shows the relation of rill-interrill erosion to overland flow path steepness observed in measured data (McCool et al., 1987). The erosion values for the two cover-management (soil) conditions were normalized to 1 at a 20 percent steep overland flow path. The relation of erosion to steepness for the bare, reclaimed surface mine soil is linear. A simple process-based erosion model assumes that rill erosion varies linearly with the sine of the overland flow path angle and that interrill erosion varies with [Foster, 1982; AH703 (Renard et al., 1997)]:

$$S_i = 3s_i^{0.8} + 0.56 \qquad [5.2]$$

where: S_i = the interrill erosion steepness factor in equation 2.11 and s_i = the steepness of the interrill steepness angle. Equation 5.2 is referenced to the unit plot steepness so that the equation gives a value of 1 for a nine percent steepness. This simple erosion model computes a steepness effect for rill-interrill erosion that is almost linear like the curve for the bare, surface mine soil.

In contrast to the linear relationship of rill-interrill erosion to steepness, the steepness

[38] The 0.046 value used in RUSLE2 differs from the 0.05 value used in RUSLE1 [AH703 (Renard et al., 1997)]. The 0.046 value was derived by D. K. McCool, USDA-Agricultural Research Service, Pullman, Washington.

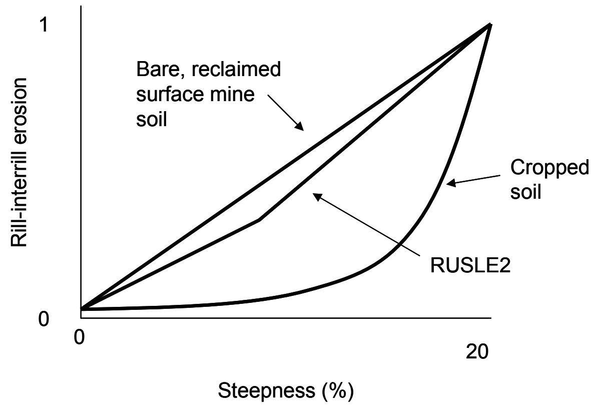


Figure 5.1. Effect of slope steepness on rill-interrill erosion.

relationship for the cropped soil is nonlinear as shown in Figure 5.1. The apparent effect for the cropped soil is that overland flow path steepness must be greater than a critical steepness for rill erosion to occur. Most of the erosion for the cropped soil at low steepness is caused by interrill erosion with little or no rill erosion. Once the overland flow path steepness exceeds a critical steepness, rill erosion begins, which results in rill-interrill erosion increasing rapidly. Runoff's shear stress must exceed a critical shear stress for rill erosion to begin, much like contouring failure. The rill erosion equation would be rill erosion being proportional to the difference between shear stress applied to the soil and a critical shear stress related to soil conditions (Meyer et al., 1975; Foster, 1982; Graf, 1971; Foster et al., 1980).

Like slope length effects, the relation of rill-interrill erosion to overland flow path steepness should be a function of the rill to interrill erosion ratio and a critical shear stress at which rill erosion begins. However, in contrast to the temporally varying slope length effect, RUSLE2 uses an invariant slope steepness factor. Although erosion theory indicates reasons why the steepness factor should vary, the experimental plot data were not sufficient to develop a RUSLE2 steepness factor as a function of the rill to interrill erosion ratio, critical shear stress, or other variables. Consequently, RUSLE2 uses the invariant steepness relationship illustrated by the middle curve in Figure 5.1. The equation for that curve is given by [McCool et al., 1987; AH703 (Renard et al., 1997)]:

$$S = 10.8s + 0.03 \qquad s_p < 9\% \qquad [5.3]$$

$$S = 16.8s - 0.50 \qquad s_p \geq 9\% \qquad [5.4]$$

where: S = steepness factor in equation 2.10, s = sine of the angle θ that the overland flow path makes with the horizontal, s_p = the steepness of the overland flow path in percent [100·tan(θ)]. Equations 5.3 and 5.4 give a value of 1 referenced to the unit plot 9 percent unit plot steepness rather than the 20 percent steepness in Figure 5.1.

5.6.2. Steepness factor for Req conditions

A special steepness factor relationship is used for Req winter conditions because erosion processes for the Req condition differ significantly from the standard rill-interrill erosion conditions. Most of the erosion is caused by surface runoff during the Req conditions. The empirically derived steepness factor for Req conditions is given by [McCool et al., 1987; McCool et al., 1997; AH703 (Renard et al., 1997)]:

$$S = 10.8s + 0.03 \qquad s_p < 9\% \qquad [5.5]$$

$$S = (s/0.0896)^{0.6} \qquad s_p \geq 9\% \qquad [5.6]$$

where: 0.0896 = the sine of the angle for 9 percent unit plot steepness. Equations 5.5 and 5.6 are also referenced to the unit plot steepness.

Equations 5.3 and 5.4 can be used for the summer period at locations where the Req winter effects occur.

5.7. Topographic relationships for short overland flow paths (x ≤ 15 ft)

Equations 2.10 and 5.1 do not apply for short overland flow path distances because these equations compute a zero erosion rate for a zero overland flow path length. Erosion rate should equal the interrill erosion rate at the origin of overland flow (x = 0). Experimental interrill erosion studies show that overland flow path length must be about 15 feet before rill erosion begins to occur (Meyer and Harmon, 1989), a distance that is also consistent with field observations, including rainfall simulator studies of the variables that affect rill-interrill erosion (Meyer et al., 1975). Therefore, equations 2.10 and 5.1 are assumed not to apply to short overland flow path distances less than 15 ft.

5.7.1. Overland flow steepness < 9 percent

The overland flow path distance x is set to 15 ft when the actual overland flow path distance is less than 15 ft to represent the concept that interrill erosion is independent of distance. The preferred steepness factor for interrill erosion is equation 5.2, but his equation conflicts with the empirically derived rill-interrill erosion S factor given by equation 5.3 for steepness less than 9 percent. Therefore, the rill-interrill erosion steepness factor, equation 5.3, is used for all overland flow distances less than 15 ft if the overland flow path steepness is less than 9 percent. The variables used for $(x/\lambda_u)^m S$ in equation 2.10 are $(15/72.6)^m S_l$ where S_l is the rill-interrill steepness factor computed from equation 5.3, 15 = 15 ft, the overland flow path length assumed for all overland flow path lengths less than 15 ft, and 72.6 = 72.6 ft, the unit plot length.

5.7.2. Overland flow path steepness ≥ 9 percent

5.7.2.1. Overland flow path length ≤ 3 ft

The inconsistency between the interrill steepness factor, equation 5.2, and the rill-interrill steepness, equation 5.4, does not occur when overland flow path steepness exceeds 9 percent. If the overland flow path length is less than or equal to 3 ft, the rill-interrill steepness factor in equation 2.10 equals the interrill steepness factor, equation 5.2. The overland flow path distance is set to 15 ft regardless of actual overland flow path distance. The variables used for $(x/\lambda_u)^m S$ in equation 2.10 are $(15/72.6)^m S_i$ where S_i is the interrill steepness factor computed from equation 5.2, 15 = 15 ft, the overland flow path length assumed for all overland flow path lengths less than 15 ft, and 72.6 = 72.6 ft, the unit plot length.

5.7.2..2 Overland flow path 3 ft < x ≤ 15 ft

A logarithmic interpolation is used to transition between the interrill steepness factor, equation 5.2, at a 3 ft overland flow distance to the rill-interrill steepness factor, 5.4, at a 15 ft overland flow distance. This interpolation is computed as:

$$\alpha_3 = (15/72.6)^m S_i \qquad [5.7]$$

$$\alpha_{15} = (15/72.6)^m S_l \qquad [5.8]$$

where: α_3 and α_{15} = the combined distance and steepness factor for 3 ft and 15 ft overland flow path lengths, respectively, at the given steepness, 15 = 15 ft, the assumed overland flow path distance for all actual overland flow path distances less than 15 ft. The interrill steepness factor S_i, equation 5.2, is used to compute and S_l = the rill-interrill steepness factor, equation 5.4, is used to compute the steepness effect at a 15 ft overland flow distance. A logarithmic interpolation is made between α_3 in equation 5.7 and α_{15} in equation 5.8 as:

$$\ln(\alpha_x) = [\ln(\alpha_{15}) - \ln(\alpha_3)][(\ln(x) - \ln(15)]/[\ln(15) - \ln(3)] + \ln(\alpha_3) \qquad [5.9]$$

$$\alpha_x = \exp[\ln(\alpha_x)] \qquad [5.10]$$

where: α_x = the combined length and steepness factor at the overland flow distances between 3 and 15 ft and overland flow path steepness greater than 9 percent. This distance and steepness factor value is used in equation 2.10 for the variables $(x/\lambda_u)^m S$.

5.8. Effect of position along overland flow path on soil loss tolerance (T) factor

The powerful conservation planning approach of comparing an estimated erosion rate to an allowable erosion rate developed in the mid 1940's (Mannering, 1981; McCormack and Young, 1981; Toy et al., 2002). Soil loss tolerance (T) values are widely used for allowable erosion rate on crop and other lands. Erosion is assumed to not to be excessive if the estimated erosion rate is less than the T value. The procedure implicitly assumes a uniform overland flow path, which is common practice in most erosion prediction applications and in research used to determine soil loss tolerance (T) values. The average erosion rate, rather than maximum erosion rate, for the entire overland flow path is compared to the soil loss tolerance (T) value.

The erosion rate computed with RUSLE2 varies along even a uniform overland flow path from an interrill erosion rate at origin of overland flow (x = 0) to (m+1) times the average erosion rate for the entire overland flow path length at the end of the path ($x = \lambda_e$). Therefore, erosion rate over the approximate lower one half of uniform overland flow path exceeds T when the average erosion rate for the overland flow path equals T. That is, the conservation planning criteria does not require that maximum erosion rate be less than soil loss tolerance, only that average erosion rate for a uniform overland flow path be less than soil loss tolerance [AH703 (Renard et al., 1997); Toy et al., 2002].

Comparing average erosion rate for the overland flow path to soil loss tolerance is not appropriate for overland flow paths on non-uniform shape profiles, especially convex profiles. To make these comparisons, RUSLE2 computes an adjusted soil loss tolerance value that is compared against the RUSLE2 estimated erosion rate for each segment along a non-uniform overland flow path (see the RUSLE2 User's Reference Guide). The comparison with the adjusted T puts conservation planning on the same basis for non-uniform overland flow paths as for a uniform overland flow path. The adjusted soil loss tolerance values are the T factor values for the soil on *jth* segment times a factor value computed with [(AH703 (Renard et al., 1997)]:

$$F_j = (x_j^{m_i+1} - x_{j-1}^{m_i+1})/[(x_j - x_{j-1})\lambda_e^{m_i}] \qquad [5.11]$$

where: F_j = the factor that is used to multiply the soil loss tolerance (T) value to obtain a soil loss tolerance value adjusted based on position of the *jth* segment along the overland flow path, x_i = distance to the lower end of the *jth* segment, m_j = slope length exponent for the *jth* segment, and λ_e = the entire length of the overland flow path. The ratio of computed erosion rate to the adjusted soil loss tolerance value is the same for all segments along a uniform overland flow path.

5.9. Conservation planning soil loss

RUSLE2 computes a conservation planning soil loss where deposition is given partial credit based on location of the deposition along the overland flow path. This type of deposition, which is referred to as remote deposition, occurs on concave overland flow profiles and at the upper edge of dense vegetations strips. The use of conservation planning soil loss in conservation planning is discussed in the RUSLE2 User's Reference Guide, and the equations used to compute a value for conservation planning soil loss are given in **Section 2.3.10.4**.

List of symbols

a = average erosion rate for the overland flow path length λ (mass/area·time)
c = coefficient that includes erosivity, soil, steepness, cover-management, and support practice factor
D_i = interrill erosion rate (mass/area·time)
F = factor used to multiply soil loss tolerance (T) to obtain adjusted soil loss tolerance value based on position of segment along overland flow path
m = slope length exponent
s = sine of the angle θ that the overland flow path makes with the horizontal
s_i = steepness of the interrill steepness angle
s_p = steepness of the overland flow path in percent [100·tan(θ)]
S = steepness factor
S_i = interrill erosion steepness factor
T = soil loss tolerance (mass/area·time)
T_c = runoff's sediment transport capacity (mass/width·time)
x = distance along overland flow path (length)

α_x = combined length and steepness factor at overland flow distances between 3 and 15 ft and overland flow path steepness greater than 9 percent
α_3 = combined distance and steepness factor for 3 ft overland flow path length at the given steepness
α_{15} = combined distance and steepness factor for 15 ft overland flow path lengths at the given steepness
λ = overland flow path length
λ_e = overland flow path length
λ_u = length of the unit plot (72.6 ft, 22.1 m)

Indices

j- day
j - segment

6. Cover-Management

Equation 2.10 includes the term c used to compute the main effect of cover-management on detachment. The c factor is the product of subfactors as:[39]

$$c = c_c g_c s_r r_h s_b s_c s_m \qquad [6.1]$$

where: c = cover-management factor, c_c = canopy subfactor, g_c = ground cover subfactor, s_r =soil surface roughness subfactor, r_h = ridge height subfactor, s_b = soil biomass subfactor, s_c = the soil consolidation subfactor, and s_m = antecedent soil moisture subfactor used when RUSLE2 is applied in Req zones (see RUSLE2 User's Reference Guide). A cover-management c factor value is computed using daily values for each of the subfactors in equation 6.1.[40]

6.1. Canopy subfactor

Canopy is live and dead vegetative cover above the soil surface that intercepts raindrops but does not contact the surface runoff. The portion of the above ground plant biomass touching the soil surface is treated as live ground cover. The canopy subfactor equation is (Wischmeier, 1975; Yoder et al. 1997):

$$c_c = 1 - f_{ec} \exp(-0.1 h_f) \qquad [6.2]$$

where: f_{ec} = effective canopy cover and h_f = effective fall height (ft). Equation 6.2 is based on how canopy cover affects the impact energy of waterdrops falling from canopy that has intercepted rainfall. The impact energy of a waterdrop striking the soil surface is:

$$e_d = m_d V_d^2 / 2 \qquad [6.3]$$

where: e_d = impact energy of the waterdrop, m_d = waterdrop mass, and V_d = the waterdrop impact velocity.

Canopy cover affects waterdrop impact energy in several ways. Canopy cover increases the size of waterdrops falling from the canopy. Waterdrops falling from canopy have about a 3 mm drop diameter compared to 1.5 mm for median drop diameter of raindrops (Wischmeier, 1975). Therefore, canopy must be sufficient close to the ground for waterdrops falling from canopy to have reduced impact velocity to offset the increased

[39] The subfactor procedure used in RUSLE2 is an extension of the one used in RUSLE1 [AH703 (Renard et al., 1997)] with improvements, added capability, and use of a daily time step rather than a half-month time step. The RUSLE1 and RUSLE2 subfactor procedures are patterned after ones developed and used by Wischmeier (1975); (Wischmeier, 1978); Dissmeyer and Foster (1981), Mutchler et al. (1982), and Laflen et al. (1985).

[40] This section describes the subfactor relationships. Other sections describe how RUSLE2 computes values for variables used by the subfactor equations.

mass of waterdrops falling from canopy in comparison to raindrops. Because of the increased drop size, the impact energy of water drops falling from tall canopies, such as 30 ft high, exceeds the impact energy of raindrops (Chapman, 1948). Equation 6.2 is based on an assumed 3 mm diameter for waterdrops falling from canopy and empirical fall velocities of waterdrops based on effective fall height h_f (Gunn and Kinzer. 1949).

Equation 6.2 should be interpreted as empirically representing the main effects of canopy cover on detachment with a particular equation form rather than describing how a physical variable, impact energy, affects detachment. Equation 6.2 does not directly represent all of the ways that canopy affects detachment. For example, some of the intercepted rainfall becomes stem flow and reaches the soil surface without falling from the canopy. Also, some of the intercepted rainfall evaporates from the vegetation, never to reach the soil surface by drop impact or stemflow. Also, RUSLE2 does not consider how wind driving rainfall in conjunction with vegetation affects erosion.[41]

Input effective fall height values are chosen based on judgment of how canopy of a particular plant type affects erosion (see RUSLE2 User's Reference Guide). The reference fall height, illustrated in Figure 6.1, is one third of the distance from the bottom of the canopy to the top of a canopy for a cylindrical shaped canopy where the vegetative surface area is uniformly distributed along the vertical axis of the canopy.

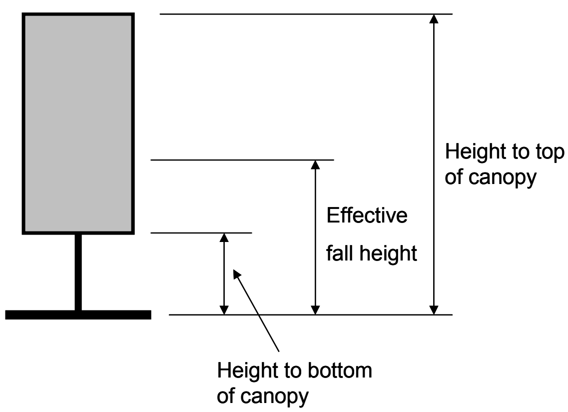


Figure 6.1. Effective fall height for a cylindrical shaped, uniform gradient canopy.

RUSLE2 also includes an equation that can be used to compute effective fall height. The equation is a function of canopy shape and vertical gradient of vegetative surface area from drops fall within the canopy. The effective fall height equation is:

$$h_f = h_b + a_s a_g (h_t - h_b) \qquad [6.4]$$

where: h_b = the height to the bottom of the canopy, h_t = the height to the top of the canopy, and a_s = a coefficient that is a function of canopy shape, and a_g = a coefficient related to the height within the canopy where vegetative surface area is concentrated. Values for the coefficient a_s and a_g are given in Tables 6.1 and 6.2, respectively.

[41] An improved approach would be to divide equation 6.2 into two parts, one part related to interrill erosion and one part related to rill erosion.

Table 6.1. Values for the coefficient used to estimate effective fall height as a function of canopy shape.

Canopy shape	Value
Inverted trianagle	0.5
Rectangle	0.33
Diamond	0.29
Round	0.29
Triangle	0.25

Table 6.2. Values for coefficient used to estimate fall height as a function of concentration of surface area within canopy.

Location of surface surface area concentration	Value
Top	1.33
Toward top	1.17
Uniform	1.00
Toward bottom	0.88
Bottom	0.75

Some vegetation communities involve multiple plant types that produce over and under stories. RUSLE2 uses only a single set of variables to represent the net effect of canopy on erosion. RUSLE2 does not mathematically combine sets of values for over and under stories nor does RUSLE2 separately compute how each canopy type affects erosion. RUSLE2 uses a single set of values in equation 6.2 to compute the net canopy effect for the vegetation that exists on any given day.

In addition to varying with plant community type, effective fall varies with production (yield) level and with time as vegetation emerges, grows, matures, and experiences senescence. The RUSLE2 computes effective fall height as a function of production (yield) level and time (see **Sections 9.1** and **9.3.1.3)**.

Canopy cover directly above ground cover is assumed not to affect erosion. The equation used to compute an effective canopy cover f_{ec} is:

$$f_{ec} = f_c(1 - f_{gn}) \qquad [6.5]$$

where: f_c = canopy cover (portion of soil surface covered with vegetative canopy) and f_{gn} = net ground cover, which takes into account the overlap of different types of ground cover (see **Section 10.2**). Net ground cover equals 1 – fraction of the soil surface exposed to direct waterdrop impact from either rainfall or waterdrops falling from canopy.

Furthermore, the RUSLE2 assumption is that canopy cover affects erosion the same way as does ground cover when effective fall height becomes zero. Therefore, the value for the canopy subfactor c_c can not be less than the ground cover subfactor g_c for ground cover equal to the effective canopy cover value f_{ec}.

6.2. Ground cover subfactor

Ground cover is provided by material directly in contact with the soil surface. Ground cover affects both waterdrop impact, which in turn affects interrill erosion, and surface runoff, which in turn affects rill erosion. The RUSLE2 equation for the ground cover subfactor is given by (Foster and Meyer, 1975; Laflen et al., 1985;Yoder et al., 1997):

$$g_c = \exp[-bf_{gn}(0.24 / R_a)^{0.08}] \qquad [6.6]$$

where: **b** = a coefficient (percent^{-1}) that describes the relative effectiveness of the ground (surface) cover for reducing erosion, f_{gn} = the net soil surface ground cover (percent), R_a = adjusted roughness used to compute the soil surface roughness subfactor (inches) (see **Section 6.3**), and 0.24 is the assumed adjusted soil surface roughness value (inches) for unit plot conditions. Research has shown that a single variable, portion of the soil surface covered by material directly in contact with the soil surface, describes how all types of ground (surface) cover affects rill-interrill erosion. Analysis based on fundamental erosion mechanics shows that large diameter, long pieces of material, such as intact corn stalks, perpendicular to the overland flow path should affect rill-interrill erosion per unit of soil surface covered more than small diameter, flat pieces (Brenneman and Laflen, 1982). A special concerns regards how rock fragments on the soil surface affects rill-interrill erosion (see **Section 4.6**). However, when data from various types and rates of surface cover are combined, portion of the soil surface covered seems adequate as a single ground cover variable to use in the ground cover subfactor, equation 6.6 (Box, 1981; Dickey et al., 1983; Dickey et al., 1985; Laflen and Covin, 1981; Meyer et al., 1972; Simanton et al., 1984; Meyer et al., 1970; Swanson et al., 1965; 1970; Mannering and Meyer, 1963; Meyer and Mannering, 1967).

Net ground cover used in equation 6.6 takes into account the overlap of ground cover materials. For example, applied materials, such as mulch and erosion control blankets, and plant residue are assumed to lie on top of rock cover entered in the RUSLE2 soil input. Live ground cover is assumed to lie on top of applied material and plant residue. Thus, net ground cover (percent) is 100 – bare ground (percent).

The soil surface roughness term in equation 6.6 computes a reduced effect of ground cover on rough soil surfaces. The RUSLE2 assumption is that ground cover in soil depressions is covered by water and deposited sediment, and therefore has no effect on erosion.

The RUSLE2 ground cover subfactor computed with equation 6.6 only partially captures the effect of ground (surface) cover material on rill-interrill erosion. A RUSLE2 ground cover subfactor value is primarily the ratio of rill-interrill erosion at a given point in time with ground (surface) cover to rill-interrill erosion from the same soil in unit plot conditions. The effect most represented by the RUSLE2 ground cover subfactor is how the physical presence of surface cover material affects the erosive forces applied to the soil by impacting raindrops and waterdrops falling from canopy and surface runoff. Other subfactors, such as soil surface roughness and soil biomass, are affected by ground (surface) cover materials (see **Sections 6.3 and 6.5**).

6.2.1. b value (ground cover effectiveness index)

Research shows that **b** values derived from measured erosion data range from approximately 0.025 to greater than 0.1 (Laflen et al., 1980; Laflen and Colvin, 1980; Colvin and Gilley. 1987; Dickey et al., 1983; Meyer et al., 1970; Gilley et al., 1986; Mannering and Meyer, 1967; Meyer and Mannering, 1967; Meyer et al., 1970; Meyer et al., 1972; Box, 1981; Simanton et al., 1984) (see **Section 6.2.1**). The reason for a variation in **b** is obvious in some cases. For example, Mannering and Meyer (1967) and Meyer and Mannering (1970) conducted two similar studies using wheat straw applied to recently tilled soil. In one case, infiltration increased significantly as mulch rate increased, which in turn gave a larger **b** value than was the case where mulch rate did not affect infiltration. In some cases, large **b** values resulted when other effects of a tillage system including roughness and residue incorporation were lumped with the ground cover effect.

Another reason for a range of **b** values is related to the erosion mechanics of rill and interrill erosion. A given amount of ground cover reduces rill erosion more than interrill erosion as illustrated in Figure 6.2 (Foster and Meyer, 1975). The term s_{cr}/s_{ci} in equation 2.13 represents the effect of ground cover on the rill to interrill erosion ratio, where s_{cr} = the surface cover subfactor for rill erosion and s_{ci} = the surface cover subfactor for interrill erosion. The equation for this ratio is:

$$\frac{s_{cr}}{s_{ci}} = \left[\frac{\exp(-b_r f_{gn})}{\exp(-0.025 f_{gn})} \right] \qquad [6.7]$$

where: b_r = the coefficient for how ground cover affects rill erosion and 0.025 = the ground cover effectiveness coefficient for interrill erosion.[42] Consequently, RUSLE2 **b** values range between the **b** value (0.025) for interrill erosion and the **b** value (b_r) for rill erosion. The **b** value of 0.025 used in RUSLE2 for interrill erosion was derived from the Lattanzi et al. (1974) and McGregor et al. (1988) data (Foster, 1982).

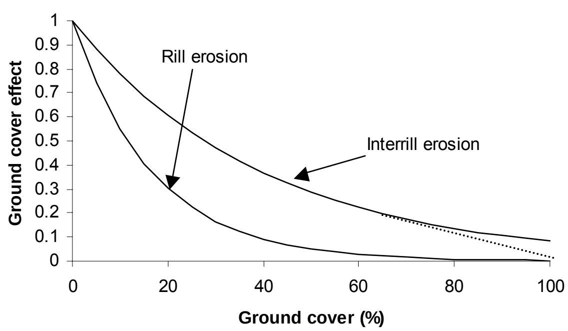


Figure 6.2. Effect of ground cover on rill and interrill erosion

The **b** value for rill erosion is the upper limit for the range of **b** values computed by RUSLE2. A 0.05 b_r value was chosen for soil conditions where ground (surface) cover does not affect infiltration, and the largest values used for b_r by RUSLE2 is 0.06 for situations where increased ground (surface) has a major effect on infiltration. RUSLE2's upper limit on **b** values is less than some values reported in the literature, partly because RUSLE2 accounts for other subfactor effects that some researchers included in a ground cover type effect. RUSLE2 computes a net b value that is larger than the one used in equation 6.6. For example, when the RUSLE2 computed erosion values for a range of corn yields for a mulch till cropping system are

42 Although not used in RUSLE2 an improved approach would be assume that the **exp** expression for ground cover effect on interrill erosion should end where it becomes tangent to the linear line in Figure 6.2, where values follow the linear line to zero for a completely covered surface.

plotted as a function of ground cover after planting, the overall (net) **b** value is 0.078, in comparison to the 0.031 value that RUSLE2 used in equation 6.6. Similarly, the overall (net) **b** value similarly obtained for RUSLE2 computed erosion values for several mulch till cropping systems and a no-till cropping system at a 112 bu/acre corn yield is 0.058, whereas RUSLE2 used 0.031 for the **b** value for the mulch till systems and 0.04 for the **b** value for the no-till system. Thus, the overall (net) **b** value effect computed by RUSLE2 is significantly larger when RUSLE2 computed erosion values are plotted as a function of ground cover after planting, which is how many of the **b** values reported in the literature were determined for conservation tillage systems.

Also, a reduced upper limit for **b** values was chosen so that RUSLE2 would be conservative in its computations of how much mulch, crop residue, and other ground cover materials reduce erosion for the purposes of conservation planning.

Thus, the coefficient b_r is assumed in RUSLE2 to increase from 0.05 to a maximum of 0.06 as ground cover increases, buried residue in the soil accounting depth increases, and as the soil consolidation subfactor decreases. Mechanical soil disturbance is assumed to disrupt macro-pores and large aggregates.

The effect represented is increased infiltration, which in turn reduces runoff and rill erosion, as biomass accumulates in a shallow, undisturbed soil surface layer with time after a mechanical soil disturbance. The equation for the rill erosion ground cover effectiveness coefficient is given by:

$$b_r = 0.05 + 0.01 c_a \qquad [6.8]$$

where: c_a = a coefficient for the combined effect of buried residue and soil consolidation on ground cover effectiveness. The equation for c_a is:

$$c_a = 3.52 \times 10^{-6} B_{rs}^2 (1 - s_c) \qquad \text{if } c_a > 1, c_a = 1 \qquad [6.9]$$

where: B_{rs} = buried residue mass (dry basis) density [$lbs_m/(ac \cdot in)$] in the accounting soil depth d_{rs}. The value for the coefficient c_a varies between 0 and 1. A value of zero is computed when the soil has been recently mechanically disturbed, which sets b_r to a value of 0.05 and a value of 1 for the combination of high buried residue and low soil consolidation subfactor. If a value greater than 1 is computed for c_a, the value is set to 1.

The equation for the soil accounting depth for the effect of buried residue on erosion is given by:

$$d_{rs} = 1 + 2(s_c - 0.45)/0.55 \qquad [6.10]$$

where: d_{rs} = the soil depth (inches) over which the density of buried residue mass is computed, 1 = the minimum accounting depth (inches) when the soil is fully consolidated (i.e., s_c = 0.45), 2 = the range (inches) over the accounting depth varies as a function of the soil consolidation subfactor s_c (see **Section 6.6**), and 0.55 = the range of the soil consolidation subfactor. The maximum accounting depth is 3 inches when the soil has just been mechanically disturbed (i.e., s_c =1).

Values computed by equation 6.10 are rounded to the nearest 1 inch. RUSLE2 divides the soil depth into 1-inch intervals and accounts for soil biomass within these 1-inch intervals. RUSLE2 does not subdivide soil depth internals in making its buried residue density computations.

The **b** value, which describes the relative effectiveness of ground cover type, in equation 6.6 is a function of the rill to interrill erosion ratio. RUSLE2 uses a series of equations to compute a **b** value.

The starting point for those equations is the simple equation that computes erosion when ground cover is present as:

$$D_c = D_b \exp(-bf_g) \qquad [6.11]$$

where: D_c = rill and interrill erosion when ground cover is present and D_b = rill and interrill erosion when ground cover is not present (bare soil). Therefore, a **b** value is computed from:

$$b = -\ln(D_c / D_b) / f_g \qquad [6.12]$$

The equation for rill-interrill erosion D_c when ground cover is present is:

$$D_c = D_{ib}(3s^{0.8} + 0.56)\exp(-0.025 f_g) + D_{rb}(s/0.0896)\exp(-b_r f_g) \qquad [6.13]$$

where: D_{rb} and D_{ib} = rill and interrill erosion, respectively, when ground cover in not present (bare soil). A value for rill erosion for bare soil is computed from:

$$D_{rb} = [\alpha/(\alpha+1)] \qquad [6.14]$$

where: the term α in equation 6.14, which represents a rill to interrill erosion ratio for bare soil. Equation 6.14 is the same as β in equation 2.13 without the ground cover effect. The term s/0.0896 adjusts for the effect of overland flow path steepness on rill erosion.[43] Rill and interrill erosion D_{rb} and D_{ib} are normalized so that they sum to 1 for a base, reference condition. Consequently, interrill erosion D_{ib} is computed from:

$$D_{ib} = 1 - D_{rb} \qquad [6.15]$$

[43] No adjustment is made for overland flow path because of mathematical limitations in devolving the USLE equation structure into rill and interrill terms while meeting the requirement that erosion computed for the entire overland flow path be independent of how many overland flow path segments are used in the computations when other conditions are uniform along the overland flow path.

where: the term ($3s^{0.8}$ + 0.56) adjusts for the effect of steepness on interrill erosion. The term D_b in equations 6.11 and 6.12 is computed as:

$$D_b = D_{ib}(3s^{0.8} + 0.56) + D_{rb}(s/0.0896) \quad [6.16]$$

The next step is to compute a value for the rill to interrill erosion ratio for bare soil as:

$$\alpha = (K_r / K_i) a_2 a_4 \quad [6.17]$$

where: the rill to interrill soil erodibility ratio (K_r/K_i) is computed using equation 4.12, the coefficients a_2 and a_4 describe how soil consolidation, soil biomass, and conformance of the ground cover to the soil surface affect the rill to interrill erosion ratio (see **Section 2.1.3**). The product a_2a_4 is comparable to the ratio (c_{pr}/c_{pi}) in equation 2.13.

The coefficient a_2 is given by:

$$a_2 = a_1 + a_b \qquad \text{if } a_2 > 8, a_2 = 8 \quad [6.18]$$

where: the coefficient a_1 is given by:

$$a_1 = 1 - \{0.9[(1 - s_c)/0.55][1 - \exp(-0.0022 B_{rt})]\} \quad [6.19]$$

where: B_{rt} = mass (dry basis) density (lbs_m/acre·inch) of the total of the live and dead roots in the soil accounting depth (10 inches) for roots. The a_1 coefficient represents how the rill to interrill erosion ratio changes as the soil becomes consolidated and as live and dead root biomass in the soil increases. The RUSLE2 assumption is that soil consolidation and root biomass have a greater relative effect on rill erosion than on interrill erosion.

The coefficient a_b, which represents how soil consolidation and buried residue affects the rill to interrill erosion ratio, is given by:

$$a_b = 1.76 \times 10^{-5} B_{rs}^2 (1 - s_c) \quad [6.20]$$

The a_b coefficient computes that the effect of buried residue reducing the rill to interrill erosion increases as the soil consolidation increases, such as for no-till crop, pasture, range, and similar lands that are not mechanically disturbed and B_{rs} = buried residue mass density in the soil accounting depth for buried residue.

The coefficient a_4 describes how conformance of ground cover to the soil surfaces affects the rill to interrill erosion ratio. Poor conformance of ground cover to the soil surface affects rill erosion more than it does interrill erosion. The equation for a_4 is:

$$a_4 = a_3 + (1 - a_3)[1 - \exp(-0.0055 B_{rt})] \quad [6.21]$$

where: the equation for a_3 is given by:

$$a_3 = \exp[-\psi(\lambda / s^{1/2})^{0.6} s] \quad [6.22]$$

where: λ = the overland flow path length and ψ = a coefficient that describes conformance of types of ground cover to the soil surface (see RUSLE2 User's Reference Guide).

Research shows that straw mulch cover is less effective at reducing rill-interrill erosion on steep overland flow paths characteristic of construction sites where mulch is applied to a smooth cut or graded soil in comparison to mulch applied to steep cropland soils [Meyer and Ports, 1976; AH537 (Wischmeier and Smith, 1978), Meyer et al., 1970; Meyer et al., 1972; Meyer et al., 1971]. RUSLE2 computes that affects assuming that the lost of ground (surface) effectiveness is determined by mulch characteristics related to how well the material conforms to the soil surface and stays in place. Three classes of ground (surface) cover conformance that vary with material properties are used in RUSLE2 (see **Section 6.2.1**).

The values used for the conformance coefficient ψ are 0.0 for material like gravel that very closely conforms to the soil surface, 0.15 for materials that conform to the soil surface much like typical pieces of soybean stems and wheat straw after having passed through a combine, and 0.3 for corn stalks and wood debris that do not conform well to the soil surface. Equations 6.21 and 6.22 compute reduced effectiveness of mulch, erosion control blankets, and similar materials applied on construction sites where overland flow paths are steep and long and no roots or plant stems are present. Both live and dead roots provide plant stems that help hold ground cover in place so that runoff does not dislodge and move mulch downslope or undercut erosion control blankets (Foster et al., 1982). The tendency for mulch failure and rill erosion under erosion control blankets increases when these materials bridge soil surface roughness elements.

6.2.2. Slope length exponent m

Equations 2.12 and 2.13 are the equations used to compute the slope length exponent **m**. The land use residual effect term in equation 2.13 is given by:

$$c_{pr} / c_{pi} = 0.45 + 1.55(s_c s_b)^2 \quad [6.23]$$

Equation 6.23 is based on the assumption that soil consolidation and soil biomass have a greater relative effect on rill erosion than on interrill erosion. The term for effective ground cover in equation 2.13 is computed from:

$$f_{ge} = f_{gn}(0.4 + 0.6\delta) \quad [6.24]$$

where: the cover adjustment term δ is given by:

$$\delta = (b_r - 0.05)/0.01 \quad [6.25]$$

Equations 6.24 and 6.25 reflects how ground cover has a greater effect on rill erosion than on interrill erosion when the soil has not been mechanically disturbed recently and soil biomass is high in the soil surface layer (e.g.., no-till type crop, pasture, range, and similar undisturbed lands).

6.2.3. Non-uniform ground cover

The user can divide the overland flow path into segments to partially represent spatial variability of ground cover. However, RUSLE2 assumes that ground cover is spatially uniform within a segment. When a soil disturbing operation occurs that disturbs only a portion of the soil surface, RUSLE2 computes detachment on both the undisturbed and disturbed portions, and it then determines the overall detachment based on the relative areas of the undisturbed and disturbed portions. An effective ground cover that gives the overall detachment is then back calculated using equation 6.6. The effective surface residue mass associated with that ground cover is determined (see **Section 10.2**). The ratio between this effective mass and the actual mass is maintained as surface residue is lost by decomposition.

6.2.4. b and m values for Req conditions

Most of the erosion during the winter Req period in Req areas is caused by rill erosion. Constant values of 0.50 and 0.046 are used for the slope length exponent **m** and the ground cover effectiveness index **b** for these conditions. These values are based on analysis of experimental research data (McCool et al., 2002).

6.2.5. Comments

The equations used to describe how ground cover affects erosion are empirically based on the RUSLE2 developers' judgment of how various factors affect the ratio rill to interrill erosion. These empirical equations replace user inputs of selecting LS tables and **b** values [AH703 (Renard et al., 1997)] or land use classes (Toy and Foster, 2000). Although the equations were not fitted to experimental research data, the equations represent qualitatively represent both laboratory and field research findings.

These equations for **b** and **m** values, along with other cover-management equations, give RUSLE2 its land use independence. RUSLE2 uses fundamental variables common to all land uses to compute how cover-management affects rill-interrill erosion.

6.3. Soil surface roughness subfactor

6.3.1. How surface roughness created by mechanical soil disturbance affects erosion

The soil surface roughness subfactor represents how random soil surface roughness created by mechanical soil disturbance affects rill-interrill erosion. Soil surface roughness includes depressions where local deposition occurs and soil peaks of large, stable soil aggregates that are resistant to detachment depending on the level of soil biomass. Infiltration is increased, which reduces runoff and rill erosion. Also, soil surface roughness slows surface runoff, which reduces its erosivity.

The RUSLE2 equation for the soil surface roughness subfactor is:

$$s_r = \exp[-0.66(R_{a,j} - 0.24)] \quad [6.26]$$

where: $R_{a,j}$ = adjusted roughness value (inches) on the *jth* day and 0.24 inches (6 mm) = the adjusted roughness value assigned to unit plot conditions. Equation 6.26 was derived from research measurements of roughness and erosion (Cogo et al., 1984).

The reference condition where the soil roughness subfactor s_r equals 1 is the unit plot condition during and after intense rainfall. The reference unit plot soil surface roughness is produced by a harrow or similar soil finishing tool after disking or similar tools used to prepare seedbeds. Most soil surface conditions are rougher than the unit plot conditions, which gives s_r values greater than 1. However, some soil surfaces are smoother than the unit plot, which gives s_r values greater than 1 up to a 1.17 value. Mechanical soil disturbing operation such as rototilling that finely pulverizes soil, cutting and filling with a blade, and rolling a finely pulverized soil surface produces a soil surface that is smoother than the unit plot soil surface.

6.3.2. Random roughness as affected by soil biomass

Biomass production (yield) level affects the soil surface roughness subfactor. The effect of biomass production level on the roughness subfactor, as seen in experimental soil loss ratio values [AH537 (Wischmeier and Smith, 1978)] is illustrated in Table 6.3. The roughness subfactor values in Table 6.3 were computed by dividing the soil loss ratio for the fallow crop stage period by the soil loss ratio for the seedbed period.[44] The only essential difference in soil conditions between these two short periods is soil surface roughness.

Experimental roughness subfactor values increased as production (yield) level decreased as shown in Table 6.3. Similarly, experimental roughness subfactor values [AH537 (Wischmeier and Smith, 1978)], as shown in Table 6.4, were significantly reduced when a corn grain crop followed an established meadow (sod), which has a very high soil

---

[44] Crop stages are periods where soil loss ratio values are considered constant in the USLE [AH537 (Wischmeier and Smith, 1978)]. The fallow period is for the time between when the soil is tilled with a primary tillage tool such as a moldboard plow and when the soil first time is tilled afterwards with a secondary tillage tool to prepare a seedbed. The seedbed period is the time between the first secondary tillage following primary tillage to when canopy cover of the planted crop reaches 10 percent.

Table 6.3. Effect of corn production level and soil biomass on roughness subfactor				
		Soil loss ratio		
Yield (bu/acre)	Management	Fallow	Seedbed	Roughness subfactor
112	Grain	0.31	0.55	0.56
87	Grain	0.36	0.60	0.60
67	Grain	0.43	0.64	0.67
49	Grain	0.51	0.68	0.75
112	Silage	0.66	0.74	0.89
87	Silage	0.67	0.75	0.89
67	Silage	0.68	0.76	0.89
49	Silage	0.69	0.77	0.90

biomass. Roughness subfactor values increased as hay yield decreased and increased in the second year of corn following sod. Residual soil biomass was less in the second year after the sod than in the first year immediately after the meadow. Also, roughness subfactor values were higher when corn followed small grain than when it followed sod. The small grain provided less soil biomass than did the sod.

Table 6.4 Effect of sod on roughness subfactor for moldboard plow period		
Hay yield (tons/acre)	Year after sod	Roughness subfactor
4	1	0.35
2.5	1	0.38
1.5	1	0.39
4	2	0.49
2.5	2	0.50
1.5	2	0.50

Roughness subfactor values are interpreted as being a function of soil biomass level caused by different yield levels, soil biomass level determined by whether crop residue is removed such as with silage or left with grain harvest, and the difference in biomass level caused by type of preceding crop such as hay, small grain, or row crop grain. Recommendations for the USLE [AH537 (Wischmeier and Smith, 1978)] are that non-sod forming meadows such as sweet clover or lespedeza have less effect on rill-interrill erosion than does sod forming vegetation, which is explained by the difference in soil biomass production between these vegetation types.

RUSLE2 computes initial soil roughness after a mechanical soil disturbance as a function of the soil biomass in the soil disturbance depth using:

$$R_{ib} = 0.24 + (R_{it} - 0.24)\{0.8[1 - \exp(-0.0015 B_{ta})] + 0.2\} \quad [6.27]$$

where: R_{ib} = the initial roughness adjusted for the soil texture and biomass effect, R_{it} (inches) = the initial roughness after the input roughness value is adjusted for soil texture and B_{ta} = the total mass (dry basis) [lbs_m/(acre·inch)] of buried residue and live and dead roots averaged over the soil disturbance depth after the operation. The 0.24-inch value is the roughness value assumed for unit plot conditions. The 0.2 value reflects the portion of the roughness value that is not affected by soil biomass.

6.3.3. Adjusting roughness input values for soil texture

Input roughness entered in the RUSLE2 database for a soil disturbing operation is adjusted for soil texture before equation 6.27 is used to adjust for the soil biomass effect on roughness. The equation that adjusts input roughness values for soil texture is:

$$R_{it} = R_{in}[0.16(P_{sl}/100)^{0.25} + 1.47(P_{cl}/100)^{0.27}] \qquad [6.28]$$

where: R_{in} = the input roughness value entered for a soil disturbing operation in the RUSLE2 database, P_{sl} = percent silt in the soil, and P_{cl} = percent clay in the soil. The roughness values R_{it} adjusted for soil texture are the same as roughness input R_{in} values for the reference silt loam soil texture. Roughness values computed by equation 6.28 are greater than the roughness input values for soils high in clay and less than roughness input values for soils high in sand. Equation 6.28 was developed based on judgment and field observations of how soil surface roughness varies with soil texture when mechanically disturbed.

6.3.4. Assigning input roughness values for operations

Input values entered in the RUSLE2 database for soil surface roughness created by a mechanical soil disturbing operation are assigned according to soil surface roughness that the operation creates for a base, reference condition. This condition is a smooth, silt loam soil (clay = 15%, silt = 65%) having a very high soil biomass (dry basis) density of greater than 1000 lbs_m/(acre·inch) in the soil disturbance depth, which includes both buried residue and dead roots. These soil biomass levels occur where crop yield exceeds 200 bu/acre corn, 70 bu/acre wheat, and 4 tons/acre hay or pasture land (see RUSLE2 User's Reference Guide).

The roughness index used in RUSLE2 for input values assigned to soil disturbing operations in the RUSLE2 database is the standard deviation soil surface elevations measured on a 1-inch grid. The elevations are relative to a plane that removes elevation differences caused by land steepness and ridges.

6.3.5. Effect of existing roughness at time of soil disturbance (tillage intensity effect)

Roughness left by a soil disturbing operation is a function of the operation itself and existing roughness at the time of the operation. The RUSLE2 assumption is that existing roughness has no effect if the roughness, adjusted for soil texture and biomass, left by a soil disturbing operation is greater than the existing soil roughness at the time of the operation. However, the RUSLE2 assumption is that the roughness left by a soil disturbing operation is a function of existing roughness if the adjusted roughness created by operation is less than existing roughness. In this case, the resulting roughness is a function of the initial adjusted roughness, existing roughness, and tillage intensity of the soil disturbing operation. Tillage intensity is a measure of the aggressiveness of the soil disturbing operation for obliterating existing roughness. The equation for how existing roughness and tillage intensity affect soil roughness is:

$$R_{ad,j} = (1-\varepsilon)(R_{a,j} - R_{ib,j}) + R_{ib,j} \qquad [6.29]$$

where: $R_{ad,j}$ = the adjusted roughness after the soil disturbing operation on *jth* day of the operation immediately after the operation, ξ = tillage intensity, $R_{a,j}$ = existing adjusted roughness on the *jth* day immediately before soil disturbing operation, and R_{ib} = the input roughness for the soil disturbance that occurs on the *jth* day after adjustment for soil biomass and soil texture, which is the value computed by equation 6.27. A tillage intensity of 1 means that the soil disturbing operation is so aggressive that existing roughness has no effect on the roughness left by the operation. Examples of these operations include moldboard plows and rototillers. Conversely, a tillage intensity of 0 means roughness after the soil disturbing operation is the same as existing roughness before the operation. Harrows that have a tillage intensity of 0.4 are examples of operations where existing roughness has a significant effect on roughness left after a soil disturbing operation.

6.3.6. Roughness decay

Roughness decays after a mechanical soil disturbance because of soil slumping (i.e., settlement and subsidence) caused by the presence of moisture, interrill erosion wearing away roughness peaks, and local deposition in roughness depressions. The RUSLE2 equation used to represent this effect is given by [AH703 (Renard et al., 1997)]:

$$\Delta R_r = \exp(-0.07 P_d - 0.006 r_d c_c g_{ci})] \qquad [6.30]$$

where: ΔR_r = the fraction of the current roughness greater than 0.24 inch that remains, P_d = the daily precipitation amount (inches), r_d = the daily erosivity (US customary units), and g_{ci} = the interrill ground cover factor. The term in equation 6.30 associated with precipitation amount represents roughness loss by settlement and subsidence and the term associated with erosivity represents roughness loss by interrill erosion. The RUSLE2 assumption is that half of the roughness loss is by settlement and the other half is by interrill erosion. Roughness loss by local deposition is not explicitly represented. Roughness decay is not computed as a function of soil properties including texture and soil biomass. The adjustment made to initial roughness by equations 6.27 and 6.28 is assumed to adequately represent the effect of soil texture and soil biomass on roughness at any time.

The interrill ground cover factor is given by:

$$g_{ci} = \exp(-0.025 f_{gn}) \qquad [6.31]$$

where: f_{gn} = the net ground cover (percent). Adjusted roughness on the *jth* day used in equation 6.26 is computed as:

$$R_{a,j} = 0.24 + \Delta R_r (R_{a,j-1} - 0.24) \qquad [6.32]$$

where: R_{j-1} = adjusted roughness on the previous day. The RUSLE2 assumption is that roughness is not decayed when the input initial roughness in the RUSLE2 database for a soil disturbing operation is less than the unit plot roughness of 0.24 inch.

6.3.7. Base roughness value

The 0.24-inch value in equations 6.27 and 6.32 represents a base roughness value for unit plot conditions. The assumption is that soil clods persist so that the unit plot surface is never becomes perfectly smooth. The unit plot final roughness value is not varied as a function of soil texture because that effect is empirically accounted for by the RUSLE2 soil erodibility factor. However, RUSLE2 allows the user to enter a “final” roughness value for an operation that is greater than 0.24 inch to represent conditions where roughness decays to a final roughness greater than 0.24 inch. RUSLE2 uses an input final roughness value greater than 0.24 inch entered in the RUSLE2 database for a soil disturbing operation for the 0.24 value in equations 6.27 and 6.32. RUSLE2 does not allow roughness to decay to a value less than 0.24 inch, even if the input final roughness is less than 0.24 inches. The input initial and final roughness values can be used to force RUSLE2 to use a particular roughness in its computations (see RUSLE2 User’s Reference Guide).

6.3.8. Long term roughness development

A natural soil roughness develops over time after the last mechanical soil disturbance. The final natural roughness is a function of soil properties, vegetation characteristics, and local erosion and deposition. RUSLE2 assumes that the time required for this long-term roughness to develop equals the time to soil consolidation (see **Section 4.8**). The RUSLE2 equation used to compute long term roughness is given by:

$$R_{l,j} = 0.24 + (R_{af} - 0.24)/\{1 + \exp[(0.5 - t_d / t_c)/0.1]\} \qquad [6.33]$$

where: $R_{l,j}$ = long term roughness, R_{af} = the adjusted final long term roughness value, t_d = number of days since the last mechanical soil disturbance, and t_c = the time to soil consolidation (days). A value for R_{af} is computed using equations 6.27and 6.28 from the input long-term natural roughness values entered in the RUSLE2 database. The biomass value used in equation 6.27 is based on total soil biomass including buried residue and dead and live roots in the upper 4 inches of the soil. The value input for final long-term roughness for a given cover-management description is relative to the reference condition for short term roughness associated with mechanical soil disturbance (see **Section 6.3.4** and RUSLE2 User’s Reference Guide). RUSLE2 adjusts this input value for soil texture and soil biomass just as it does roughness created by mechanical disturbance. The assumption is that vegetation must be present for much of the long term surface roughness to develop and be effective. Equation 6.33 is illustrated in Figure 6.3 where the time to soil consolidation is 7 years.

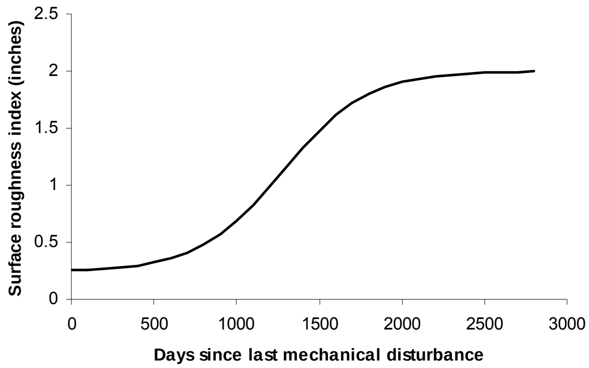


Figure 6.3. Development of long term roughness as a function of time since last mechanical soil disturbance.

RUSLE2 tracks both short term roughness resulting from mechanical soil disturbance and long term roughness development. RUSLE2 uses the maximum of the two roughness values in equation 6.26 to compute a roughness subfactor value.

6.3.9. Accounting for spatial variability in roughness

RUSLE2 can take partially take soil surface roughness spatial variability into account by dividing the overland flow path into segments. However, roughness is assumed to be uniform within a segment. Some mechanical soil disturbing operations disturb the soil in strips. For these operations, RUSLE2 computes roughness subfactor values for both the undisturbed and disturbed areas and the overall subfactor value based on the portion of the soil surface that the operation disturbs. RUSLE2 then back-calculates an effective roughness using equation 6.26 that gives the effective roughness subfactor value. This single effective roughness value is assigned to the segment and decayed over time using equation 6.30.

6.3.10. Comments

RUSLE2 captures the main effects of roughness on rill-interrill erosion. The intent is not to explicitly model soil roughness to produce roughness values comparable to field measured values except for input values determine from the reference condition (see **Section 6.3.4**). For example, internal RUSLE2 computed roughness values are less than those measured in the field on construction sites where soil clay content is high. The roughness effect on erosion is more than the geometric effect of soil surface roughness slowing runoff, ponding water, and depositing sediment. It also includes an infiltration effect that is less directly related to soil surface roughness than are the other erosion processes. The adequacy of the soil roughness relationships in RUSLE2 should be judged on the basis of how well RUSLE2 computes rill-interrill erosion as affected byt soil disturbing operations that create soil surface roughness.

6.4. Ridge height subfactor

6.4.1. Effect of ridges on rill-interrill erosion

Ridges affect erosion principally in two ways. When the ridges are oriented parallel to the overland flow path, ridges increase rill-interrill erosion because of increased interrill erosion on the ridge sideslopes, which is represented by the ridge height subfactor. When ridges are nearly perpendicular to the overland flow path, ridges alter the runoff flow path by partially redirecting runoff around the hillslope or by ponding runoff behind the ridges if the ridges are perfectly on the contour. This effect of ridges is considered in the contouring subfactor (see **Section 7.1**).

Increased ridge height increases ridge sideslope (interrill) steepness, which in turn increases interrill erosion steepness (Lattanzi et al., 1974). RUSLE2 uses only ridge height to compute ridge height subfactor values although both ridge height and spacing determine interrill steepness. Accurately identifying ridge spacing or number of ridges per unit overland flow path width is difficult whereas ridge height can be easily visualized and determined.

6.4.2. Reference condition for ridge height subfactor

The reference condition for the ridge height subfactor, as with all cover-management subfactors, is the unit plot condition. Unit plots are prepared to a seedbed condition (see **Section 2.1** and **Footnote 2**) using tools like spike tooth harrow that leave small ridges up and down slope. The RUSLE2 ridge subfactor must be 1 for the unit plot condition. Unit plot conditions are not static because the unit plots are periodically tilled to break soil crusts and to control weeds. A ridge subfactor value of 1 for unit plot conditions represents an average over time because of periodic ridge formation and decay.

The ridge subfactor equations are also derived for the reference condition of the ridges being parallel to the overland flow path (i.e., up and down slope).

6.4.3. Ridge height subfactor for low steepness

The RUSLE2 ridge height subfactor is constant for overland flow path steepness less than six percent as determined from experimental data and the judgment of scientists who experimentally measured the effect of ridges on rill-interrill erosion from almost flat slopes (<1%) to land steepness as great as 5 percent (Young and Mutchler, 1969; Mutchler and Murphree, 1985; McGregor et al., 1999).[45] The RUSLE2 ridge height subfactor equations derived from experimental data are:

$$r_{h6} = 0.9(1 + 0.0582H^{1.84}) \qquad H \le 3 \text{ inches} \qquad [6.34]$$

$$r_{h6} = 2.136[1 - \exp(-0.484H)] - 0.336 \qquad H > 3 \text{ inches} \qquad [6.35]$$

where: r_{h6} = daily ridge height subfactor when the overland flow path steepness is less than or equal to 6 percent and H = daily ridge height (inches). The significance of the 0.9 in equation 6.34 is that the minimum ridge height subfactor is 0.9 for a flat soil surface and the maximum ridge height subfactor from equation 6.35 is 1.8, which is consistent with the values given in AH537 (Wischmeier and Smith, 1978) for applying the USLE to cotton production on high ridges [Mutchler et al., 1982; Mutchler and Murphree, 1985, AH537 (Wischmeier and Smith, 1978)]. Also, equation 6.34 gives a subfactor value of 1

[45] C.K. Mutchler and K.C. MCGregor. 1999. Effect of ridge height on erosion on low slopes. Personal communication. Scientists (retired) at the USDA-National Sedimentation Laboratory, Oxford, MS.

for a ridge height of 1.42 inch, which represents unit plot conditions except for the difference between a six percent steepness and the unit plot nine percent steepness.

6.4.4. Adjustment for effect of overland flow path steepness

Interrill steepness is affected by land steepness. Interrill steepness is much greater than land steepness on flat slopes than on steep slopes. For example, local interrill steepness with high ridges (about 8 inches high when formed) like those used in cotton production in the Mississippi Delta is about 20 percent (Meyer and Harmon, 1985; Mutchler and Murphree, 1985), which is the interrill steepness when the land is flat (about 0.5%). As land steepness increases, local interrill steepness increases but much more slowly than does land steepness. Local interrill steepness of the ridge sideslope almost equals land steepness on steep slopes. For example, the same ridges that that give a 20 percent steep ridge sideslope on a 6 percent land steepness give a 54 percent interrill steepness on a land steepness of 50 percent. The ridge height subfactor, therefore, approaches 1 for steep overland flow paths.

A simple rill-interrill erosion equation was used to develop equations for the ridge height subfactor for overland flow path steepness greater than six percent. That simple equation is:

$$D_t = 0.5[(s/0.0896) + (3\sin^{0.8}\theta_i + 0.56)] \qquad [6.36]$$

where: the 0.5 represents the assumption that rill and interrill erosion are equal for unit plot conditions (Foster and Meyer, 1975; Foster et al., 1977a, 1977b; Foster, 1982), the term s/0.0896 represents the effect of steepness on rill erosion, and the term $3\sin^{0.8}\theta_i+0.56$ represents the effect of steepness on interrill erosion. Steepness of the interrill area represented by θ_i is greater than the steepness of the rill area represented by **s** because ridge height increases interrill steepness (i.e., the ridge sideslope steepness).

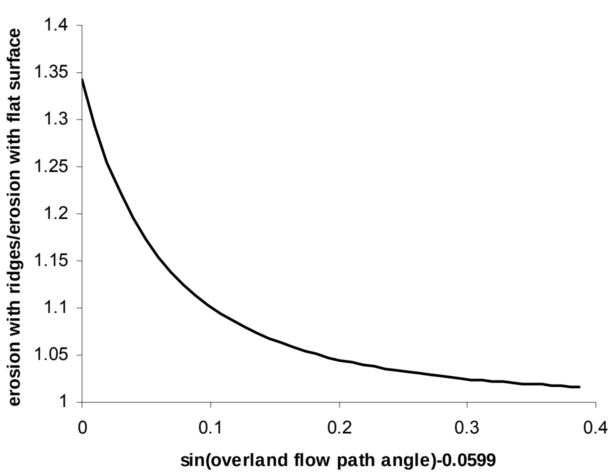


Figure 6.4. Effect of overland flow path steepness on the ratio of erosion with a 20% ridge sideslope to erosion from a flat surface.

Equation 6.36 was solved for overland flow path steepness between and 6 and 50 percent for a range of ridge side slope steepness and for a flat (i.e., non-ridged soil surface). Erosion computed for a given ridge sideslope steepness for a particular flow path steepness was divided by erosion for a flat soil surface at that same overland flow path steepness. An example of those values is shown in Figure 6.4 for a ridge sideslope of 20 percent. The RUSLE2 equations used to represent this effect are:

$$r_h = r_{h6} \qquad s_p < 6\% \qquad [6.37]$$

$$r_h = 1 + (r_{h6} - 1)\exp[-a_h(s_p - 0.05989)] \qquad s_p \geq 6\% \qquad [6.38]$$

where: s_p = the sine of the overland flow path slope angle and a_h is computed from:

$$a_h = 16.02 - 0.927H \qquad H \leq 10 \text{ inches} \qquad [6.39]$$

$$a_h = 6.75 \qquad H > 10 \text{ inches} \qquad [6.40]$$

where: ridge height H has units of inches.

6.4.5. Effect of row grade on ridge height subfactor

The ridge height subfactor equations given above apply to the reference condition of the ridges being parallel to the overland flow path (i.e., up and down slope). As relative row grade (i.e., ratio of grade along the ridges to overland flow path steepness) decrease from 1 (up and down slope) to 0 (on contour), the ridge subfactor value should become 1. The effect of ridge height on rill-interrill erosion is represented in the contouring subfactor when the ridges are on the contour (see **Section 7.1**). However, this requirement can not be met because of RUSLE2's mathematical structure. Instead, the ridge subfactor value is 0.9 when ridges are perfectly on the contour, which is the ridge height subfactor value for a flat soil surface.

The equations that compute ridge height subfactor values as a function of ridge orientation (i.e., relative row grade) are:

[6.41]

$$r_h = 0.9 - (0.9 - r_{h,u\&d})g_r^2 \qquad r_{h,u\&d} \leq 1$$

$$r_h = 0.9 + (r_{h,u\&d} - 0.9)g_r^2 \qquad r_{h,u\&d} > 1 \qquad [6.42]$$

where: $r_{h,u\&d}$ = the ridge height subfactor value when ridge orientation is parallel to the overland flow path and g_r = relative row grade (grade along the ridges/overland flow path steepness).

6.4.6. Ridge height decay

Ridge height decays because of settlement and interrill erosion. Settlement occurs quickly after the ridges are formed when water is presence. The RUSLE2 assumption is that forty percent of the initial ridge height is lost by settlement while the remaining sixty percent is lost by interrill erosion based on analysis of experimental data (Lyles and.

Tatarko. 1987).[46] Thus, the initial ridge height left by a soil disturbing operation is divided into two parts as:

$$H = H_s + H_e \qquad [6.43]$$

where: H_s = the ridge height component associated with settlement and H_e = the ridge height component associated with interrill erosion. The initial value for H_s is 0.4 times the ridge height left by the soil disturbing operation, while the initial value for H_e is 0.6 times the ridge height left by the soil disturbing operation. The daily settlement component ridge height is computed as:

$$H_{s,j} = H_{s,j-1} \exp(-0.2343 P_d) \qquad [6.43]$$

where: j is a day subscript and P_d = daily precipitation (inches). The daily interrill erosion ridge height is computed as:

$$H_{e.j} = H_{e,j-1} - a_e r_d c_c g_{ci} \qquad [6.45]$$

where: r_d = the daily erosivity (US customary units) and the coefficient a_e is computed as:

$$a_e = 0.033 - 0.002 H_i \qquad H_i \le 10 \text{ inches} \qquad [6.46]$$

$$a_e = 0.013 \qquad H_i > 10 \text{ inches} \qquad [6.47]$$

where: the units for a_e are inches/(US customary EI unit) and H_i = initial ridge height left by the soil disturbing operation (inches). The reason for the coefficient a_e being a function of ridge height is the RUSLE2 assumption that high ridges have a wide base so that the overall lost of ridges occurs more slowly than does the loss of ridges with a narrow base. The minimum allowable ridge height is zero. These equations and their coefficients were derived from research data (Lyles and Tatarko, 1987) and from field observations in cotton fields in the Mississippi Delta.[47]

6.4.7. Effect of existing ridge height, soil, and cover-management on ridge height when new ridges are formed

The RUSLE2 assumption is that existing ridges have no effect on the ridges created by a soil disturbing operation. Also, the RUSLE2 assumption is that initial ridge height or the decay rate for ridges is not a function of soil properties or cover-management conditions. Ridge height at formation is determined entirely by the soil disturbing operation. The effect of existing ridges and soil and cover-management conditions on ridge height can

---

[46] K.C. McGregor. 1999. Field observations of ridge height decay in the Mississippi Delta. Personal communtation. Scientist (retired), USDA-National Sedimentation Laboratory, Oxford, MS.
[47] McGregor, K.C. 1999. Loss of ridge heights in the spring in the Mississippi Delta. Personal communication. USDA-Agricultural Research Service (retired scientist), Oxford, MS.

be taken into account in RUSLE2 by creating multiple soil disturbing operations having a range of ridge height values. The user then selects a particular operation for RUSLE2 input that gives the desired ridge height for the given situation.

6.4.8. Comments

The intent in RUSLE2 is to capture the main effect of ridge height on rill-interrill erosion as ridge height interacts with land steepness and to capture the main effect of variables that cause ridge height to decay. The intent is not to explicitly model ridge height. The adequacy of the RUSLE2 ridge height subfactor equations should be judged on the basis of how well RUSLE2 computes rill-interrill erosion as a function of soil disturbing operations that create ridges.

RUSLE2 not giving 1 for the ridge subfactor when ridges are perfectly on the contour is a limitation of RUSLE2's empirical mathematical structure not being consistent with process-based equations. RUSLE2 was constructed so that these problems do not significantly affect RUSLE2's utility as a conservation and erosion control planning tool.

6.5. Soil biomass subfactor

6.5.1. Soil biomass effect

The RUSLE2 soil biomass subfactor estimates how soil biomass affects rill-interrill erosion [Mannering et al., 1968; Foster et al., 1985; McGregor et al., 1990; Brown et al., 1989; Toy et al., 2002; Van Liew and Saxton, 1983, AH537 (Wischmeier and Smith, 1978)]. Soil biomass represented by RUSLE2 includes buried residue, live roots, and dead roots,

Live roots produce exudates that reduce soil erodibility. Also, live root biomass is a measure of plant transpiration, which reduces soil moisture that in turn increases infiltration and reduces runoff. Dead roots add organic matter to the soil that increases infiltration and decrease soil erodibility. Both live and dead roots mechanically hold the soil in place, hold soil in "clumps" when the soil is mechanically disturbed, and reduce waterdrop impact and runoff erosivity if the roots are exposed.

Buried residue is biomass that has been mechanically incorporated into the soil. RUSLE2 also "incorporates" up to 25 percent of the daily decomposition of surface residue into the soil to represent the accumulation of high organic matter at the soil surface for no-till and other conditions where little or soil disturbance occurs (Kay and VanderBygaart, 2002; Shelton and Bradley, 1987). Incorporated biomass, such as crop residue, manure, or bio-solids in sewage waste, provides organic compounds that increase infiltration and decrease soil erodibility [Browning et al., 1948; Copley et al., 1944; Hays et al., 1949; AH537 (Wischmeier and Smith, 1978)]. Also, pieces of organic material, such as incorporated crop residue, can be sufficiently large to mechanically reduce rill erosion (Brown et al., 1989).

6.5.2. Soil biomass subfactor equation

The equation for the RUSLE2 soil biomass subfactor is:

$$s_b = 0.951 \exp(-0.0026\, B_{rt} - 0.0006\, B_{rs} / s_c^{0.5}) \qquad s_b \le 0.9035 \qquad [6.48]$$

$$s_b = \exp[-1.9785(0.0026 B_{rt} + 0.0006 B_{rs} / s_c^{0.5})] \qquad s_b > 0.9035 \qquad [6.49]$$

Equation.6.49 is used for very low soil biomass where the soil biomass subfactor s_b is greater than 0.9035. Equation 6.48 does not give the required value of 1 for unit plot conditions that has no soil biomass (i.e., B_{rt} and B_{rs} = 0). The common point of s_b = 0.9035 results from the product of 0.951 in equation 6.48 and 0.95, the upper value for which the exp(…) term in equation 6.48 is assumed to apply.

The coefficient values in equation 6.48 was obtained by fitting the equation to soil biomass subfactor values estimated from soil loss ratio values determined from measured research data and summarized in AH537 (Wischmeier and Smith, 1978) except for the data points for no-till and mulch (reduced) till, which were research based values obtained from the literature.[48] The data used in the fitting are given in Table 6.5, and the fit of equation 6.48 to the observed values is shown in Figure 6.5. The data points (soil loss ratio values) shown in Table 6.5 were selected across the range of soil biomass represented by Table 5, AH537. Equation 6.48 fits the observed values well except for the 112 bu/acre corn following 1.5 tons/acre meadow.

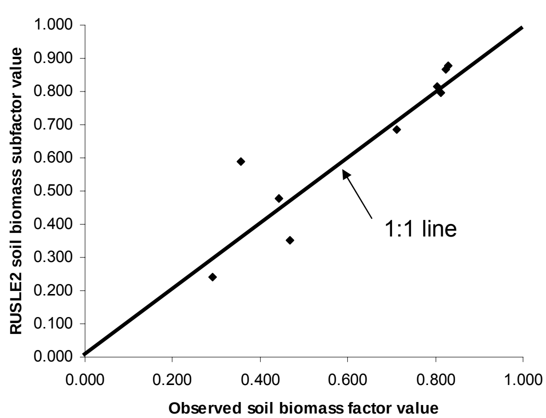


Figure 6.5. Comparison of RUSLE2 soil biomass values to observed values

Observed soil biomass subfactor values were estimated from the soil loss ratio values given in Table 6.5. Soil biomass subfactor values were computed from soil loss ratio values by rearranging equation 6.1 to solve for the soil biomass subfactor and substituting RUSLE2 estimated values for the other subfactors. Soil loss ratio values were substituted for cover-management factor c in equation 6.1.

Using soil loss ratios in Table 5, AH537 for the seedbed crop stage period for conventional, clean tillage, which is most like the unit plot condition, minimizes the error in estimated subfactor values used in equation 6.1 to estimate soil biomass subfactor values. The major subfactor affecting soil loss ratio

---

[48] More than 100 articles were reviewed to evaluate the effect of no-till and mulch till cropping on rill-interrill erosion. Those articles are listed in the **Additional References Section** (??).

values for the seedbed crop stage for conventional, clean tillage is soil biomass although some ground (surface residue) cover is present and soil surface roughness is rougher than for unit plot conditions.

Table 6.5. Soil biomass subfactor values used to derive RUSLE2 subfactor equation

Cover-management (yield)	Data source	Seedbed soil loss ratio	Soil biomass factor Obs	RUSLE2
conv corn 112 bu/ac	AH537	0.55	0.71	0.69
conv corn 50 bu/ac	AH537	0.68	0.80	0.82
conv corn sillage 112 bu/ac	AH537	0.74	0.81	0.79
conv corn sillage 50 bu/ac	AH537	0.77	0.83	0.88
conv corn 112 bu/ac soybeans 25 bu/ac	AH537	0.72	0.82	0.87
conv corn 112 bu/ac after meadow 4 tons/acre	AH537	0.18	0.29	0.24
conv corn 112 bu/ac after meadow 1.5 tons/acre	AH537	0.29	0.35	0.59
no till corn 112 bu/ac		0.028	0.47	0.35
mulch till corn 112 bu/ac		0.24	0.44	0.48

Soil loss ratio values given in Table 5, AH537 are assumed to apply to the reference silt loam soil at Columbia, Missouri. RUSLE2 was used to compute subfactor values for ground cover (surface residue) and surface roughness for all conditions listed in Table 6.5 and soil consolidation for the no-till data condition. The canopy subfactor value was 1 for all conditions and the soil consolidation subfactor was 1 except for no-till. RUSLE2 was used to compute soil biomass values using values in the RUSLE2 **core database** (see RUSLE2 User's Reference Guide).

The soil consolidation term s_c in equation 6.48 gives increased credit for buried residue to represent no-till cropping and other undisturbed soil conditions. For example, a given amount of buried residue at the soil surface decreased rill-interrill erosion more with no-till than with clean tillage. Increased soil macro-pores and aggregation develop in the upper few inches of soil under no-till cropping and other undisturbed soil conditions (Kay and VanderBygaart, 2002). Frequent, routine tillage and other mechanical soil disturbance prevent these conditions from developing. Mechanical soil disturbance disrupts these favorable soil conditions for reducing rill-interrill erosion, and time is required for these soil conditions to become reestablished. The term $1/s_c^{0.5}$ in equation 6.48 is used as an index for the development of these favorable soil properties.

Values for the accounting depths d_{rs}, described in **Section 6.2** for buried residue, and d_{rt} for roots were determined during the fitting of equation 6.48. The best fit was obtained with a buried residue accounting depth of three inches for conventional, clean tillage, which is represented by $s_c = 1$. The accounting depth is reduced to 1 inch as the soil consolidation subfactor value decreases from 1 for a soil recently mechanically disturbed to 0.45 for a fully consolidated soil (see equation 6.10). The accounting depth for buried residue reflects the soil depth over which buried residue has its major effect on infiltration, soil erodibility, and runoff erosivity.

The accounting depth determined for roots was 10 inches. This depth contains the bulk of roots for most vegetation, especially major agricultural crops like corn, soybeans, and wheat. The apparent depth over which roots affect erosion is greater than that for buried residue because live roots affect infiltration by extracting soil water. The 10-inch accounting depth for roots is also influenced by the common depth of 10 inches for modern moldboard plows, which invert the soil. Moldboard plow bring roots near the bottom of the plow depth being to near the soil surface. Moldboard plows also move surface residue and buried residue near the soil surface to near the bottom of the plow depth, where the buried residue has little effect on rill-interrill erosion. Although the case can be made that live roots and dead roots should be treated differently in RUSLE2 because of moisture extraction, the effect of live roots and dead roots per unit mass are considered to be the same for both live and dead roots.

Table 6.6. Effect of manure additions on erosion at Clarinda, IA

			Ratio of erosion with manure to erosion without manure	
Cover	Yield (bu/ac)	Manure application (tons/acre wet basis)	Obs	RUSLE2
Corn	22	0	1.00	1.00
Corn	30	8	0.42	0.39
Corn	36	16	0.21	0.20
Fallow		0	-	-
Fallow		8	0.79	0.42
Fallow		16	0.63	0.24

Table 6.7. Effect of manure additions on erosion at La Crosse, WI

			Ratio of erosion with manure to erosion without manure	
Cover	Yield (bu/ac)	Manure application (tons/acre wet basis)	Obs	RUSLE2
Corn	30	0	1.00	1.00
Corn, manure spring applied	30	8	0.82	0.42
Corn, manure fall applied	30	8	0.80	0.42
Fallow		0	1.00	1.00
Fallow, manure spring applied		5	0.85	0.75

See **Sections 8.2** and **9.2.1** for additional comments.

6.5.3. Soil biomass subfactor equation for Req conditions

When RUSLE2 is applied to Req conditions (see **Section 3.2.5** and the RUSLE2 User's Reference Guide), soil biomass values are multiplied by 1.65 to give increased erosion reduction per unit biomass. Most of the rill-interrill erosion for Req conditions is rill erosion, and soil biomass has a greater relative effect on rill erosion than on interrill erosion (Van Liew and Saxton,1983; Brown et al., 1989; McGregor et al., 1990). The 1.65 value was determined by fitting RUSLE2 to data collected at Pullman, Washington (McCool et al., 2002).

6.5.4. Applicability of soil biomass subfactor equation for biomass additions

The data used to derive equation 6.48 were for cropped conditions

Table 6.8. Effect of biomass additions on erosion with cotton at Statesville, NC				
			Ratio of erosion with biomass to erosion without manure	
Yield (lbs/acre seed cotton)	Biomass type	Biomass application (tons/acre wet basis)	Obs	RUSLE2
800	-	none	1.00	1.00
1800	Animal manure	8	0.19	0.27
1800	Compost	12	0.39	0.21
1800	Compost	18	0.13	0.16
1800	Compost	60	0.03	0.04
1800	Wood litter	24	0.09	0.13
1800	Pine needles	24	0.10	0.13

where the biomass source was vegetation grown on-site. RUSLE2 must also represent the effect of incorporation of applied biomass from other sources including animal manure, compost, bio-solids in sewage and similar waste, and forest litter. The applicability of RUSLE2 for these conditions was evaluated by computing and comparing rill-interrill RUSLE2 erosion estimates with measured erosion in research studies. Tables 6.6 and 6.7 show estimated and observed erosion values for surface application of manure and its incorporation into the soil using primary tillage at Clarinda, Iowa and La Crosse, Wisconsin (Browning et al, 1948; Hays et al., 1949). Table 6.8 shows erosion values for various biomass types applied and incorporated in the soil for cotton grown at Statesville, North Carolina (Copley et al., 1944). RUSLE2 is judged to adequately estimate how surface applied and soil incorporated biomass affects rill-interrill erosion.

Several factors complicate this analysis. One factor is data variability. Incorporated animal manure decreased erosion much more at Clarinda, Iowa than at La Crosse, Wisconsin. RUSLE2 seems to seriously over estimate the effect of manure applied to fallow conditions at both Clarinda and La Crosse. A comparison of observed erosion with manure applied to corn with erosion for manure applied to fallow soil at Clarinda indicates a much greater effect of the corn biomass than is supported by data in Table 5, AH537 (Wischmeier and Smith, 1978). Another problem with the experimental data is that manure applied to the corn at La Crosse did not reduce erosion as much as expected based on the results for the fallow soil. Such unexplained variability in erosion data is common.

Another complicating factor is how well the biomass was incorporated into the soil by the 6-inch deep manual spading operation used on the research plots to replicate moldboard plowing. The RUSLE2 inputs were based on the assumption that the spading incorporated the biomass more like a chisel plow than like a moldboard plow. Assuming that the incorporation was like a moldboard plow rather than a chisel plow results in RUSLE2 estimating that the ratio of erosion with incorporated biomass to erosion without incorporated biomass increases from 0.42 to 0.48 for applying 8 tons/acre of manure at Clarinda, Iowa. Consequently, the uncertainty in how the spading operation incorporated the biomass does not seem to account for the large difference between the RUSLE2 values and the measured values for fallow conditions.

Another complicating factor is that the reported application rates were on a wet basis rather than a dry basis required as input to RUSLE2. The dry biomass was assumed to be 25 percent of the wet basis application rates for all biomass types. The erosion ratios for fallow conditions at La Crosse assuming a 6 inch deep moldboard plowing are 0.65, 0.48, and 0.29 for the dry biomass inputs of 2000, 4000, and 8000 lbs/acre biomass inputs, respectively. Errors in estimating the dry biomass can have a significant effect on the RUSLE2 estimate erosion.

RUSLE2 assumes that the effect of all types of buried residue on rill-interrill erosion is described solely by biomass amount on a dry basis. Mechanical characteristic, such as diameter and length of individual pieces, of buried residue are assumed in RUSLE2 not to affect rill-interrill erosion. This assumption is supported by the experimental and RUSLE2 results for the Statesville, North Carolina data.

The experimental results given in Tables 6.6 - 6.8 do not indicate the effect of biomass addition on rill-interrill erosion with modern farming practices. The depth of incorporation in these studies, which were conducted primarily in the late 1930's, was six inches while common modern moldboard plows incorporate material to 10 inches deep. Changing incorporation depth would have reduced the RUSLE2 estimated ratio of erosion with incorporated biomass to erosion without biomass incorporation from 0.42 assuming a chisel plow type incorporation in the soil (0.48 assuming a moldboard plow incorporation) to 0.82 assuming incorporation with a modern moldboard plow for the 8 tons/acre manure spring application to corn at La Crosse, Wisconsin. The reason for the major difference is the effect of machine operation depth on the fraction of the biomass that is incorporated (see **Section 8.2.4.2**) and the biomass density in the surface 3-inch soil depth.

6.5.5. Soil biomass subfactor for pasture, range, and similar undisturbed lands

Equations 6.48 and 6.49 are assumed to apply to all land use conditions. Range, pasture, and other undisturbed lands are highly variable in both time and space. Accurately measuring root biomass is extremely difficult, if not impossible for undisturbed lands because of temporal and spatial variability. Reliable measurements of root biomass and buried residue are not available to either directly validate equations 6.48 and 6.49 or derive alternative equations for these lands.[49] Therefore, erosion data from research plots under simulated rainfall were used to derive effective root biomass values for rangeland plant communities rather than use measured root biomass values. [50]

---

[49] An extensive review of measured root biomass for rangeland plant communities was conducted during the development of RUSLE1. The variability in these values, as indicated in Table 5-4, [H703 (Renard et al., 1997) , is far too great to use these values as either input to RUSLE2 or to develop a soil biomass subfactor, especially a temporally varying one, for these conditions.

[50] Data from the WEPP study (Simanton et al., 1991) was used in the analysis to computed effective root biomass values. Data from the USDA Range Study Team study Spaeth et al., 2003) were considered for use in the development of RUSLE2, but the data were not used because of inconsistencies in the data, which were not resolved by the researchers who collected the data (see the RUSLE2 User's Reference

The common approach for applying the USLE [AH537 (Wischmeier and Smith, 1978)] and RUSLE1 [AH703 (Renard et al., 1997)] to undisturbed lands is to input values that represent average annual conditions to make a single erosion computation using subfactors similar to those in equation 6.1 to for the year rather than to compute daily erosion. This approach can also be used in RUSLE2, although a better approach is to use time varying inputs to represent temporal effects on rill-interrill erosion (see RUSLE2 User's Reference Guide). The lack of both measured soil biomass data and research that establishes how soil biomass and its characteristics affect rill-interrill erosion required derivation of effective root biomass ratio values, which is defined as the ratio of effective root biomass to average annual above ground biomass production on a dry basis. Values for this ratio vary by plant community and were determined directly from the experimental soil erosion research data (See RUSLE2 User's Reference Guide; Simanton et al., 1991). This derivation empirically accounts for differences between cropland and undisturbed land conditions and overcomes the impossibility of measuring root biomass on undisturbed lands.

First, a **c** factor value was computed for each site from measured erosion data by rearranging equation 2.1 as:

$$c_p = A_p / [R_p K_n (\lambda_p / \lambda_u)^m S_p] \qquad [6.50]$$

where: c_p = the c factor value for the measured erosion data obtained from applying simulated rainfall to field plots 12 ft wide by 35 ft long, A_p = measured erosion, R_p = the erosivity for the simulated rainfall, K_n = the soil erodibility value determined by applying the standard soil erodibility nomograph (see **Sections 4.1.1** and **4.1.2**) using soil property values measured at each site, λ_p = the plot length, λ_u = unit plot length, and S_p = the slope steepness factor computed from the measured plot steepness. Next an observed soil biomass subfactor value s_c was computed for each experimental site by rearranging equation 6.1, substituting values for the other subfactors, and solving for the soil biomass subfactor value.

An effective root biomass value was computed by rearranging equation 6.48 and assuming no buried residue effect (i.e., assuming that buried residue biomass B_{rs} = 0). RUSLE2 does not consider a buried residue effect when using a single average annual input for root biomass. The approach also requires using RUSLE2 inputs that add surface residue that does not decompose (see RUSLE2 User's Reference Guide). The value for the effective root biomass was divided by the average annual dry matter above ground biomass production to compute a value for effective root biomass ratio for the site. These values were averaged where the same plant community occurred at multiple sites. RUSLE2 multiplies the input value for above ground annual production by the effective root biomass ratio to obtain a value for effective root biomass B_{rt} that is used in equation 6.48 or 6.49 to compute a value for the soil biomass subfactor. Derivation of RUSLE2 effective root biomass values was the same as that used to derive comparable

---

Guide).

values for RUSLE1 [Yoder et al., 1997; AH703 (Renard et al., 1997)], except that RUSLE2 equations and procedures were used for equations 6.1, 6.48, and 6.50.

The RUSLE2 User's Reference Guide discusses how time varying inputs can be used in RUSLE2 to represent changes in time during the establishment of permanent cover such as on construction sites, reclaimed mined lands, rangelands disturbed by mechanical soil disturbance, and forest lands disturbed by logging and burning. This Guide also describes how time varying inputs can be used in RUSLE2 to represent long-term vegetation that has reached maturity on undisturbed land. Using time varying inputs for canopy and root biomass allows RUSLE2 to compute a litter cover produced by senescence, soil biomass produced by dead (soughed) roots, and soil biomass produced by buried residue that are a function of plant community, production level, and location (Reeder et al., 2001).

RUSLE2 was fitted directly to the measured erosion data for rangelands to determine the soil biomass effect for these lands. However, RUSLE2 erosion estimates for undisturbed lands, especially rangelands, have more uncertainty than erosion estimates for cropland. This increased uncertainty exists for all erosion prediction technologies and is not unique to RUSLE2. Reasons for this uncertainty and its magnitude are discussed in detail in the RUSLE2 User's Reference Guide.

6.5.6. Sources of soil biomass in RUSLE2

The sources of soil biomass in RUSLE2 are biomass applied to the soil surface or directly injected into the soil, above ground biomass from vegetation grown on site, and roots from vegetation grown on-site. The amount of applied biomass is a direct input to RUSLE2 (see **Section 10**). The amounts of above ground and root biomass for vegetation grown on-site are directly related to RUSLE2 inputs (see **Section 9**). Once live above ground biomass becomes dead biomass (i.e., residue) by senescence or killed by an operation such as mowing, it disappears by decomposition discussed in **Section 10.4.1.** Similarly, once live roots become dead roots either by the plants being killed or by root sloughing, this biomass disappears by decomposition. Operations, including soil disturbing operations, move biomass between the various biomass pools and redistribute biomass within the soil (see **Section 8**). The RUSLE2 User's Reference Guide describes the RUSLE2 biomass pools in detail and how these pools are manipulated in RUSLE2.

6.5.7. Transfer of surface residue to soil biomass by decomposition in RUSLE2

The organic matter content of the approximate 2-inch soil depth for no-till cropped soil is about twice that for conventional, clean-till cropping (Kay and VanderBygaart, 2002; Shelton and Bradley, 1987). A RUSLE2 assumption is that biomass occurs in the soil only by roots grown in the soil or a mechanical soil disturbing operation incorporating biomass. To accommodate the accumulation of high organic matter level in a shallow soil surface layer where little or no mechanical soil disturbance occurs, such as for no till croplands and undisturbed lands, RUSLE2 assumes that a portion of the daily surface residue decomposition is added to the top 2-inch soil layer. Once in this soil layer, this biomass is treated as any other buried residue that is subject to decomposition and has the same effect on rill-interrill erosion as any other buried residue.

This empirical procedure is used as a mechanism for increasing soil biomass in the upper soil layer when the soil is minimally disturbed. The equation used to compute this buried residue addition is:

$$f_b = 0.25[(1/s_c) - 1] \qquad [6.51]$$

where: f_b = the fraction of the daily biomass decomposed from surface residue that is added to the buried residue biomass in the upper 2-inch soil layer. The 0.25 value was determined during the fitting of equation 6.48 to the observed data. The 0.25 variable was adjusted so that RUSLE2 computes a soil biomass in the top 2-inch soil layer for the no-till data point that is approximately twice the soil biomass for conventional, clean tillage. The structure of equation 6.51 was chosen so that the rate of change in the effect of soil consolidation is least immediately after a mechanical soil disturbance (i.e., $s_c = 1$). The rate in f_b increases as the soil approaches full soil consolidation (i.e., $s_c = 0.45$).

The soil consolidation s_c subfactor term in equation 6.51 and the time to soil consolidation (see **Section 4.8**) determine the time required after a conversion from conventional, clean tillage to no tillage for soil biomass to come to a new equilibrium. Seven years is used for the time to soil consolidation in the eastern US, which is too short for all of the soil biomass changes to occur (Kay and VanderBygaart, 2002). However, seven years for time to soil consolidation is sufficient for RUSLE2 to represent particular organic matter, and seven years seems sufficiently long for most major land use changes that affect rill-interrill erosion in the context of conservation planning. The time to soil consolidation is also used to compute change in soil erodibility when no biomass is present, and thus the time to soil consolidation is a compromise for describing multiple effects.

Equation 6.51 computes no transfer of biomass from the surface residue to the buried residue when the soil has been recently mechanically disturbed, which is indicated by s_c = 1, which gives $f_b = 0$ from equation 6.51. If the soil is totally undisturbed where c_s = 0.45, $f_b = 0.31$, which means that each day approximately 30 percent of the surface residue that is lost by decomposition on that day is added to the buried residue in the upper 2-inch soil depth. In no-till corn cropping where the only soil disturbing operation is a planter that disturbs 15 percent of the soil surface, the c_s ranges from 0.54 to 0.61 during the year. The approximate annual average is 0.58, which gives a value of 0.18 from equation 6.51. That is, approximately 18 percent of the daily surface residue decomposition is added to the upper 2-inch soil depth for a typical no-till corn cropping in comparison to almost 30 percent being added for a completely undisturbed soil condition.

6.5.8. Spatial variability in the soil biomass subfactor

Soil biomass and the soil biomass subfactor are assumed to be spatially uniform within a segment along the overland flow path, even when the soil is disturbed in strips. Non-uniformity in soil biomass along the overland flow path can be represented by dividing the overland flow path into segments.

6.5.9. Comments on soil biomass subfactor

The purpose of the soil biomass subfactor is to capture the main effect of live and dead roots and buried residue on rill-interrill erosion. The RUSLE2soil biomass relationships are not meant to be a model of soil biomass that stands alone from how it used in RUSLE2 to estimate rill-interrill erosion for conservation and erosion control planning. The soil biomass subfactor does not capture all interactions, such as how the effect of soil biomass on erosion is affected by soil texture.

The importance of the soil biomass subfactor is often overlooked in evaluating how cover-management practices affect rill-interrill erosion. For example, large amounts of biomass added to the soil can greatly reduce rill-interrill erosion as indicated in Table 6.8. Similarly, large amounts of live and dead root biomass also greatly reduce erosion.

Very few experiments have been conducted where the direct effect of roots on erosion has been studied. Much research, such as that summarized in AH537 (Wischmeier and Smith, 1978), conclusively shows that root biomass reduces erosion. No studies have shown how root characteristics affect rill-interrill erosion. Therefore, very minimal research information is available that allows the development of a soil biomass equation as a function of root characteristics.

RUSLE2 only uses biomass amount as the variable to capture how soil biomass affects erosion. For example, RUSLE2 makes no distinction between how small and larges roots affect erosion. However, preference in selecting root biomass input values is given to fine roots instead of coarse roots (see RUSLE2 User's Reference Guide). Not much of the mass of coarse roots is entered for root biomass because coarse roots are assumed to have relatively little effect on erosion. Fine roots are assumed to have much greater effect on erosion per unit biomass than do coarse roots. Fine roots have greater surface area per unit mass than coarse roots and often are very close to the soil surface where they have a greater effect on runoff and erosion than coarse roots. Fine roots are readily sloughed and become a part of the soil organic matter pool.

Similarly, limited and incomplete research has been conducted to directly determine the effect of buried residue on rill-interrill erosion (Van Liew and Saxton, 1983; Brown et al., 1989; McGregor et al., 1990; Box, Jr. and Bui, 1993). Measuring soil buried residue and its characteristics as they affect rill-interrill erosion is difficult and has not been done.

Getting good results from RUSLE2 requires that instructions in the RUSLE2 User's Reference Guide for selecting input values be carefully followed. RUSLE2's soil biomass subfactor equation, as well as other subfactor equations, was calibrated using the data in the RUSLE2 **core database**. When those values and the procedures described in the RUSLE2 User's Reference Guide are followed, RUSLE2 users can expect good results from RUSLE2 for conservation and erosion control planning. If one disagrees with the soil biomass values used by RUSLE2, one can not simply change RUSLE2 input values because of RUSLE2 having been calibrated using values from the RUSLE2 core database. If soil biomass values are changed, the soil biomass subfactor equation must be re-derived because the RUSLE2 equation was derived using RUSLE2 soil biomass values.

The importance of this point can not be over emphasized.

6.6. Soil consolidation subfactor

6.6.1. Soil consolidation effect

The RUSLE2 assumption is that mechanical soil disturbance by tillage, construction activities, and other soil loosening operations significantly increases soil susceptibility to erosion. Rill-interrill erosion immediately after a mechanical soil disturbance is assumed to be about twice that when the soil has not been disturbed for an extended period. The effect is much greater for rill erosion than for interrill erosion (Foster, 1982; Foster et al., 1982).

The term soil consolidation does not accurately connote the process by which soil becomes less susceptible to erosion over time. The reduction in soil erodibility over time represented by the soil consolidation subfactor is related to internal cohesive soil bonding increasing over time rather than to a mechanical increase in soil bulk density. Cohesive bonding increases as the soil experiences wetting and drying cycles in the presence of organic matter and chemical bonding agents in the soil (Foster et al., 1985; Toy et al., 2002). The important role of soil moisture is the reason for the time to soil consolidation being a function of average annual precipitation between 20 and 30 inches (see **Section 4.8**).

The soil consolidation effect is based on a comparison of erosion in unit plot condition to erosion of the same soil that has not been mechanically disturbed for some time being left in unit plot condition by the last mechanical soil disturbance. Soil disturbance also affects the ground cover, soil surface roughness, and soil biomass subfactors in addition to the soil consolidation subfactor. The soil consolidation subfactor represents solely the effects of soil loosening on erosion relative to time since the last mechanical soil disturbance that left unit plot conditions. The soil consolidation subfactor variable is also used to compute values for the soil biomass subfactor, rill to interrill erosion ratio, and runoff curve number. Therefore, the effect of soil loosening computed by RUSLE2 can be significantly greater than the effect represented by the soil consolidation subfactor.

6.6.2. Soil consolidation subfactor equation

The equation for the RUSLE2 soil consolidation subfactor is:

$$s_c = 0.45 + \exp\{-3.314[0.1804 + (t_d / t_c)^{1.439}]\} \quad [6.52]$$

where: t_d = days since last mechanical soil disturbance and t_c = the time to soil consolidation The 0.45 value in equation 6.52 represents the minimum soil consolidation subfactor value that occurs for time exceeding the time to soil consolidation.[51] The soil consolidation subfactor value is 1 for $t_d = 0$, which is immediately after a mechanical soil disturbance. A plot of equation 6.52 is shown in Figure 6.6 for two times to soil consolidation.

Equation 6.52 was derived from experimental erosion data collected from natural runoff plots at Zanesville, Ohio (Borst et al., 1945). Erosion was measured for a few years from a plot periodically tilled to maintain unit plot conditions. Tillage was stopped and erosion measurements were continued for several years after tillage stopped. Measured annual erosion values were adjusted based on the annual erosivity to account for weather differences between years. Observed soil consolidation subfactor values were computed by dividing the adjusted annual erosion values after tillage stopped by adjusted average annual erosion before tillage stopped.

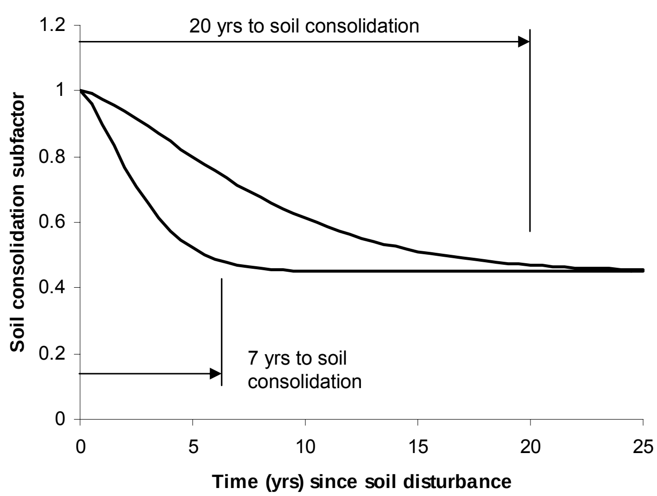


Figure 6.6. Variation of the soil consolidation subfactor as a function of time after last mechanical soil disturbance.

6.6.3. Spatial variability effect on soil consolidation subfactor

RUSLE2 accommodates spatial variability along the overland flow path when the overland flow path is divided into segments. RUSLE2 also represents the effect of operations that disturb only a portion of the soil surface (e.g., strip tillage) based on the fraction of the soil surface that the operation disturbs. An effective value for the soil consolidation subfactor is computed as the weighted average of $s_c = 1$ for the portion disturbed and the s_c value for the undisturbed portion at the time of the mechanical soil disturbance. An effective time since soil disturbance is calculated by rearranging equation 6.52 and solving for the time t_d that gives the effective s_c value. The time since last soil disturbance is reset to this effective

[51] Equation 6.52 approaches 0.45 asymptotically. The time to soil consolidation is defined as the time when 95 percent of the decrease in the soil consolidation subfactor has occurred (see **Section 4.8**).

time, and time accounting for soil consolidation begins again from the effective time value.

6.6.4. Comments on soil consolidation subfactor

The RUSLE2 soil consolidation subfactor only captures the soil loosening effect on rill-interrill erosion in the broadest terms. The soil consolidation subfactor is the most poorly defined of all the RUSLE2 cover-management subfactors. Very little empirical and not much fundamental research has been conducted to determine how the soil consolidation effect varies with climate, soil texture, and other factors. The RUSLE2 soil consolidation subfactor is determined from a single set of data collected at a single location on a single soil texture. The effect is greater for rill erosion than for interrill erosion (Foster et al., 1982). However, the soil consolidation effect on rill erosion can be quite variable. In one study, rill erosion of a silt loam soil decreased by about 75 percent over about a year's time (Dissmeyer and Foster, 1981). In another study, sediment eroded from ridges and deposited in furrows became quite resistant to erosion in just four weeks (Foster et al., 1982).

The soil consolidation effect surely must be a function of soil texture. For example, the range in the soil consolidation subfactor for soils high in sand is assumed to be less than for silt loam soils. Also, the time to soil consolidation is assumed to be a function of soil texture. However, available research information is not sufficient to include these effects in the RUSLE2 soil consolidation subfactor.

The RUSLE2 assumption is that mechanical soil compaction (i.e., mechanical increases in soil bulk density) does not affect rill-interrill erosion. Soil compaction has two offsetting effects. One is to increase infiltration, which increases runoff and hence rill-interrill erosion. The other effect is to decrease erosion by decreasing the detachability of soil particles by raindrop and runoff forces. The assumption of no effect of soil compaction on erosion is false for a high clay soil being mechanically compacted at optimum soil moisture. Soil compaction of a high clay soil can greatly reduce rill erosion (ref). Rill erosion can be highly variable for other soil textures as a function of mechanical soil compaction (ref). Available research information was not sufficient to include a RUSLE2 relationship that computes erosion as a function of soil bulk density. An adjustment can be made to the soil erodibility input value to represent a compaction.

RUSLE2 does represent the effect on rill-interrill erosion of subsoiling, scarifying, and similar mechanical soil disturbances designed to break up soil to increase infiltration, which in turn decreases runoff and erosion. RUSLE2 represents this effect though the soil surface roughness subfactor (see the RUSLE2 User's Reference Guide).

The RUSLE2 soil erodibility factor does not represent the effect of soil compaction. Soil compaction is a cover-management effect. Changing a soil erodibility input value to represent soil compaction is for convenience only in RUSLE2 because no other input method is available to represent the effect of compaction.

6.7. Antecedent soil moisture subfactor

The antecedent soil moisture subfactor is used only when RUSLE2 is applied to Req conditions (see **Section 3.2.5**).

6.7.1. Antecedent soil moisture effect

Rill-interrill erosion under Req conditions is highly sensitive to soil moisture [AH703 (Renard et al., 1997); Van Klaveren and McCool,1998]. Low soil moisture significantly reduces erosion during the Req period. Freezing and thawing cycles in the presence of very high soil moisture and other processes dramatically increase soil erodibility during the winter months at Req locations [see RUSLE2 User's Reference Guide, AH703 (Renard et al., 1997); Van Klaveren and McCool,1998). Highly saturated soil in the tilled surface layer plays a major role in Req processes that do not occur to nearly the same degree or regularity in non-Req locations.

6.7.2. Antecedent soil moisture subfactor equations

The RUSLE2 antecedent soil moisture subfactor equations are a refinement of those in RUSLE1 [Yoder et al., 1997; AH703 (Renard et al., 1997); McCool et al., 2002]. The year is divided into periods of soil moisture replenishment (October 1 – March 31), stable at maximum soil moisture (April 1 – April 30), depletion (May 1 – July 31), and stable at minimum soil moisture (August 1 – September 30).

6.7.2.1. Replenishment (October 1 – March 31)

The average daily soil moisture replenishment rate is computed as:

$$R_m = 0.5/182 \qquad P_a \le 10 \text{ inches} \qquad [6.53]$$

$$R_m = [0.5 + 0.062(P_a - 10)]/182 \qquad 10 < P_a \le 18 \text{ inches} \qquad [6.54]$$

$$R_m = 1/182 \qquad P_a > 18 \text{ inches} \qquad [6.55]$$

where: R_m = an index (dimensionless) for daily moisture replenishment rate, P_a = average precipitation (inches), and 182 = number of days over which replenishment occurs.

$$s_{m,j} = s_{m,j-1} + R_m \qquad if\,(s_m > 1) s_m = 1 \qquad [6.56]$$

where s_m = antecedent soil moisture subfactor for the *jth* day.

6.7.2.2. Depletion (May 1 – July 31)

The daily soil moisture depletion rate is computed as:

$$D_m = \phi_m / 91 \qquad [6.57]$$

where: D_m = an index (dimensionless) for daily moisture depletion rate, φ_m = the total soil moisture depletion as a function of vegetation, and 91 is the number of days over which depletion occurs. Example values for φ_m are given in Table 6.9.

$$s_{m,j} = s_{m,j-1} - D_m \qquad if\,(s_m < 0) s_m = 0 \qquad [6.58]$$

6.7.2.3. Minimum and maximum periods (April 1 – April 30) and (August 1 – September 30)

The soil moisture subfactor is assumed not to change during the minimum period between the depletion and replenishment periods and the maximum period between the replenishment and depletion periods. That is:

$$s_{m,j} = s_{m,j-1} \qquad [6.59]$$

6.7.2.4. Initial s_m value

The initial default value for the antecedent soil moisture subfactor s_m is 1. The initial condition is not important when cover-management practice are rotations (i.e., the set of operations is repeated continuously). RUSLE2 runs until dynamically stable conditions are reached. However, when the cover-management practice is not a rotation, the initial operations in the cover-management description are used to set the desired initial condition (see RUSLE2 User's Reference Guide). Specific values can not be entered in the RUSLE2 computer program to set initial values of RUSLE2 variables.

Table 6.9. Soil moisture depletion index for vegetation grown in Req location

Vegetation	Depletion index
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
Vegetation that has been killed	0.00

6.7.2.5. Applicability of RUSLE2 antecedent soil moisture subfactor equations

The RUSLE2 antecedent soil moisture subfactor equations (equations 6.53 - 6.59) strictly apply only to the portion of the Req zone from central Washington across northern Idaho and in northeastern Oregon (see RUSLE2 User's Reference Guide). Although Req conditions occur in other locations, equations 6.53 – 6.59 do not apply to those locations because of differences in precipitation patterns. These equations were empirically derived from data collected at Pullman, Washington. Differences in monthly precipitation distributions between Pullman Washington and Salt Lake City, Utah are illustrated in Figure 6.7. Equation 6.53 – 6.55 do take into account differences in annual precipitation between locations but not differences in monthly precipitation and vegetation extraction patterns. Replenishment and depletion rates are expected to differ among locations as monthly precipitation distributions vary.

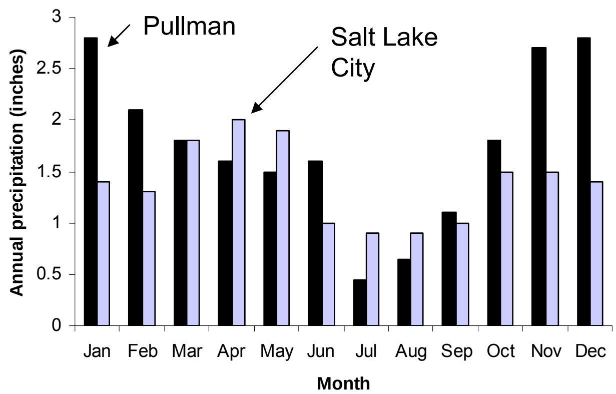


Figure 6.7. Distribution of monthly precipitation at Pullman, WA (P_a = 20.9 inches) and Salt Lake City, UT (P_a = 16.9 inches)

6.7.3. Comments on antecedent soil moisture subfactor

The antecedent soil moisture subfactor is a very important variable at Req locations. For example, changing the moisture depletion variable φ_m from 1, its standard value, to 0 for no moisture depletion, increased estimated erosion from 8.9 to 14 tons/acre per year for a typical conventional, clean-till continuous wheat crop at Pullman, Washington. Given that the antecedent soil moisture subfactor has a major effect on rill-interrill erosion emphasizes the need for improved equations for this subfactor as a function of monthly precipitation distribution.

TheRUSLE2 antecedent soil moisture subfactor should only be used for Req locations. The antecedent soil moisture subfactor equations were empirically derived from data collected at Pullman, Washington where climatic conditions are very different from those in other US regions. Antecedent soil moisture affects rill-interrill erosion in all location. Those effects are empirically described by the canopy and soil biomass subfactors and by the precipitation and temperature variables used to compute temporal soil erodibility factor values (see **Section 4.5**). Using the antecedent soil moisture subfactor in non-Req location causes serious errors in RUSLE2 estimating erosion.

6.8. Validation of cover-management factor values

RUSLE2 should represent the effect of cover-management on rill-interrill erosion better than it does for any other major factor. Rill-interrill erosion varies more as cover-management varies over its likely range than it does for the likely range of any other factor. Cover-management type erosion control practices are used more widely than any other type of erosion control practice. RUSLE2 must accurately estimate how cover-management affects erosion to avoid excessive expense of installing more erosion control than necessary. Likewise, RUSLE2 must accurately estimate how cover-management affects erosion to ensure adequate erosion control and prevention of excessive damages. The RUSLE2 User's Reference Guide extensively discusses the validity of RUSLE2 for estimating how cover-management affects rill-interrill erosion.

Tables 6.10 – 6.12 illustrate how well the RUSLE2 cover-management subfactors compute soil loss ratios in relation to summarized experimental data taken from AH537 (Wischmeier and Smith, 1978) and other sources. As these tables show, RUSLE2 estimates very well the variation in soil loss ratios as a function of crop stage periods and as a function of the major cover-management variables that affect rill-interrill erosion.

In addition, an extensive set of literature was reviewed and analyzed in validating RUSLE2 for conservation tillage especially no till. Those papers are listed in the **No-till References** section in the list of references.

Table 6.10. Soil loss ratios for conventional clean tilled continuous 112 bu/ac from AH537 and RUSLE2 computed values.

Crop stage (defined in AH537)	AH537 soil loss ratio	RUSLE2 computed soil loss ratio
Fallow	0.31	0.28
Seedbed	0.55	0.54
1 - 10% < canopy cover < 50%	0.48	0.52
2 - 50% < canopy cover < 75%	0.38	0.3
3 - 75% < canopy cover to maturity	0.23	0.18
4 after harvest (stalks spread)	0.06	0.06

Table 6.11. Soil loss ratio values for conventional clean till flat planted continuous 750 lbs/acre cotton at Holly Springs, MS.

Crop stage (defined in AH537)	AH537 soil loss ratio	RUSLE2 computed soil loss ratio
Fallow	0.39	0.54
Seedbed	0.64	0.74
1- 10% canopy cover < 35%	0.59	0.74
2 - 35% < canopy cover < 60%	0.46	0.49
3 - 60% canopy cover to maturity	0.32	0.23
Defoliation to Dec 31	0.26	0.24
Jan 1 to Feb. tillage	0.32	0.32

Table 6.12. Soil loss ratio values for conventional clean till ridge (hipped) continuous planted 750 lbs/acre cotton at Holly Springs, MS.

Crop stage (defined in AH537)	AH537 soil loss ratio	RUSLE2 computed soil loss ratio
1st hip, no prior tillage	0.84	0.88
Split ridges with a “do-all”	0.54	0.52
Hip after 2 prior tillages	1.08	1.01
Split ridges with a “do all”	0.62	0.58
Hip after 3 or more tillages	1.1	1.12
Split ridges with a “do all”	0.64	0.64
Seedbed	0.64	0.64
1 - 10% canopy cover < 35%	0.59	0.64
2 - 35% < canopy cover < 60%	0.46	0.45
3- 60% canopy cover to maturity	0.32	0.21
Defoliation to Dec 31	0.22	0.23
Jan 1 to Feb. tillage	0.32	0.27

List of symbols

a_b = coefficient for effect of buried residue reducing rill to interrill erosion increases as soil consolidation increases
a_e = coefficient used to compute ridge height decay
a_g = coefficient related to height within the canopy where vegetative surface area is concentrated, used to compute effective fall height
a_h = coefficient used to compute ridge subfactor values
a_s = coefficient that is a function of canopy shape used to compute effective fall height
$a_1 = 1 - \{0.9[(1 - s_c)/0.55][1 - \exp(-0.0022 B_{rt})]\}$
a_2, a_4 = coefficient for how soil consolidation, soil biomass, and conformance of the ground cover to the soil surface affect rill to interrill erosion ratio
$a_3 = \exp[-\psi(\lambda / s^{1/2})^{0.6} s]$
$a_4 = a_3 + (1 - a_3)[1 - \exp(-0.0055 B_{rt})]$
A_p = measured erosion from simulated rainfall applied to plots used to determine c factor values (mass/area)
b = coefficient (percent^{-1}) that is a function of ground cover type and the ratio of rill to interrill erosion
b_r = coefficient for how ground cover affects rill erosion
B_{rs} = buried residue mass (dry basis) density in soil accounting depth for buried residue (mass/area·length)
B_{rt} = live and dead root mass (dry basis) density in soil accounting depth for roots (mass/area·length)
B_{ta} = total mass (dry basis) density of buried residue and live and dead roots averaged over soil disturbance depth after the operation (mass/area·length)
c = daily cover-management factor
c_a = coefficient for combined effect of buried residue and soil consolidation on ground cover effectiveness
c_c = daily canopy subfactor
c_p = c factor value for measured erosion data obtained from applying simulated rainfall to field plots
c_{pr}/c_{pi} = rill to interrill prior land use soil erodibility ratio
d_{rs} = accounting soil depth for buried residue (length)
D_b = rill and interrill erosion when ground cover is not present (bare soil) (mass/area0
D_c = rill and interrill erosion when ground cover is present (mass/area)
D_{ib} = interrill erosion when ground cover is not present (bare soil) (mass/area)
D_m = index for daily moisture depletion rate
D_{rb} = rill erosion when ground cover in not present (bare soil) (mass/area)
D_t = normalized rill-interrill erosion
e_d = impact energy of the waterdrop (force-distance)
f_b = fraction of the daily biomass decomposed from surface residue added to buried residue biomass in upper 2-inch soil layer
f_c = canopy cover (portion of soil surface covered with vegetative canopy)
f_{ec} = daily effective canopy cover

f_g = ground cover, portion of soil surface covered
f_{ge} = effective ground cover
f_{gn} = net ground cover, portion of soil surface covered
g_{ci} = the interrill ground cover factor
h_b = height to bottom of canopy (length)
h_f = daily effective fall height (length)
h_t = height to top of canopy (length)
g_c = daily ground cover subfactor
g_r = relative row grade (grade along the ridges/overland flow path steepness)
H = daily ridge height (length)
H_e = ridge height component associated with interrill erosion (length)
H_s = ridge height component associated with settlement (length)
K_n = soil erodibility value determined from standard soil erodibility nomograph using soil property values measured at each site [mass/area)/erosivity unit]
K_r/K_i = rill to interrill soil erodibility ratio
L = USLE slope length factor
m = slope length exponent
m_d = waterdrop mass
P_a = average precipitation (length)
P_{cl} = portion of soil composed of clay
P_d = daily precipitation amount (length)
P_{sl} = portion of soil composed of silt
r_d = daily erosivity (erosivity units)
r_h = daily ridge height subfactor
$r_{h,u\&d}$ = ridge height subfactor value when ridge orientation is parallel to overland flow path
r_{h6} = daily ridge height subfactor when overland flow path steepness is less than or equal to 6 percent
R = roughness index (length)
R_a = adjusted roughness used to compute the soil surface roughness subfactor (length)
R_{ad} = adjusted roughness after soil disturbing operation (length)
R_{af} = adjusted final long term roughness value (length)
R_{at} = adjusted roughness value (inches) at a particular time (length)
R_e = existing roughness at time of soil disturbing operation (length)
R_{ia} = input roughness for soil disturbance after adjustment for soil biomass and soil texture
R_{ib} = initial roughness adjusted for the soil texture and biomass effect (length)
R_{in} = input roughness value entered for a soil disturbing operation in the RUSLE2 database (length)
R_{it} = initial roughness after input roughness value is adjusted for soil texture (length)
R_{lt} = long term roughness (length)
Req = equivalent erosivity related to greatly increased soil erodibility during winter months
R_m = index for daily moisture replenishment rate
R_p = erosivity for simulated rainfall applied to plots used to determine c factor values
s = sine of slope angle of overland flow path

s_b = daily soil biomass subfactor
s_c = daily soil consolidation subfactor
s_{ci} = surface cover effect for interrill erosion
s_{cr} = surface cover effect for rill erosion
s_m = daily antecedent soil moisture subfactor used in Req zone
s_p = sine of steepness angle of overland flow path
s_r = daily soil surface roughness subfactor
s_{cr}/s_{ci} = ratio of ground cover effects for rill and interrill erosion in rill to interrill erosion ratio
S = steepness factor
S_p = slope steepness factor computed from steepness of plots used with simulated rainfall to determine c factor values
t_c = time to soil consolidation (days)
t_d = time since the last mechanical soil disturbance (days)
V_d = the waterdrop impact velocity (length/time)

α = rill to interrill erosion ratio for bare soil
δ = cover adjustment term
ΔR_r = portion of current roughness greater than 0.24 inch that remains (length)
ξ = tillage intensity
λ = overland flow path length (length)
λ_p = length of plots used with simulated rainfall to determine c factor values
φ_m = the total soil moisture depletion as a function of vegetation
ψ = coefficient that describes conformance ground cover to soil surface
θ_i = interrill slope angle with respect to horizontal

Indices
j - day

7. Support practice subfactor relationships

7.1. Contouring (ridging)

7.1.1. Description of contouring (ridging)

Contouring is an erosion control practice where ridges are placed on the contour around the hillslope perpendicular to the overland flow path. Runoff flows uniformly over the ridges along their length when the ridges are perfectly on the contour and the ridge top is level. Ponded water in the furrows between the ridges reduces detachment and causes a major portion of the sediment eroded from the ridges to be deposited in the furrows.

These ideal conditions seldom occur in the field. Breakovers occur in low ridge areas and where the soil is susceptible to rill erosion. Erosion reduction with contouring is less when breakovers occur. However, erosion reduction occurs even with breakovers if furrow (row) grade is sufficiently flat to cause deposition in the furrows or to cause reduced rill erosion in relation to the rill-interrill erosion that occurs when the ridges are parallel to the overland flow path. Runoff travels long distances in the furrows between high ridges to concentrated flow areas where ephemeral gully erosion occurs. RUSLE2 does not explicitly estimate ephemeral gully erosion (see RUSLE2 User's Reference Guide), although ephemeral gully erosion occurred in the small watersheds used to derive the RUSLE2 contour subfactor relationships. Thus, ephemeral gully erosion is partially included in RUSLE2 erosion estimates for contoured conditions.

The effect of ridging (contouring) on rill-interrill erosion must be considered even when ridging is not used explicitly as an erosion control practice. For example, tillage direction in an agricultural field is often parallel to a field boundary, which results in ridges at an angle to the overland flow path. Rill-interrill erosion varies between the extremes of being minimal when the ridges are perfectly on the contour and maximum when the ridges are parallel to the overland flow path.

The base, reference unit plot condition is that ridges-furrows are parallel to the overland flow path. Thus, the RUSLE2 contouring subfactor represents the effect of ridge-furrow orientation with respect to the overland flow path on rill-interrill erosion.

7.1.2. Contouring (ridging) effect

Figure 7.1 is a plot of experimental data that shows how contouring affects rill-interrill erosion on plots that ranged in width from12 to 150 ft and small watersheds that were about 5 acres in area (Foster et al., 1997; see **Contouring References**). Plots are often assumed not to represent well the effect of contouring on rill-interrill erosion as well as do watersheds.

Each type of measurement area has shortcomings. A short coming of watersheds is that measured sediment from watersheds includes sediment produced by ephemeral gully erosion, which is not estimated by RUSLE2. A short coming of plots narrower than about 20 ft is that runoff rates are too low at the ridge breakovers. Several plot widths exceeded 20 ft with some as wide as 150 ft, which are sufficiently wide to represent field contouring. Although, neither plot nor watershed data are entirely satisfactory, data from both plots and watersheds were combined to derive RUSLE2 contouring subfactor equations.

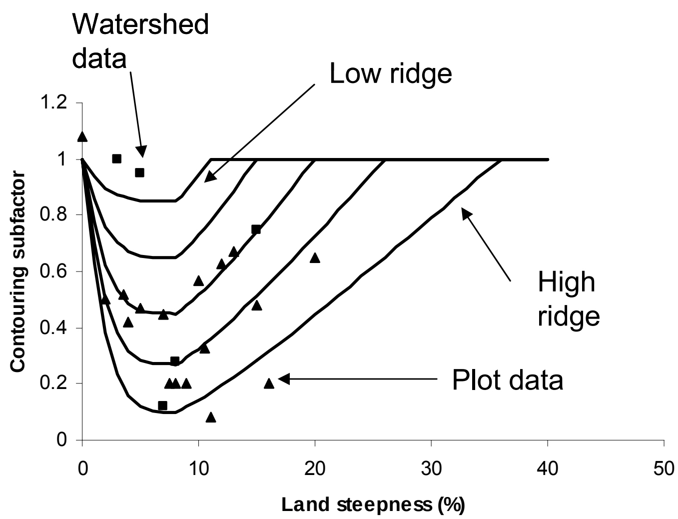


Figure 7.1. Experimental data from plots and small watershed (~ 5 acres) for effect of contouring (ridging) on rill-interrill erosion and fitted lines for effect of ridge height on contouring.

The well accepted general contouring subfactor relationship is an upward concave curve that starts at 1 for a zero steepness, decreases to a minimum as land steepness increases to an approximate 8 percent steepness and then increases to 1 at an upper steepness beyond which contouring is assumed not to reduce erosion [AH537 (Wischmeier and Smith, 1978)]. Contouring has no effect at zero land steepness because no flow direction is defined. Contouring has no effect beyond a maximum steepness that is a function of ridge height because the land is so steep that no water can be stored by the ridges.

The range in the data illustrated in Figure 7.1 for the effect of contouring on rill-interrill erosion is assumed to be caused primarily by a ridge height variation. Experimental data show that contouring's erosion reduction increases as ridge height increases (Moldenhauer and Wischmeier, 1960). Increased ridge height increases storage of runoff, decreases interrill detachment, and increases deposition in the furrows, which is the basis for the curves in Figure 7.1 being a function of ridge height. Also, dense plant stems in narrow rows on the contour have the same effect on rill-interrill erosion as ridges on the contour (Daniel et al., 1943; Van Doren et al., 1950). Also, experimental data show that contouring is less effective for large intense runoff events than for small ones (Moldenhauer and Wischmeier, 1960). In some cases, erosion on watersheds was greater with contouring than with tillage up and down hill as illustrated in Figure 7.1 (Hill et al., 1944). Thus, the effective of contouring on rill-interrill erosion depends on storm, soil, and cover-management characteristics that affect runoff.

A long accepted principle by soil conservationists is that contouring fails if the overland flow path length exceeds a critical length that is a function of land steepness [(Ah282 (Wischmeier and Smith, 1965); AH537 (Wischmeier and Smith, 1978)]. That critical length is assumed in RUSLE2 to be a function of the shear stress applied to the soil by runoff, which in turn is a function of storm characteristics, inherent potential of the soil for generating runoff, and how cover-management affects runoff and the shear stress that runoff applies to the soil.

The RUSLE2 contouring subfactor equations are very similar to the comparable RUSLE1 equations [Foster et al, 1997, AH703 (Renard et al., 1997)] except for the RUSLE2 equations being a function of daily ridge height, runoff, and cover-management conditions.

7.1.3. Contouring (ridging) subfactor equations

The RUSLE2 contouring equations were developed to give accepted values for a base, reference condition of conventional, clean tilled 50 bu/ac corn grown on a silt loam hydrologic C soil group soil located at Columbia, Missouri. This management practice was common when the contouring data were collected from the mid 1930's to the mid 1950's for much of the data represented in Figure 7.1. The RUSLE2 equations vary contouring subfactor values about base, reference values as climate, soil, and cover-management conditions depart from the base, reference condition. The RUSLE2 equations were structured to meet required boundary conditions and were calibrated to experimental data and to give similar contouring subfactor values used by the USLE and computed by RUSLE1 for base, reference conditions. In contrast to the RUSLE1 equations that used a representative ridge height and cover-management condition to represent the cover-management practice to compute an average annual contouring subfactor value (Foster et al, 1997), the RUSLE2 equations compute daily subfactor values as climate, cover-management, runoff, and ridge height vary daily.

7.1.3.1. Base equations

The data shown in Figure 7.1 were collected from several locations in the eastern US. However, the data were insufficient for directly deriving explicit equations and coefficient values that consider all of the major variables related to contouring's effect on rill-interrill erosion. The data in Figure 7.1 were assumed to represent the overall effect of contouring for the base, reference condition described in **Section 7.1.3**.

The first step in deriving the RUSLE2 contouring equations was to develop a set of equations that represent the base, reference condition. Those equations, which follow similar RUSLE1 equations, are given by:

$$p_b = a(s_m - s_c)^4 + p_{bm} \qquad s_c < s_m \qquad [7.1]$$

$$p_b = c(s_c - s_m)^{1.5} + p_{bm} \qquad s_m \le s_c < s_{be} \qquad [7.2]$$

$$p_b = 1 \qquad\qquad s_{be} \le s_c \qquad [7.3]$$

where: p_b = base contouring subfactor value, s_c = a scaled land steepness (sine of slope angle), s_m = the land steepness (sine of slope angle) at which $p_b = p_{bm}$, the minimum base contouring value and s_{be} = the steepness (sine of slope angle) that the contouring subfactor reaches 1. Values for the coefficients a and c are computed from:

$$a = (1 - p_{bm}) / s_m^4 \qquad [7.4]$$

$$c = (1 - p_{bm}) / (s_{be} - s_m)^{1.5} \qquad [7.5]$$

These equations satisfy the boundary conditions that $p_b = 1$ at $s_c = 0$, $p_b = p_m$ at $s_c = s_m$, $p_b = 1$ at $s_c = s_{be}$, and the slope of equations 7.1 and 7.2 is zero at $s_c = s_m$.

7.1.3.2. Ridge height adjustments

The minimum contouring subfactor value p_{bm}, which occurs at $s = s_m$, is assumed to be a function of ridge height as (Moldenhauer and Wischmeier, 1960):

$$p_{bm} = 0.05 + 0.95 \exp(-0.5512 h_e) \qquad if\,(h_e > 8) h_e = 8 \text{ inches} \qquad [7.6]$$

where: h_e = effective total ridge height (inches), which is the sum of the soil ridge height (see **Section 8.3.4**) and the effective vegetation ridge height (see **Section 9.2.5**). The steepness s_{bm} at which the base contouring subfactor is minimum (i.e., $p_b = p_{bm}$) is also assumed to be a function of effective ridge height as:

$$s_{bm} = 4[1 - \exp(-0.7903 h_e)] + 4 \qquad if\,(h_e > 8) h_e = 8 \text{ inches} \qquad [7.7]$$

The steepness s_{be} at which the contouring subfactor p_b becomes 1 as steepness increases is assumed to be a function of effective ridge height as:

$$s_{be} = \sin\{\tan^{-1}[(9 + 53.09 h_e / 8) / 100]\} \qquad if\,(h_e > 8) h_e = 8 \text{ inches} \qquad [7.8]$$

where: s_{be} = the steepness (sine of slope angle) that the contouring subfactor becomes 1. Maximum effective ridge height for equations 7.6, 7.7, and 7.8 is limited to 8 inches.

7.1.3.3. Runoff adjustments

The minimum contouring subfactor values p_{rm} at s_m are assumed to vary directly with the ratio of runoff with the given climate, soil, and cover-management condition to the runoff for the base, reference condition as:

$$p_{rm} = p_{bm}(d_r / 4.16) \qquad [7.9]$$

where: p_{rm} = the minimum contouring subfactor value adjusted for runoff, d_r = runoff depth (inches) for the 10 year-24 hour precipitation amount $P_{10y\text{-}24h}$ at the given location, soil, and cover-management condition on the day that a contouring factor value is computed, and 4.16 (inches) = runoff computed with the 10 year-24 hour storm for the base, reference condition (see **Section 2.3.7**).

The steepness at which the contouring subfactor becomes 1 for a given condition is assumed to be related to the shear stress that the runoff applies to the soil. It is computed from:

$$s_{re} = s_{be} / (d_r / 4.16)^{0.8571} \qquad [7.10]$$

where: s_{re} = the runoff adjusted steepness (sine of slope angle) above which the contouring subfactor equals 1.

7.1.3.4. Steepness scaling

A scaled steepness s_c is used to compute a base contouring p_b subfactor value using equation 7.1, 7.2, or 7.3. The equation for the scaled steepness at low steepness is given by:

$$s_c = s \qquad s \le s_m \qquad [7.11]$$

where: s = the steepness (sine of slope angle) of the overland flow path. The scaled steepness for $s > s_m$ is given by:

$$s_c = s_{bm} + \frac{(s - s_{bm})(s_{be} - s_{bm})}{s_{re} - s_{bm}} \qquad s > s_m \qquad [7.12]$$

The reason that steepness used to compute a p_b value must be scaled is that the upper steepness where the contouring subfactor becomes equal to 1 varies as conditions vary from the base, reference condition.

.

7.1.3.5. Contouring subfactor scaling

The contouring subfactor value must also be scaled because the contouring factor value at s_m for the given condition differs from the contouring subfactor value for the base, reference conditions. The contouring subfactor value for level furrow (row) is computed from the scaling equation as:

$$p_{c0} = 1 - \frac{(1 - p_b)(1 - p_{rm})}{1 - p_{mb}} \qquad if\,(p_{c0} > 1)\, p_{c0} = 1 \qquad [7.13]$$

where: p_{c0} = the contouring subfactor for a zero row grade (grade along furrows separating the ridges).

7.1.3.6. Contouring subfactor limits

Contouring subfactor values computed by equation 7.13 must be within certain limits. The upper limit is that contouring subfactor values can not be greater than 1. The other limit is a lower limit assumed to be acceptable for conservation and erosion control planning. RUSLE2 must account for the possibility of an extreme storm occurring even when annual erosivity and the $P_{10y\text{-}24h}$ precipitation amounts are low. The lower limit for contouring subfactor values is computed from:

$$p_{c0,\min} = 0.05 + 0.95\exp(-h_e) \qquad [7.14]$$

$$if\,(p_{c0} > p_{c0,\min})\, p_{c0} = p_{c0,\min} \qquad [7.15]$$

where: $p_{c0,min}$ = minimum contouring subfactor value for a given ridge height.

7.1.3.7. Adjusting for row grade

The RUSLE2 assumption, which is the same as the RUSLE1 assumption, is that contouring rapidly loses its effectiveness as row grade increases (Foster et al., 1997).

$$p_c = p_{c0} + (1 - p_{c0})(s_f / s)^{1/2} \qquad [7.16]$$

where: p_c = the daily contouring subfactor and s_f = grade along the furrows separating the ridges (row grade). The variable s_f/s is designated as relative row grade. Measured erosion on 150 ft wide plots on a 5 percent land steepness showed that contouring subfactor values vary with row grade (McGregor et al., 1969). The observed contouring subfactor values were 0.10 and 0.39 for the ridges perfectly on the contour and ridges on a 0.3 percent row grade, respectively. Given the 0.10 contouring subfactor value for ridges perfectly on the contour (i.e., row grade = 0), the computed contouring subfactor value from equation 7.16 is 0.32, which is slightly less than the observed value.

7.1.4. Contouring failure

The RUSLE2 assumption is that contouring fails when the shear stress applied to the soil by runoff exceeds a critical shear stress. The contouring subfactor is set to 1 for those portions of the overland flow path where contouring failure is computed. The equations used in these computations are described in **Section 3.4.3**.

Once contouring failure occurs at a location on an overland flow path, the daily contouring subfactor remains at 1 until the next soil disturbing operation. The RUSLE2 assumption is that contouring failure results from runoff breaking through the ridges, and thus the contouring effect can be regained only after ridges are re-established to fill the breakover areas. The RUSLE2 procedure is that only a soil disturbing operation creates ridges that repair the ridge breakthroughs that represent contouring failure (see RUSLE2

User's Reference Guide).

7.1.5. Comments on contouring subfactor

RUSLE2 allows row grade to be input as absolute row rate or as relative row grade. In most applications, relative row grade should be used as the input for consistency with the concepts behind equation 7.16 for the effect of row grade on the contouring subfactor. Using relative row grade implicitly results in the quality of contouring being treated equally regardless of land steepness (see RUSLE2 User's Reference Guide).

RUSLE2 accurately represents the general trends of how major variables affect contouring's reduction on rill-interrill erosion. However, local conditions that can not be easily measured or visualized, especially before a storm event show runoff and erosion patterns, greatly affect contouring's effectiveness. For example, slight and imperceptible variations in ridge height and furrow grade along the ridges greatly affect the number and locations of breakovers. Therefore, while RUSLE2 accurately represents the overall effect of contouring on rill-interrill erosion, the uncertainty in how contouring affects rill-interrill erosion on a specific site is greater than for any other major RUSLE2 variable (see RUSLE2 User's Reference Guide).

7.2. Porous barriers

7.2.1. Description of porous barriers

A porous barrier is a portion of the overland flow path that has a significantly higher hydraulic resistance than the overland flow path immediately upslope of the barrier. The RUSLE2 assumption is that runoff passes through porous barriers. That is, porous barriers do not end the overland flow path. Porous barriers include strips of dense vegetation used in rotational strip cropping; grass buffers, filter strips, and stiff grass hedges; a strip of dense vegetation left undisturbed along a channel on construction and logging sites; and fabric fences and gravel bag dams used on construction sites (see RUSLE2 User's Reference Guide).

7.2.2. Processes associated with porous barriers

The significantly increased hydraulic resistance of the porous barrier slows and ponds runoff in backwater at the upper edge of the barrier. Runoff's sediment transport capacity is greatly reduced in both the backwater and within the porous barrier. Deposition occurs if the sediment transport capacity is reduced to less than the sediment load coming into the backwater and barrier. Most of the deposition caused by porous barriers actually occurs in the backwater. The upper edge of deposited sediment and backwater advance upslope as deposition occurs in the backwater, which increases transport capacity within the backwater. Eventually the backwater becomes filled with sediment and most of the incoming sediment load is then transported into the barrier itself. However, RUSLE2 does not account for sediment accumulation within the backwater and change in sediment transport capacity as sediment accumulates in the backwater.

Runoff is assumed to pass through porous barriers. Infiltration rate within the barrier can be much higher than that on the overland flow path immediately upslope of the barrier, - which reduces runoff downslope of the barriers. The high hydraulic resistance in a porous barrier can eliminate rill erosion and spread runoff within the barrier so that runoff exits the barrier as a thin uniform depth flow along the lower edge of the barrier. Spreading of the runoff reduces its erosivity immediately downslope of a porous barrier.

7.2.3. RUSLE2 equations used to describe porous barriers

The RUSLE2 equations used to compute deposition caused by porous barriers and the sediment load leaving porous barriers are described in **Section 3.4**. This section describes key features of these equations.

RUSLE2 uses the same cover-management values to compute detachment within the backwater as it uses to compute detachment within the porous barrier. The RUSLE2 assumption is that detachment downslope of a porous barrier is not affected by the barrier except as the barrier affects contouring failure. RUSLE2 does not compute how increased infiltration on an overland flow path segment affects detachment on downslope segments because of reduced runoff. That is, RUSLE2 computes the same detachment, except for contouring failure, immediately downslope of a porous barrier regardless of the presence or absence of the barrier. The conceptual basis for this assumption is that spreading the overland flow by the porous barrier reduces runoff erosivity, but this reduction is offset by increased runoff erosivity because of very low sediment concentration in the runoff leaving the barrier. Flow has greater erosivity when it has a very low sediment load in contrast to when the runoff's sediment transport capacity is nearly filled with sediment (Foster and Meyer, 1975; Foster, 1982).

This assumption that downslope detachment is unaffected by high infiltration on an upslope segment is obviously invalid where a porous barrier is sufficiently wide and has a sufficiently high infiltration rate to significantly reduce the runoff that leaves the barrier. The RUSLE2 User's Reference Guide describes how to choose RUSLE2 inputs to partially represent conditions where high infiltration and reduced runoff affects downslope detachment.

RUSLE2 computes reduced runoff from segments, including those with porous barriers, having high infiltration rates. RUSLE2 computes reduced sediment yield from these segments if transport capacity is less than sediment load within the segment because of reduced runoff. Also, reduced runoff from high infiltration segments affects downslope sediment transport capacity and deposition computations. For example, computed deposition and sediment load on a concave shaped overland flow profile is affected by high infiltration and reduced runoff for an upslope segment.

RUSLE2 computes how reduced runoff caused by high infiltration within a porous barrier and runoff spreading by the barrier affects shear stress applied by runoff to the soil immediately below the barrier. Contouring failure is assumed to occur if this shear stress exceeds a critical shear stress (see **Section 3.4.3**). RUSLE2 computes reduced erosion below a porous barrier where RUSLE2 computes no contouring failure below the barrier but computes contouring failure without the barrier.

Hydraulic resistance is a major variable that affects the amount of deposition caused by a porous barrier. A Manning's n value, RUSLE2's measure of hydraulic resistance, is computed as a function of retardance (see **Section 3.4.6**), which varies temporally as vegetation changes through time. All porous barriers are represented in RUSLE2 as strips of vegetation, even when the barriers are non-vegetative including fabric fences, gravel bags, and similar behaving barriers. Non-vegetative porous barriers slow runoff as do vegetative porous barriers.

Eight retardance classes are used to describe porous barriers based on the degree that a barrier slows runoff (see **Section 3.4.6** and RUSLE2 User's Reference Guide). The eighth retardance class is a special case used to describe barriers such as stiff grass hedges and silt fences that provide maximum retardance. The minimum backwater length that RUSLE2 uses for this retardance class is 3 ft, whereas no minimum backwater length is used for the other retardance classes (see **Section 3.4.4**). The maximum backwater length allowed by RUSLE2 is 15 ft for all retardance classes.

7.2.4. Effect of row grade

Runoff must pass through porous barriers for them to reduce sediment load. A ridge of soil at the upper side of porous barriers left by tillage or deposited sediment or debris collected on a fabric fence causes runoff to flow along the upper edge of the barrier and never enter the barrier if the grade along the upper edge of the barrier is too steep. The barrier acts as a flow interceptor (see **Section 7.3**) that ends the overland flow path.

Inputs used to describe porous barriers can be entered in two ways. One way is to select porous barriers from a list of supporting practices. When this input method is used, RUSLE2 requires that the relative row grade for the barrier be less than 10 percent. RUSLE2 assumes that trapping efficiency is independent of row grade for relative row grade less than 10 percent. The RUSLE2 assumption with this input method is that runoff does not enter the barrier but runs along the upper edge of the barrier if the relative row grade along the upper edge of the barrier exceeds 10 percent. In that case, the barriers operate as a flow interceptor barrier.

The other way to input information to describe porous barriers in RUSLE2 is to divide the overland flow path into segments and enter information for each segment, including those segments used to represent the porous barriers. When this input method is used, RUSLE2 assumes that runoff enters the porous barrier regardless of the relative row grade along the upper edge of the porous barrier.

7.2.5. Spatial variability

When the RUSLE2 input method of selecting a support practice is used to represent porous barriers, RUSLE2 assumes that multiple barriers are spaced uniformly along the overland flow path length. Also, the conditions are assumed to be the same for each barrier. When the input method of dividing the overland flow path into segments is used, each segment can be described individually and barriers can be spaced non-uniformly. Conditions are assumed to be uniform within a segment.

7.2.6. Validation of RUSLE2 computed values

7.2.6.1. Strip cropping

RUSLE2 computed values for the effect of strip cropping and narrow stiff grass hedges on sediment yield from an overland flow path were compared with measured data reported in the literature, which is referenced in the **Strip Cropping References** subsection of the **References Section**. Because strip cropping data are highly variable, many more years of data and/or experimental plots and small watersheds are required to accurately evaluate strip cropping than for any other soil conservation practice. Sediment yield from strip cropping is closely related to the storm events that occur when the erodible strips are at the end of the overland flow path. Data must be recorded over a sufficiently long duration for representative storms to occur on the erodible strips in all positions along the overland flow path. Sediment yield is much less when an extreme event occurs when an erodible strip is near the upper end of the overland flow path than at the lower end of the overland flow path. Data from such a storm would indicate that strip cropping is much more effective than it actually is. Very little of the available strip cropping data are for an adequate duration. Also, much of the strip cropping data are inconsistent. In one study, erosion with a small grain in a rotation in a strip cropping system was much less than when in the same crop rotation was not in strip cropping.

Priority was given to ensuring that RUSLE2 fits strip cropping data from Wisconsin (Hays et al., 1949; Hays and Attoe,1957) and to values given in AH282 and AH537 (Wischmeier and Smith, 1965, 1978) for a base, reference condition. Strip cropping has been used extensively and highly successfully since the 1930’s in the La Crosse, Wisconsin region. The support practice factor values given in AH282 and AH537 have been well accepted in conservation planning by USDA-NRCS personnel for this region. Also, the Wisconsin data seem to be of higher quality than most of the other available data. Wischmeier and Smith (1965, 1978) and technical and scientific personnel from the USDA-Agricultural Research Service and Soil Conservation Service reviewed these same data and developed recommendations included in AH282 and 537. These values are established and accepted based on many years of field applications of the USLE.

The values in AH282 and AH537 are that strip cropping reduces sediment yield from the end of an overland flow path by 50 percent “For 4-year rotation of row crop, small grain with meadow (mixture of legume and grass hay), and 2 years of meadow. A second row crop can replace the small grain if meadow is established in it [AH537 (Wischmeier and Smith, 1978)].” The comparable RUSLE2 computed value is 0.43 for the base, reference condition of a 150 ft long, six percent steep overland flow path on a silt loam soil at Columbia, Missouri for crops and yields comparable to those represented in the data on which the AH282 and 537 values are based. The comparable measured values from research in Wisconsin are 0.42 and 0.55 (Hays et al, 1949; Hays and Attoe, 1957).

The AH282/537 values for the ratio of sediment with strip cropping to sediment yield without strip cropping is 0.75 "For 4-year rotation of 2 years row crop, winter grain with meadow seeding, and 1-year meadow." The RUSLE2 computed value is 0.54.

The AH282/537 values for the ratio of sediment with strip cropping to sediment yield without strip cropping is 1 "For alternate strips of row crop and small grain." RUSLE2 also computes a value of 1 for this condition.

7.2.6.2. Stiff grass hedges

RUSLE2 computed values for fraction of 0.?? of the incoming sediment load from a conventional, clean tilled cotton that is trapped by a stiff grass hedge at Holly Springs, MS is very close to the measured value of 0.25 (McGregor et al., 1999). RUSLE2 computes a value of ?? for no-till cotton upslope of the stiff grass hedge while the measured value was 0.43. The study was run for three years. The hedges were much better established and uniform in the third year of the experiment than in the first year. The fraction of the incoming sediment load that was trapped by the hedges in the third year was 0.29 and 0.33 for the conventional and no-till managements, respectively, which are quite close to the RUSLE2 computed values.

7.2.7. Comments

The RUSLE2 intent for computing how porous barriers affect erosion is for the purpose of conservation and erosion control planning where the main effects of the major variables are captured. The equations are based on well accepted hydraulic principles. The performance of porous barriers is highly dependent on how well the barriers are installed and maintained. For example, fabric fences are widely used on construction sites to control sediment leaving the site. However, very poor sediment control occurs in far too many cases because of substandard installation and/or maintenance. The actual sediment trapping of fabric in a typical field situation is much less than the sediment trapping measured in laboratory studies.

A comparable situation exists with vegetative strips that are poorly established and/or maintained. For example, non-uniform grass stands within a strip or damage caused by tillage, construction activities, or other soil disturbing operations can significantly reduce sediment trapping efficiency.

RUSLE2 does not represent the variations that result from poor installation and maintenance. RUSLE2 represents the performance of porous barriers that are installed and maintained according to specifications and inspections.

The RUSLE2 equations and input values were chosen to represent barriers that perform well in the field but less than would be measured in laboratory hydraulic studies.

7.3. Interceptor barriers

7.3.1. Characteristics of interceptor barriers

Interceptor barriers are topographic features that end the overland flow path. Examples of interceptor barriers represented by RUSLE2 include terraces, diversions, and small impoundments. Terraces are defined as channels on a sufficiently flat grade to cause deposition while diversions are channels are on a sufficiently steep grade that deposition does not occur in them but are not on such a steep grade that erosion occurs in them. Impoundments are water bodies where flow velocities are almost negligible. RUSLE2 represents typical impoundments comparable to those used with impoundment terraces in farm fields [e.g., parallel tile outlet (PTO) terraces] and small sediment basins used on construction sites.

Interceptor barriers reduce erosion by cutting overland flow path length and causing deposition. RUSLE2 also computes how deposition by interceptor barriers affects sediment characteristics. RUSLE2 does not compute ephemeral gully erosion that occurs in concentrated flow areas (channels) (Foster, 1985).

7.3.2. Channels (Terraces/diversions)

7.3.2.1. Deposition and sediment load equations

Deposition occurs in a channel when the incoming sediment load exceeds sediment transport capacity of flow in the channel (Foster, 1982; Foster et al., 1980). Deposition rate is computed in RUSLE2 using (Renard and Foster, 1983):

$$D_{p,k} = f_k\left(\frac{\phi_k}{1+\phi_k}\right)\left(\frac{dT}{dx} - g_o\right) \qquad dT/dx < g_o \qquad [7.17]$$

$$D_{p,k} = 0 \qquad dT/dx \geq g_o \qquad [7.18]$$

$$\phi_k = 400000 V_{f,k} / q_o \qquad [7.19]$$

where: $D_{p,k}$ = deposition rate for the *kth* particle class [(mass/(unit channel length·time)], f = fraction, based on mass, of the incoming sediment load g_0 (mass/time) from the overland flow area made up of the *kth* particle class, T = sediment transport capacity of the flow in the channel (mass/time), x = distance along the channel $V_{f,k}$ = the fall velocity (ft/sec) of the *kth* sediment particle class, and q_o = the discharge rate at the end of the overland flow path (ft^3/sec per ft channel length). Equation 7.17 is derived from equation 2.16 and the assumptions of uniform channel grade, uniform sediment input from the overland flow area along the channel length, incoming sediment load for each particle class exceeds the sediment transport capacity in the channel for that particle class, and channel sediment transport capacity for each particle is proportional to the distribution (mass basis) of the incoming sediment load.

The change in sediment load with distance along the channel is computed from:

$$dT / dx = 450 s_{ch}^{1.16} q_0 \qquad [7.20]$$

where: T = transport capacity (lbs_m/sec), s_{ch} = grade of the channel (sine of channel angle with horizontal), and x = distance along the channel (ft). Equation 7.20 was derived from the assumptions that transport capacity is directly proportional to the 3/2 power of shear stress applied to the channel boundary by the flow and that Manning's equation is used to compute hydraulic radius for flow in the channel (Foster and Meyer, 1975; Foster, 1982; Foster et al., 1980). The channel's hydraulic roughness is assumed to be that of deposited sediment that covers soil surface roughness, surface residue, and standing vegetation. The effect of standing live or dead vegetation on deposition in channels is not considered in RUSLE2 because most of the deposition is assumed to occur when little vegetation is present, such as at seedbed time when crops are planted. The 450 coefficient value in equation 7.20 was determined by calibrating RUSLE2 to compute values similar to those given by the RUSLE1 sediment delivery ratio equation, which was empirically derived from field data [AH703(Renard, 1997); Foster et al., 1997; Foster and Ferreira, 1981; Foster and Highfill, 1983).

Equation 7.17 and its companion equations compute a uniform deposition rate along the channel. The sediment leaving the channel is computed with:

$$g_{ch,k} = g_{o,k} - D_{p,k} \qquad [7.21]$$

where: $g_{ch,k}$ = the sediment load (mass/unit channel length·time) leaving the end of the channel for the *kth* particle class. The sediment load leaving the channel expressed as the ratio of sediment load at the end of the channel to unit drainage area for the channel is computed with:

$$A_{ch,k} = g_{ch,k} / \lambda_o \qquad [7.22]$$

where: $A_{ch,k}$ = the sediment load for the *kth* particle class leaving the end of the channel expressed as mass/time per unit drainage area. The sediment delivery ratio for the channel for the *kth* particle class is given by:

$$\omega_{ch,k} = 1 - D_{p,k} / g_{o,k} \quad [7.23]$$

where: $\omega_{ch,k}$ = sediment delivery ratio for a channel for the *kth* sediment particle class. Total sediment load is computed by summing the sediment load values for all of the particle classes.

7.3.2.2. Comments

When flow interceptors are represented in RUSLE2 as a support practice, the spacing between flow interceptors is the same for all flow interceptors represented by the support practice. However, non-uniform spacing among flow interceptors can be represented by manually entering appropriate spacing values. Similarly, the grade is assumed the same for all channels when flow interceptors are represented as a support practice. However, separate grade values for each channel can be entered in RUSLE2.

RUSLE2 requires that a representative channel grade be chosen for channels on a non-uniform grade. This limitation can be of consequence for parallel terraces where grade varies along the channel. In most of these situations, channel grade is flattest at the upper channel end with grade increasing along the channel. RUSLE2's estimates for deposition for these conditions are less accurate than for uniform grade channels. A grade flatter than the average channel grade for its length is the appropriate input grade.

RUSLE2 does not represent channels where sediment inflow varies along the channel length. Not many field situations occur where this limitation is of consequence.

The RUSLE2 equations used to compute deposition in channels are based on commonly used equations for channel hydraulics. However, RUSLE2 is a conservation and erosion control planning tool, not a hydraulic design tool. Appropriate hydraulic equations should be used to design the channels represented in RUSLE2. Channels are usually designed to accommodate runoff rate from a particular design storm under particular soil and cover conditions whereas most conservation and erosion control planning is based on average annual erosion rates for the range of cover-management conditions expected over the time period being represented in the RUSLE2 computation.

7.3.3. Impoundments

7.3.3.1. Sediment delivery ratio equation

The RUSLE2 assumption is that sediment transport capacity in impoundments is essentially zero. Impoundments are treated as a fixed length settling basin in RUSLE2. The RUSLE2 equation for computing sediment deliver ratio for an impoundment is:

$$\omega_{i,k} = \exp(-c_i V_{f,k}) \quad [7.24]$$

Table 7.1. Values for the coefficient c_i used to compute sediment delivery ratio for deposition of sediment from reference silt loam soil in impoundments.	
Sediment trapping ratio (%)	c_i (ft/sec)$^{-1}$
6.4	10000 (1)
10	5900
15	3500
20	2300
25	1700

Note 1: Coefficient value determined by fitting RUSLE2 equation to experimental data for impoundment terraces

where: $\omega_{i,k}$ = the sediment delivery ratio for an impoundment for the *kth* sediment particle class. Sediment delivery ratio is the ratio of sediment mass leaving the sediment basin to incoming sediment mass.

A 10000 (ft/sec)$^{-1}$ value for the coefficient c_i for a base reference silt loam soil was determined by fitting equation 7.24 to experimental data for impoundments used in parallel tile outlet terraces (Laflen et al., 1972). The average trapping efficiency of those impoundments was 94 percent. Literature reporting measured trapping efficiency of sediment basins on construction sites was reviewed during the development of RUSLE1.06 (Toy and Foster, 2000; Bonta and Hamon, 1980, Fennessey and Jarret, 1997; USEPA, 1976 a, b). The trapping efficiency of these basins is comparable to that for impoundment terraces when the sediment basins are well designed, constructed, and maintained and perform at maximum efficiency. Also, no deposition is assumed to occur between the point that the sediment is detached and where the sediment reaches the impoundment. If deposition occurs along the overland flow path upstream of the impoundment, trapping efficiency will be less than computed by RUSLE2 (see **Section 7.3.3.2**).

Many sediment basins on construction sites do not perform at maximum efficiency because of poor design, the basins being partly filled with sediment, and water/sediment chemistry that keeps fine sediments highly dispersed.

The RUSLE2 user can select a base sediment delivery ratio for the reference silt loam soil texture to accommodate trapping efficiency variations by specific site. The c_i coefficient values used in RUSLE2 for a range of sediment delivery ratios are given in Table 7.1.

7.3.3.2. Effect of incoming sediment characteristics

RUSLE2 computes trapping efficiency for impoundments solely as a function of incoming sediment characteristics. RUSLE2 does not consider basin geometry or flow withdrawn characteristics in these computations. However, RUSLE2 computes sediment delivery ratios as a function of texture of the soil that produces the sediment, upslope deposition amount, and the feature that produces the upslope deposition as shown in Table 7.2 because these variables affect sediment characteristics. As a point of reference, the RUSLE2 computed sediment characteristics leaving the uniform overland flow path represented in Table 7.2 are the same as the sediment characteristics at the point of detachment because RUSLE2 computed no local deposition for this particular overland flow path.

Table 7.2. RUSLE2 computed sediment delivery ratio for sediment basin in various flow sequence.				
	Flow path			
Soil texture	uniform overland flow path into basin	steep flow segment onto low steepness segment into basin	uniform flow path into grass strip into basin	uniform overland flow path into basin into basin
silt loam	0.064	0.469	0.317	0.678
silt	0.068	0.157	0.101	0.216
silty clay	0.119	0.612	0.581	0.825
clay	0.105	0.741	0.905	0.902
loamy sand	0.014	0.125	0.531	0.890
sand	0.009	0.127	0.333	0.900

The primary particle distribution of the soil producing the sediment does not accurately indicate the RUSLE2 computed sediment delivery ratio for impoundments. Sediment is eroded as a mixture of primary particles and aggregates (see **Section 4.7**). The size and density distributions of the sediment do not parallel the distribution of primary particles in the soil. Clay is assumed in RUSLE2 to be a bonding agent that influences aggregate sizes and densities and the mass distribution between the particle classes, especially the small and large aggregates. Consequently, sediment eroded from high clay soils has a large portion of the sediment in aggregates of increased size. Conversely, soils very high in silt produce poorly aggregated sediment that is almost entirely in small-sized primary silt particles that are not rapidly deposited. Soils high in sand produce poorly aggregated sediment that is almost entirely in sand-sized primarily particles that are readily deposited. Consequently, the sediment delivery ratio computed for sediment eroded from high clay soils is not proportionally higher than that for silt loam soils when no upslope or local deposition occurs. Expecting RUSLE2 computed sediment delivery ratio values for an impoundment to be directly related to the primary particle distribution of either the soil or sediment is a very serious error.

As illustrated in Table 7.2, RUSLE2 computed sediment delivery ratio values for impoundments also vary with the type of upslope feature that causes deposition. Even though the sediment delivery ratios for the overland flow path with a low steepness segment, a grass strip, and a sediment basin are comparable, the characteristics of the sediment leaving each of these flow paths and entering a sediment basin are quite different because of differences in upslope erosion and deposition processes. RUSLE2 computes a relatively high interrill erosion rate for the overland flow path that has the low steepness segment in comparison to the one with a dense grass strip at the end of the overland flow path. Interrill erosion is very low in the grass strip, which adds very little sediment to the sediment load in the grass strip in contrast to interrill erosion adding sediment to the sediment load on the low steepness segment. The sediment leaving the grass strip is finer than the sediment leaving the low steepness segment. Consequently, the RUSLE2 computed sediment delivery ratio values for impoundments are generally larger for the grass strip overland flow path than for the low steepness segment overland flow path. Sediment delivery ratios for sediment eroded from high silt soils are not affected as much as for the other soil textures because sediment eroded from the high silt soils is poorly aggregated and has a very narrow size range in a relative small size range.

Sediment delivery ratio values are high for a basin downstream of another sediment basin. That is, much less sediment trapping occurs in the second basin than in the first basin, except for the sediment eroded from the high silt soils. The upstream sediment basin removes almost all of the sediment that is easily deposited.

7.3.3.3. Design

RUSLE2 should not be used to design sediment basins unless regulations explicitly state that RUSLE2 can be used. The RUSLE2 values computed for impoundments are for the purpose of conservation and erosion control planning. The accuracy of RUSLE2's computations for sediment trapping by small impoundments is comparable to that for other erosion and sediment control practices. The specific hydraulic and sediment trapping performance of impoundments depends on many complex, interactive variables. Accepted design procedures should be used to design impoundments (e.g., see Haan et al., 1994).

7.3.3.4. Comments

RUSLE2 results for sediment trapping by impoundments must be interpreted very carefully. The flow path up to the sediment basin must be properly represented. For example, RUSLE2 seriously under-computes sediment delivery by an impoundment if a uniform steepness overland flow path is assumed when in fact the overland flow path has a segment at the lower end of the overland flow path causes a high degree of deposition. Likewise, when RUSLE2 computed values are compared to research and field measurements, the RUSLE2 inputs must be very carefully selected to accurately represent measurement conditions. The characteristics of the sediment entering the experimental basin must match those assumed in RUSLE2. For example, as Table 7.2 shows, if upstream deposition is not considered, the sediment delivery values computed by RUSLE2 will be much less than is measured.

Another consideration is that RUSLE2 does not represent basin geometry, degree that the basin is filled, and other factors. The assumption in RUSLE2 is that the basin is well designed and maintained. Standards and specifications for design, construction, and maintenance of impoundments should be a principal tool used to ensure expected results.

7.3.4. Hydraulic flow paths

Simple channels and impoundments can be combined into simple hydraulic flow paths. RUSLE2 can represent an overland flow area discharging into a channel from a single side and the channel in turn discharging into an impoundment or a series of impoundments. Non-uniform conditions along the channel can not be represented. RUSLE2 can not represent a channel on a particular grade discharging into a channel on a different grade. That is, RUSLE2 can not represent channels in series nor can RUSLE2 represent an impoundment discharging into a channel. However, RUSLE2 can represent overland areas discharging into a channel from both sides. Also, RUSLE2 can represent an overland flow area discharging directly into an impoundment without involving a channel.

7.3.5. Benefit of deposition caused by porous barriers and flow interceptors

7.3.5.1. Concepts

Deposited sediment trapped on the hillslope by porous barriers and by flow interceptors including channels/impoundments (e.g., terraces) is assumed to be a soil conservation benefit. Landscape quality is degraded less when sediment is retained by deposition on the hillslope.

Partial credit is taken for deposition on the hillslope as soil saved based on position of the location of the deposition along the overland flow path (see Section **2.3.10.4)**. The credit taken for deposition caused by flow interceptors is less than the credit taken for porous barriers because most flow interceptors are much more permanent and the deposition more localized than with porous barriers. Porous barriers such as grass strips are assumed to be periodically removed and reestablished in new locations. An increased portion of the hillslope benefits from deposition with these barriers than occurs with flow interceptor such as impoundment-type terraces. Full credit for deposition as soil saved is taken for rotational strip cropping (see Section **2.3.10.4**).

Partial credit is given to deposition as soil saved with flow interceptors (e.g., channels/impoundments in farm fields) because the deposition is localized although the deposited sediment is spread over a significant-sized area on either side of channels/impoundments in farm fields. The absolute size of this area is the same regardless of channel/impoundment spacing. Consequently, the fraction of the total field area over which the sediment is spread becomes less as channel/impoundment spacing increases.

Deposition near the end of the original overland flow path before porous/interceptor barriers were placed is assumed to be less valuable for maintaining landscape quality than sediment deposited near the upper end of the overland flow path. This concept is consistent with that used to compute the benefit of deposition on the overland flow area (see **Section 2.3.10.4**).

Deposition is a selective process that enriches the deposited sediment in coarse particles. Even though coarse sediment is deposited first, clay and silt primary particles are deposited because sediment is assumed to be a mixture of primary particles and aggregates so that fine primary particles are deposited along with sand particles (see **Section 4.7.5**). The assumption that deposition on overland flow areas is predominantly sand is erroneous. Thus, deposition is assumed to be beneficial because deposited sediment includes clay and silt particles even though the deposited sediment is partially enriched in sand.

7.3.5.2. Equations for benefit of deposition caused by flow interceptors

The RUSLE2 equation for the benefit of deposition by flow interceptor is:

$$b_s = 0.45 + \exp[-0.011(\delta_s - 100)] \qquad \delta_s \geq 100 \text{ ft} \qquad [7.25]$$

$$b_s = 0.45 \qquad \delta_s < 100 \text{ ft} \qquad [7.26]$$

where: b_s = the fraction of the deposition that is credited as soil saved and δ_s = flow interceptor spacing (ft). The credit for deposition as affected by the position of the flow interceptor along the original overland flow path is computed with:

$$b_p = 1 - (\lambda_s / \lambda_o)^{1.5} \qquad [7.27]$$

where: λ_s = distance from the origin of overland flow for the original overland flow path to the flow interceptor and λ_o = the overland flow path length without flow interceptors. The conservation planning sediment load (see **Section 2.3.10.4**) for each channel is computed from:

$$g_{cp,j} = g_{o,j}[1 - (b_{s,j} + 0.2b_{p,j})(1 - \omega_j)] \qquad [7.28]$$

where: $g_{cp,j}$ = the conservation planning sediment load per unit channel length for the *jth* channel, the $g_{o,j}$ = the sediment load for conservation planning from the overland area immediately above the *jth* channel, and ω = sediment delivery ratio. The conservation planning soil loss in term of mass per unit area for the area represented by the overland flow path without channels is:

$$A_{cp} = \left(\sum_{j=1}^{J} g_{cp,j}\right) \Big/ \lambda_o \qquad [7.29]$$

where: A_{cp} = the conservation planning soil loss (mass/area) for the area represented by λ_o and j = the subscript for each flow interceptor along the original overland flow path, and J = number of flow interceptors.

7.4. Subsurface drainage

The effect of subfactor drainage on detachment is represented by the subsurface drainage subfactor p_d in equation 2.10.[52] In general, research has shown that subsurface drainage reduces rill-interrill erosion by approximately 40 percent (Bengston and Sabbage, 1988; Formanek et al., 1987; Schwab and Fouss, 1967; Schwab, 1976; Skaggs et al., 1982). The reduction is caused by reduced runoff and increased vegetation production (yield) level. The input value for production (yield) level in vegetation descriptions should reflect production level under subsurface drained conditions. RUSLE2 does not adjust production (yield) level as a function of environmental inputs.

[52] The effect of subsurface drainage on runoff is discussed in **Section 3.3.1.2.4**.

The runoff effect on erosion with subsurface drainage is assumed to be same as the soil erodibility factor being a function of a soil's runoff potential. Therefore, equation 4.9, the permeability subfactor equation used to compute soil erodibility factor values, is used to compute how subsurface drainage affects detachment. The subsurface drainage subfactor is computed as:

$$p_d = K_d / K_u \qquad if\,(p_d < 0.2)\,p_d = 0.2 \qquad [7.30]$$

where: K_d and K_u = soil erodibility factors (US customary units) for the drained and undrained conditions, respectively (see **Section 4.1**). A minimum value of 0.2 is set for the subsurface drainage subfactor. A base soil erodibility factor value without the permeability subfactor is computed as:

$$K_b = K_u - 0.025(P_{r,u} - 3) \qquad [7.31]$$

where: K_b = a base soil erodibility factor value (US customary units) computed without the permeability subfactor and $P_{r,u}$ = the soil profile permeability class for the undrained condition. The soil erodibility factor with subsurface drainage is computed with:

$$K_d = K_b + 0.025(P_{r,d} - 3) \qquad [7.32]$$

where: $P_{r,d}$ = the soil profile permeability class for the drained condition.

Table 7.3. Relation between hydroligc soil groups and permeabiltiy classes.

Hydrologic soil group	Permeability class
A	1
B	2.67
C	4.33
D	6

Table 7.4. Subsurface drainage subfactor values as affected by soil erodibility factor value (US customary units)for undrained soil condition and for a change in hydrologic soil group by hydrologic soil group.

	subsurface drainage subfactor p_d			
Location	K = 0.20 D to A	K = 0.20 D to C	K = 0.30 D to A	K = 0.55 D to A
Ft Wayne, IN	0.38	0.83	0.58	0.77
Raleigh, NC	0.38	0.78	0.57	0.76
Jackson, MS	0.38	0.75	0.60	0.77

Hydrologic soil group (see **Section 3.3.1 and RUSLE2 User's Reference Guide**) used in NRCS soil survey descriptions is used as the RUSLE2 input to describe how subsurface drainage affects soil profile permeability class. The RUSLE2 relationship between hydrologic soil group and the soil profile permeability class is given in Table 7.3.

RUSLE2 computed subsurface drainage subfactor values are shown in Table 7.4. As expected, subsurface drainage reduces the subsurface drainage subfactor the greatest when subsurface drainage causes the greatest change in hydrologic soil group from D to A in contrast to a change from D to C. The erosion reduction is also related to the soil erodibility (K factor) value. The subsurface drainage subfactor reduction is greatest when soil erodibility factor values are low. This effect results from the additive equation form used to compute soil erodibility factor values (See **Section 4.1.1**). Location has only a slight effect on the RUSLE2 subsurface drainage subfactor and probably should be greater than is computed by RUSLE2. However, the values computed by RUSLE2 are considered adequate for conservation and erosion control planning. Other erosion estimation procedures can be used when increased accuracy is desired (Skaggs et al., 1982).

7.5. Irrigation

RUSLE2 computes how irrigation affects rill-interrill erosion caused by precipitation, but RUSLE2 does not compute erosion caused by water drop impact and surface runoff directly produced by the applied irrigation water. The increase soil moisture from irrigation affects rill-interrill erosion by precipitation during the irrigation period because of increased soil erodibility, increased biomass decomposition, and increased vegetation production (yield). The effect of irrigation on production (yield) level is accounted for by inputting yield values appropriate for production under irrigated conditions. RUSLE2 does not adjust production (yield) level as a function of environmental inputs.

The effect of increased soil moisture on soil erodibility during the irrigation period is computed using equation 4.12 that computes temporal (daily) values for the soil erodibility factor. This equation is modified as:

$$K_j / K_n = 0.704 - 0.336 T_j / T_n + 0.632 (P_j + I_j) / P_n \qquad [7.33]$$

where: K_j = the soil erodibility factor on the *jth* day, K_n = the soil erodibility factor value computed with a RUSLE2 soil erodibility nomograph for the frost free period defined as the period that average daily temperature is above 40 oF, T_n = the average temperature during the frost free period (oF), P_j = daily precipitation (inches), I_j = average daily water added by irrigation (inches), and P_n = average daily precipitation during the frost free period.

The average daily water added by irrigation is computed from:

$$I_j = V_j - P_j \qquad if (I_j < 0) I_j = 0 \qquad [7.34]$$

where: V_j = the daily consumption use by the vegetation (Schwab et al., 1966). Daily irrigation values I_j are added to the daily precipitation values P_j to compute decomposition during the irrigation period (see **Section 10.3**).

Plant consumption use values are input for the vegetation descriptions that represent irrigated conditions. The

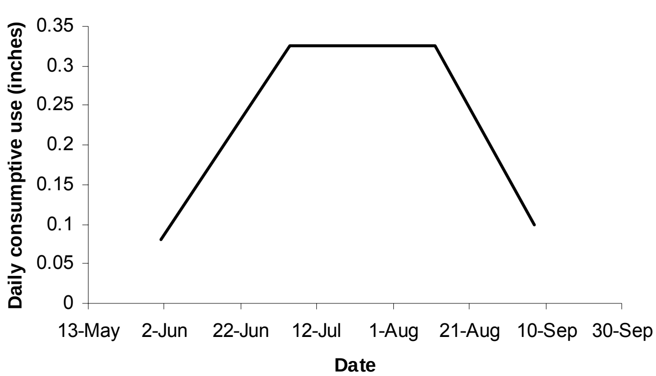


Figure 7.2. Daily consumptive water use for a 120 day corn crop grown at Lincoln, Nebraska.

input yield for the vegetation description is the yield expected for the consumptive use water values entered because RUSLE2 does not compute how environmental conditions affect yield. RUSLE2 adjusts consumptive use values in its yield adjustment procedures directly in proportion to live above ground biomass (see **Section 9.3**).

Individual vegetation descriptions must be created to account for consumptive use being a function of soil properties and location. Figure 7.2 illustrative consumptive use values for a particular corn crop grown at Lincoln, Nebraska.

List of symbols

a = coefficient used to compute values for base contouring subfactor values
$A_{ch,k}$ = sediment load for *kth* particle class leaving end of the channel (mass/ unit drainage area·time)
A_{cp} = conservation planning soil loss for the area having channels (mass/area)
b_s = fraction of the deposition that is credited as soil saved
c = coefficient used to compute values for base contouring subfactor values
c_i = coefficient used to sediment delivery ratio in an impoundment for base reference silt loam soil
d_r = runoff depth for $P_{10y-24h}$ storm (length)
$D_{p,k}$ = deposition rate for *kth* sediment class [(mass/(unit channel length·time)]
f = fraction, based on mass, of the incoming sediment load g_0 (mass/time) from the overland flow area made up of *kth* sediment class
$g_{ch,k}$ = sediment load leaving end of the channel for *kth* particle class (mass/unit channel length·time)
$g_{cp,j}$ = conservation planning sediment load for the *jth* channel (mass/unit channel length)
g_o = incoming sediment load from overland flow area (mass/unit channel length·time)
$g_{o,j}$ = sediment load for conservation planning from overland area immediately above the *jth* channel (mass/unit channel length·time)
h_e = effective total ridge height, which is sum of soil ridge height and effective vegetation ridge height length)
I_j = average water added by irrigation on *jth* day (length)
K_b = base soil erodibility factor value computed without the permeability subfactor (mass/area·erosivity unit)
K_d = soil erodibility factor for drained condition (mass/area·erosivity unit)
K_j = soil erodibility factor on the *jth* day (mass/area·erosivity unit)
K_n = soil erodibility factor computed with a RUSLE2 soil erodibility nomograph for frost free period
K_u = soil erodibility factor for undrained condition (mass/area·erosivity unit)
p_b = base contouring subfactor value
p_{bm} = minimum base contouring value
p_c = the daily contouring subfactor
p_{c0} = contouring subfactor for a zero row grade (grade along furrows separating the ridges)
$p_{c0,min}$ = minimum contouring subfactor value for a given ridge height
p_d = subsurface drainage subfactor
p_{rm} = minimum contouring subfactor value adjusted for runoff
P_j = daily precipitation (length)
P_n = average daily precipitation during the frost free period (length)
$P_{r,d}$ = the soil profile permeability class for the drained condition
$P_{r,u}$ = the soil profile permeability class for the undrained condition
$P_{10y-24h}$ = 10 year-24 hour precipitation amount (length)
q_o = discharge rate at end of the overland flow path (volume/time per unit channel length)
s = steepness (sine of slope angle) of the overland flow path
s_{be} = steepness (sine of slope angle) that the contouring subfactor reaches 1

s_c = scaled land steepness (sine of slope angle)
s_{ch} = grade of the channel (sine of channel angle with horizontal)
s_f = grade along the furrows separating the ridges (row grade)
s_f/s = relative row grade
s_m = land steepness (sine of slope angle) at which $p_b = p_{bm}$
s_{re} = runoff adjusted steepness (sine of slope angle) above which contouring subfactor equals 1
T = total sediment transport capacity of the flow in the channel (mass/time)
T_n = average temperature during the frost free period (oF)
V_j = daily consumption watercuse by vegetation (length)
$V_{f,k}$ = fall velocity of *kth* sediment class (length/time)
x = distance along the channel (length)

δ_s = flow interceptor spacing (length)
λ_o = overland flow path length without flow interceptors (length)
λ_s = distance from origin of overland flow for the original overland flow path to flow interceptor (length)
φ = a deposition coefficient ($length^{-1}$)
ω_{ch} = sediment delivery ratio
ω_{ch} = sediment delivery ratio for channel

Indices
j – channel
j - day
k – sediment class

8. Operations

A RUSLE2operation is an event that changes vegetation, residue, or soil conditions. RUSLE2 uses a set of rules and 10 processes to represent how operations rill and interrill erosion (see the RUSLE2 User's Reference Guide). RUSLE2 computes erosion based on user supplied descriptions of the variables that affect rill-interrill erosion. For example, RUSLE2 does not use simulation modeling to compute how environmental conditions affect vegetation. This section describes the RUSLE2 equations used to describe how operations affect vegetation, residue, and soil variables.

8.1. Effect on vegetation

RUSLE2 uses **begin growth**, **kill vegetation**, and **remove live vegetation processes** to describe how operations affect vegetation variables.

8.1.1. Begin growth

The **begin growth** process tells RUSLE2 to stop using data in the current vegetation description and start using data from another vegetation description. The change occurs on the date of the operation that uses the begin growth process (See RUSLE2 User's Reference Guide).

RUSLE2 uses only a single vegetation description on any particular date. RUSLE2 does not combine data from multiple vegetation descriptions to represent a composite of vegetations having different properties. For example, a single vegetation description is used to describe a rangeland plant community that involves multiple plant types such as shrubs that provide an over-story and grasses that provide an under-story under the shrubs with open space between the individual shrub-grass clumps.

8.1.2. Kill vegetation

The **kill vegetation** process transfers the biomass (dry basis) of live vegetation to the dead standing residue pool and to transfer live root biomass to the dead root biomass pool in the soil. Both the standing residue and dead root biomass pools disappear by daily decomposition.

8.1.3. Remove live vegetation

The purpose of the **remove live vegetation** process is to determine the amount of residue left by a field operation like a hay harvest that removes live biomass that leaves both standing and surface residue. The standing and surface residue biomass left by a remove live vegetation process is computed as:

$$\Delta B_{tr} = f_{tl}(f_{lr} B_{al}) \qquad [8.1]$$

$$\Delta B_{sr} = f_{sl}(f_{lr}B_{al}) \quad [8.2]$$

where: ΔB_{tr} = the biomass left as standing residue that is added to the existing standing biomass pool, $f_{lr}B_{al}$ = the live biomass that is affected by the operation, f_{tl} = the fraction of the affected biomass that is left as standing residue, f_{lr} = the fraction of the above ground live biomass that is affected by the operation, B_{al} = existing live vegetation biomass, ΔB_{sr} = the biomass left as surface residue that is added to the existing surface residue biomass pool, and f_{sl} = the fraction of the affected biomass that is left as surface residue. These residue biomass values are added to the existing biomass values in these residue pools.

The amount of live aboveground biomass left after a remove live biomass process is computed as:

$$B_{al,j} = (1 - f_{lr})B_{al,j-1} \quad [8.3]$$

where: the j-1 subscript refers to the above ground live biomass immediately before the operation and j = subscript refers to the above live ground biomass immediately after the operation.

8.2. Effect on residue/dead roots

RUSLE2 tracks the three residue pools of standing residue, surface residue, and buried residue. Operations that include a flatten standing residue process transfer biomass from the standing residue pool to the surface residue pool. Operations that include a disturb soil process bury transfer surface residue to the buried residue pool and transfers buried residue to the surface residue pool. RUSLE2 rules are that standing residue can not be buried without first being flattened and live above ground biomass can not be flattened or buried without being killed (i.e., transferred from the live above ground biomass pool to the standing residue pool).

8.2.1. Flatten standing residue

The **flatten standing residue** process transfers biomass from the standing residue pool to the surface residue pool using:

$$\Delta B_{tr} = f_f B_{tr} \quad [8.4]$$

where: f_f = the fraction of the existing standing residue that is flattened (i.e., added to the surface biomass pool).[53] The standing residue biomass pool after the operation is

[53] Flattening, burial, and resurfacing ratios are based on mass, not portion of the soil surface covered (see RUSLE2 User's Reference Guide).

computed as:

$$B_{tr,j} = B_{tr,j-1}(1 - f_f) \quad [8.5]$$

where: the subscript *j-1* refers to conditions before the operation and the subscript *j* refers to conditions after the operation.

8.2.2. Burial of surface residue

Burial of surface residue is the transfer of biomass from the surface residue pool to the buried residue pool. The amount of surface residue that is buried is computed by:

$$\Delta B_{sr} = f_b B_{sr} \quad [8.6]$$

where: ΔB_{sr} = the mass of the surface residue that is transferred to the buried residue pool and f_b = the fraction of the surface residue that is buried.

The surface residue mass is computed by (wagner-nelson ref):

$$B_{sr,j} = (B_{tr,j-1} f_f + B_{sr,j-1})(1 - f_b) + B_{br,j-1} f_u \quad [8.7]$$

where: $B_{sr,j}$ = the surface residue mass immediately after the operation, Bsr,j-1 = the surface mass immediately before the operation, f_u = the fraction of the buried residue mass that is resurfaced and $B_{br,j-1}$ is the amount of buried biomass in the soil disturbance depth immediately before the operation. Note that the surface residue mass in equation 8.7 is the sum of the existing surface residue mass plus the mass added by flattening of standing residue and the mass of buried residue that is resurfaced.

8.2.3. Resurfacing of buried residue

The mass of buried residue that is resurfaced by the operation is computed from:

$$\Delta B_u = f_u B_{br} \quad [8.8]$$

where: ΔB_u = residue that is resurfaced from soil disturbance depth, f_u = the resurfacing ratio, and B_{br} = the mass of buried residue in the soil disturbance depth. RUSLE2 does not resurface dead roots.

8.2.4. Determining values for the flattening, burial, and resurfacing ratios

8.2.4.1. Base, reference values

A single data point can be used to determine a value for the flattening ratio. However, equation 8.7 involves the two unknowns of burial and resurfacing ratios, which requires at least two data points to determine values for these two ratios. The proper data for determining values for these ratios is where the same operation is repeated multiple times, preferably at least four times. Only two data sets were found that meet this requirement (Brown et al., 1992; Wagner and Nelson, 1995) and even then the (Brown et al., 1992) data set did not include standing residue. Most data previously used to determine burial ratio values are not usable because they are from situations where a particular operation was used a single time.

Base, reference values for the flattening ratio were determined by fitting equation 8.5 to observed data reported by (Wagner and Nelson, 1995). Values for the burial and resurfacing ratios were determined by fitting equation 8.7 to observed data reported by (Brown et al., 1992; Wagner and Nelson, 1995). Surface residue biomass values were estimated for the (Brown et al., 1992) data from measured surface residue cover values using equation 10.1 that estimates surface cover as a function of surface biomass (see **Section 10.2**).

The minimization function that was minimized to fit equations 8.5 and 8.7 to measured data to determine flattening, burial, and resurfacing ratio values is:

$$\delta = \left\{ \sum_{n=1}^{N} \left[\ln(y_{e,n}) - \ln(y_{o,n}) \right]^2 \right\} \Big/ N \qquad [8.9]$$

where: δ= the function that is minimized, $y_{e,n}$ = estimated value for the *nth* data point, $y_{o,n}$ = observed value for the *nth* data point, and N = number of observations. A minimization function using logarithms rather than absolute values gives a more uniform relative error among the observations in comparison to a minimization function that uses absolute values. A minimization function using absolutes values gives flattening, burial, and resurfacing ratio values that are biased to the large surface biomass values. Equations 8.5 and 8.7 were fitted by implement type represented in the observed data. The flattening, burial, and resurfacing ratio values obtained by fitting equations 8.5 and 8.7 were used to guide assign values in the RUSLE2 core database (see the RUSLE2 User's Reference Guide).

8.2.4.2. Effect of soil disturbance depth on residue burial

The input value for burial ratio is for a reference depth, which is assumed to the manufacturer recommended or normal operating depth for the implement, machine, tool, or other residue burial process.

The effect of operation depth (i.e., soil disturbance depth) on the residue burial ratio is computed using:

$$\alpha_d = [1 - (1 - y_d / y_m)^{2.7}] / [1 - (1 - y_{rc} / y_m)^{2.7}] \qquad [8.10]$$

where: α_d = an adjustment factor for depth, y_{rc} = reference soil disturbance depth, y_d = the soil disturbance depth of the operation, and y_m = the maximum soil disturbance depth for the operation. The fit of equation 8.10 to observed data is shown in Figure 8.1 (Hanna et al., 1995; Hill and Stott, 2000; Johnson, 1988).[54]

8.2.4.3. Effect of speed on surface residue burial

The effect of operation speed on residue burial ratio values is computed using:

$$\alpha_s = [0.6 + 0.4(v_s / v_m)^{1/2}]/[0.6 + 0.4(v_r / v_m)^{1/2}] \qquad [8.11]$$

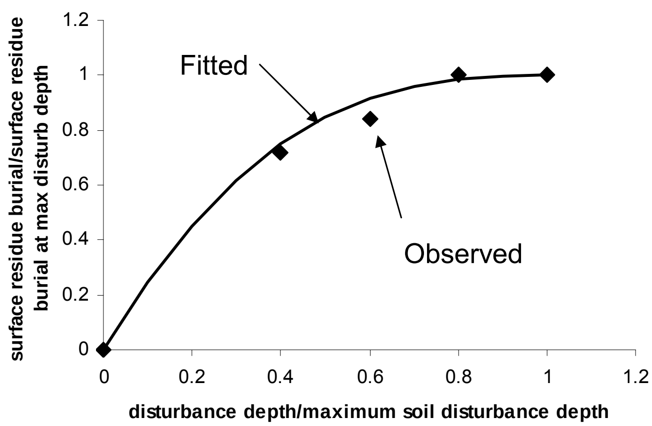


Figure 8.1. Effect of soil disturbance depth on surface residue burial.

where: $\alpha_{,s}$ = an adjustment factor for speed, v_r = reference speed, v_s = operation speed, and v_m = maximum operation speed. The fit of equation 8.11 to observed data is shown in Figure 8.2 (Hanna et al., 1995; Hill and Stott, 2000; Johnson, 1988).

8.2.4.4. Combined effect of soil disturbance depth and speed on surface residue burial

The burial ratio for the effect of both depth and speed is computed from:

$$f_b = \alpha_d \alpha_s f_{b,r} \qquad [8.12]$$

where: $f_{b,r}$ = the burial ratio for the given residue type for the reference soil disturbance depth y_{rc} and reference operation speed v_r.

8.2.5. Distribution of buried residue and dead roots by soil disturbing operations

Soil disturbing operations resurface buried residue but not dead roots, redistribute existing buried residue in the soil, redistribute dead roots in the soil, and bury surface residue. RUSLE2 makes these computations in three steps. The first step computes inversion of the burial material. The second step computes the redistribution of existing buried residue and dead roots and resurfacing of buried residue from the upper soil

[54] R.L. Raper, USDA-Agricultural Research Service, researched the literature and assembled the data used to derive the equations for effect of soil disturbance depth and operation speed on residue burial and equations for distribution of buried material by soil layer.

layer(s). The third step computes the mass distribution by soil layer of the material buried by the operation.

8.2.5.1. Types of soil disturbance operations

Three RUSLE2 types of soil disturbing operations are used to describe how these operations distribute buried residue and dead roots in the soil. These types are inversion, mixing with some inversion, and mixing. The inversion type represents machines like moldboard plows and soil disturbances (e.g., hand tillage with a spading fork) that primarily bury and mix material in the soil by inverting the disturbed soil layer. The mixing with some inversion type represents machines like field cultivators, chisel plows, tandem disks, and scarifiers and soil disturbances that bury mix material in the soil primarily by mixing with some inversion. The mixing type represents machines like rotary powered machines (e.g., rototillers); shank machines used to inject manure, fertilizers, and other materials into the soil; and soil disturbances that incorporate material by mixing with essentially no inversion and by cattle trampling, sheep's foot compactors, and similar operations that press material into the soil.

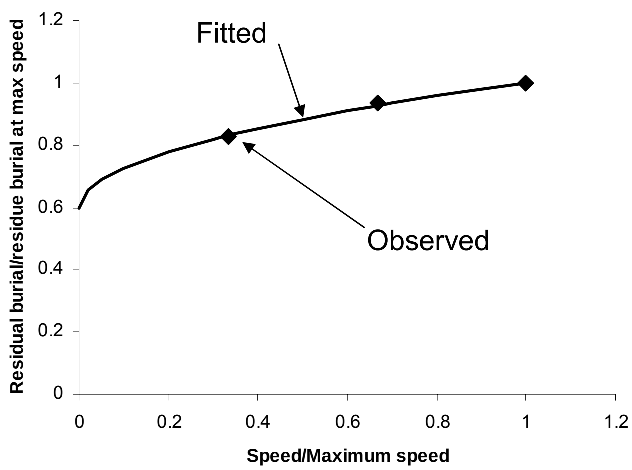


Figure 8.2. Effect of speed on surface residue burial.

8.2.5.2. Equations for redistribution of buried residue and dead roots

A sifting concept is used in RUSLE2 to compute redistribution of buried material by soil disturbing operations. RUSLE2 computes separately the redistribution of buried residue and dead roots. Conceptually, soil disturbance "sifts" each soil layer so that some of the buried material (i.e., buried residue or roots) is retained in each layer and the remainder moves downward to the next soil layer.[55]

RUSLE2 assumes that no material moves upward except by inversion type soil disturbances. The first step is to compute inversion of the buried material for inversion type soil disturbing operations. This computation assigns the existing buried material mass in the bottom soil layer to the top soil layer, the existing material in the top layer to the bottom layer, the existing material in the next to bottom soil layer is assigned to the

[55] The RUSLE2 equations used to redistribute buried residue and dead roots are based on empirical data reported in the literature cited in the References Section **Redistribution of Material in Soil by Soil Disturbing Operations.**

soil layer next to top layer, and so forth. For example, the buried material mass in the top soil layer after inversion is set equal to the material mass in the bottom soil layer before inversion and the mass in the bottom layer after inversion is set equal to the mass in the top soil layer before inversion.

Table 8.1. Retention coefficient values for redistributing buried material among soil layers

	Type soil disturbance operation		
Layer	Inversion w/mixing	Mixing w/inversion	Mixing
1 (top)	0.40	0.32	0.50
2	0.40	0.39	0.56
3	0.40	0.47	0.61
4	0.40	0.54	0.67
5	0.40	0.62	0.72
6	0.40	0.69	0.78
7	0.40	0.77	0.83
8	0.40	0.84	0.89
9	0.50	0.92	0.94
10	1.00	1.00	1.00

The next step for all soil disturbing operations is to "sift" the soil layers to compute the buried material that leaves each soil layer using:

$$\Delta B_{i,j} = (1-\phi_{i,k})(B_{i,j-1} + \Delta B_{i-1,j} - R_i) \qquad [8.13]$$

where: ΔB = the buried material (mass/area) that moves from the *ith* soil layer to the *(i+1)th* layer, φ = the fraction of the buried material in the *ith* layer that is retained, B = existing buried material (mass/area) in a soil layer, R = the buried residue that is resurfaced, j-1 and j = index for conditions before and after, respectively, the sifting by a soil disturbing operation, and k = type of soil disturbance operation. The soil disturbance depth is divided into 1-inch (25 mm) layers to make these computations where i = index for the soil layers (i = 1 for surface soil layer). The computations start with the top layer and proceed downward. The inflow to the top layer is set to zero in this step. The amount of material that enters the top layer by burial is added in the third step described below.

Dead roots are not resurfaced. Thus, values for R in equation 8.13 are zero when equation 8.13 is used to compute the redistribution of dead roots. The total mass of buried residue that is resurfaced is computed using equation 8.8. The value for R in the top soil layer (i.e., R_1) in equation 8.13 is set to the value computed by 8.8. If the value computed by equation 8.8 exceeds the buried residue mass in layer 1, the value for the mass removed is set equal to the buried residue in layer 1 before sifting. The remainder of the buried residue mass needed to provide the mass computed by equation 8.8 is removed from layer 2. If the buried residue mass in layer 2 is insufficient, the entire buried residue before sifting is removed from layer 2. The check moves to subsequent layers until the total resurfaced residue mass computed by equation 8.8 is satisfied.

Values for the retention coefficient φ are given in Table 8.1. The 1-value for the *10th* layer denotes that no buried material passes through the bottom layer in the soil disturbance depth. Retention values for the mixing-type soil disturbing operations are assumed to increase linearly from the value for the top layer to 1 for the bottom layer. This increase with depth means that buried material is more likely to move downward in the upper part of the disturbed soil layer than in the lower part. The increased retention coefficient values with depth indicate greater retention because of less stirring and mixing in the bottom of the soil disturbed layer. In contrast, stirring, mixing, and retention are assumed to be nearly uniform with depth for inversion-type soil disturbing operations as shown in Table 8.1.

The retention φ values in Table 8.1 were determined by fitting equation 8.13 to measured data where the same operation was repeated multiple times. These data conclusively show that buried material redistributed by multiple events of mixing with some inversion and mixing types soil disturbing operations forms a bulge that moves downward in the soil rather than producing a uniform distribution (see RUSLE2 User's Reference Guide). In contrast, the distribution of buried material becomes nearly uniform with multiple events of an inversion-type soil disturbing operation. Retention values were independent of characteristics of the buried material.

The third step is to distribute surface residue by soil layer when it is buried by a soil disturbing operation. That mass is added to the buried residue mass after sifting as computed with equation 8.13 for redistribution and resurfacing of existing buried residue. The equation used to compute the distribution of surface residue when it is buried in the soil by mixing-type soil disturbing operations is:

$$m = (y/D)^b \qquad [8.14]$$

where: m = cumulative normalized mass (cumulative mass above depth in soil/total mass buried in soil depth disturbed by operation) of buried residue with depth (i.e., m =0 at y = 0 and m =1 at y = D), y = depth in soil, D = soil disturbance depth, and b = 0.5 for mixing with some inversion type soil disturbing operations and b = 0.3 for mixing type soil disturbing operations.

The comparable equations for inversion-type soil disturbing operations are:

$$m = 0.28\{\exp[1.83(y/D) - 1]\} \qquad y/D \le 0.6 \qquad [8.15]$$

$$m = 1 - 0.441\{[1 - (y/D)]/0.4\}^{1.4} \qquad y/D > 0.6 \qquad [8.16]$$

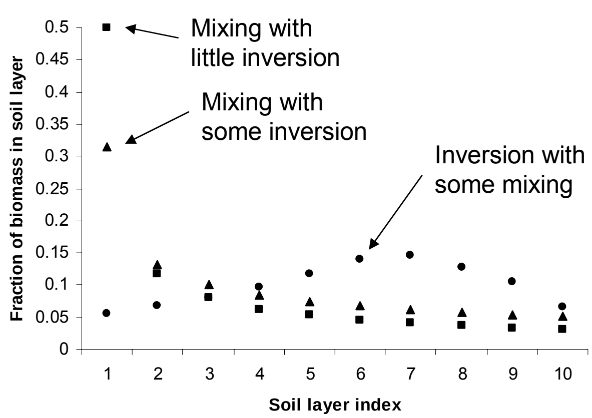


Figure 8.3. Distribution of residue by soil layer when initially buried by a soil disturbing operation.

Equations 8.14 - 8.16 were derived from observed data where surface material was buried by a single event of an operation when no buried residue existed in the soil. The distributions of buried residue computed by equations 8.14 – 8.16 are shown in Figure 8.3.

In summary, RUSLE2 computes buried residue mass in each soil layer after an operation by (1) computing inversion of buried residue biomass if the operation is an inversion-type operation, (2) using equation 8.13 to compute redistribution of existing buried residue mass caused by stirring and mixing (i.e., sifting), and (3) using equations 8.14 – 8.16 to distribute the surface biomass among soil layers that is buried by the operation and adding this mass to the buried residue mass computed in step 2. The steps for computing redistribution of dead roots is to (1) add the dead roots produced by the kill live vegetation process to the existing dead roots in each soil layer if the operation includes a kill vegetation process, (2) invert the dead roots by soil layer if the operation is an inversion type operation, and (3) compute the sifting of dead roots using equations 8.13.

8.2.6. Add other cover

The **add other cover** process is used to apply material to the soil surface and/or place (inject) material into the soil.

8.2.6.1. Add cover to soil surface

The add other cover process has the inputs of the residue, amount (dry mass) added, and the portion added to the soil surface and the portion placed (injected) in the soil. The mass of the material added to the soil surface is added to the surface residue pool.

8.2.6.2. Injection of material (residue) into the soil by a soil disturbing operation

The **add other cover** process along with a **disturb soil** process are used together to inject material into the soil. This material is assumed to be distributed in the lower half of the disturbed soil depth as a parabola. The equations for cumulative mass with depth for material injected into the soil are:

$$m = 6\left[\frac{(2y/D-1)^2}{2} - \frac{(2y/D-1)^3}{3}\right] \qquad y/D \geq 0.5 \qquad [8.17]$$

$$m = 0 \qquad y/D < 0 \qquad [8.18]$$

where: m = cumulative normalized mass (cumulative mass above depth in soil/total mass), y = depth in soil, and D = soil disturbance depth. The mass placed in the soil is added to the buried residue pool.

8.2.7. Remove residue cover

The **remove residue cover** process is used to describe removal of standing and surface residue. Inputs for this process include the portions of the standing and surface residue masses that are removed. The masses of standing and surface residue are reduced by these portions. Another input is whether the residue removal applies to all residues involved in the RUSLE2 computation or only the last residue added to the soil surface in the computation. An example is where corn and wheat are grown in sequence. The harvest of each crop leaves residue. The straw is baled (removed) but the corn residue is left in the field. The input to remove the last residue is selected in this situation. Another example is burning where all residues is selected.

8.2.8. Add/remove non-erodible cover

8.2.8.1. Description of add/remove non-erodible cover processes

The **add non-erodible** cover process sets detachment to zero for the portion of the soil surface covered with non-erodible cover. That is:

$$c = c_c(1 - f_n) \qquad [8.19]$$

where: c = the c in equation 2.10 used to compute detachment and f_n = the faction of the surfaced by non-erodible cover.

Non-erodible cover also affects runoff. The equations used to adjust cover number values used to compute runoff with non-erodible cover are given in **Section 3.3.1.2.3**.

The **remove non-erodible cover** process removes non-erodible cover. The input value is the portion of the existing non-erodible cover that is removed by the operation. A 100 percent input value removes all of the existing non-erodible cover. A 40 percent input value removes 40 percent of the existing non-erodible cover. For example, assume that the existing non-erodible cover is 72 percent on the day of an operation that 40 percent of the non-erodible cover. The remaining non-erodible cover is 43 percent after the operation.

8.2.8.2. Loss of non-erodible cover over time

RUSLE2 assumes that non-erodible cover disappears over time because of photo-chemical and other processes. The equation for the loss of non-erodible cover is given by:

$$f_n = f_0 \exp(-\alpha_n \Delta t_n) \qquad [8.20]$$

where: f_0 = the fraction of the soil surface covered by non-erodible cover immediately after an operation affected non-erodible cover (i.e., added or removed) and Δt_n = the days since the non-erodible cover was affected. The coefficient α_n = a coefficient (days^{-1}) that describes the rate of loss of non-erodible cover. Equation 8.20 is not a function of environmental condition. Users select α_n values that reflect both material properties and local environmental conditions. Consequently, α_n values can differ among locations for the same material based on variation of environmental conditions between locations.

8.3. Effect on soil

The **disturb soil** process is used to describe how operations affect the soil. An operation that includes a disturb soil process is referred to as a soil disturbing operation. Soil disturbing operations loosen the soil, buries surface residue, resurfaces buried residue, redistributes buried residue and dead roots, affects soil roughness, and affects ridges. Some operations such as planting only disturb a portion of the soil surface.

8.3.1. Loosen soil

The effect of an operation loosening the soil is described by the soil consolidation subfactor. The equation for the soil consolidation subfactor is given in **Section 6.6.2**.

For those operations that do not disturb the entire soil surface area, RUSLE2 computes a net soil consolidation subfactor as:

$$s_{c,n} = f_d + (1 - f_d) s_{c,u} \qquad [8.21]$$

where: $s_{c,n}$ = the net soil consolidation subfactor for the overall soil surface, f_d = the fraction of the soil surface that is disturbed, $s_{c,u}$ = the soil consolidation subfactor for the portion of the soil surface not disturbed by the operation, and 1 = the consolidation subfactor value for the soil surface portion that is disturbed.

An effective soil consolidation time $t_{d,e}$ since last soil disturbance is computed by solving equation 6.52 for the time that gives the value for the net soil consolidation subfactor value computed with equation 8.21. The time used in equation 6.52 to compute the soil consolidation subfactor starts from this effective soil consolidation time.

8.3.2. Burying and resurfacing residue

Soil disturbing operations bury surface residue and resurface buried residue. That is, the RUSLE2 assumption is that surface residue can only be buried by disturbing the soil. The equations used to compute residue mass buried and resurfaced by soil disturbing operations are given in **Section 8.2**. Important variables used in these computations are the fraction of the surface residue mass that the operation buries and the faction of the buried residue mass in the soil disturbance depth that is resurfaced. **The burial and resurfacing ratios apply to the entire soil surface and not just to the portion of the soil surface that is disturbed** (see the RUSLE2 User's Reference Guide).

8.3.3. Redistribution of buried residue and dead roots

Soil disturbing operations redistribute existing buried residue and dead roots on the date of the operations. The equations used in these computations are given in Section **8.2.5**.

The RUSLE2 assumption is that soil disturbance is required to place material in the soil (e.g., manure and fertilizer injection). The equations used to compute the distribution of material placed in the soil by an **add other cover** process are given in **Section 8.2.6.1**.

8.3.3. Soil surface roughness

A soil disturbing operation affects soil surface roughness. An operation can either smooth the soil surface (i.e., reduce soil surface roughness) or roughen the soil (i.e., increase soil surface roughness). Roughness decays over time because of subsistence, interrill erosion, and local deposition.

Conversely, the RUSLE2 assumption is that soil surface roughness can only be created by a soil disturbing operation. Consequently, operations with a disturb soil process must be used to represent soil surface roughness creation.

8.3.3.1. Inputs for soil surface roughness in an operation description

Three inputs are used in a **disturb soil** process to describe soil surface roughness. One input is initial roughness, which is the roughness created by the operation when performed on a smooth surface under the base, reference condition of high biomass and silt loam soil (see **Section 6.3.1** and RUSLE2 User's Reference Guide). Equations given in **Sections 6.3.2** and **6.3.3** are used to adjust this initial roughness value for soil texture and biomass to represent site specific conditions where RUSLE2 is being applied.

RUSLE2 computes roughness decay over time as a function of precipitation and interrill erosion using equations given in **Section 6.3.6**. RUSLE2 computes decay of roughness to the final roughness value input for the particular operation. The final roughness value is usually set to 0.24 inches and not adjusted for soil texture or soil biomass. This final roughness value represents persistent, highly stable soil clods that remain even after extensive erosivity applied to the reference silt loam soil in unit plot conditions. The roughness subfactor value is 1 for unit plot conditions (see **Section 6.3.1**). Final roughness on unit plots varies by soil texture, but that effect on rill-interrill erosion is captured in the soil erodibility factor (see **Section 4.1**).

In special cases such as construction sites where a high clay soil is scarified, a final roughness value greater than 0.24 inches can be entered to represent an increased roughness effect (see the RUSLE2 User's Reference Guide). A final roughness value less than 0.24 inches is used for operations, such as for fine seedbeds used in vegetable production or smooth surfaces left by a blading operation on a construction site, that create roughness smoother than that for unit plot conditions. When the final roughness value is less than 0.24 inches, the initial roughness input value should be the same as the final roughness input value. RUSLE2 computes no roughness decay when the final roughness input is less than 0.24 inches.

8.3.3.2. Partial soil disturbance

In contrast to the assumption made for burying and resurfacing residue, the RUSLE2 assumption is that the input roughness values only apply to the portion of the soil surface disturbed. A net soil surface roughness value is computed as:

$$s_{r,n} = f_d s_{r,o} + (1 - f_d) s_{r,t} \qquad [8.22]$$

where: $s_{r,n}$ = the net soil surface roughness subfactor immediately after a soil disturbing operation that occurs on day t, $s_{r,o}$ = the soil surface roughness subfactor for the disturbed portion of the soil surface immediately after the operation on day t, and $s_{r,t}$ = the soil surface roughness subfactor for the undisturbed portion of the soil surface on day t. The starting value in equation 6.26 for the roughness subfactor on day t that is decayed is the $s_{r,n}$ value computed with equation 8.22.

RUSLE2 assumes that an operation that disturbs only a portion of the soil surface disturbs some of the undisturbed soil. Consequently, multiple occurrences of an operation that disturbs only a portion of the soil surface ultimately disturb most of the soil surface. That is, RUSLE2 can not represent an operation that disturbs the same area with each occurrence of the operation.

8.3.3.3. Tillage intensity (effect of existing roughness)

The RUSLE2 assumption is that the roughness left by a soil disturbing operation can depend on existing roughness. The input for this effect is a **tillage intensity** value assigned to the disturb soil process (see RUSLE2 User's Reference Guide). Tillage intensity refers to the degree that a soil disturbing operation obliterates existing roughness (i.e., conversely the degree that existing roughness affects roughness left by the soil disturbing operation). A tillage intensity value of 1 means that the soil disturbing operation is so aggressive that existing roughness has no effect on roughness left by the operation. For example, the tillage intensity value of 1 is used to describe moldboard plows and rototillers. A tillage intensity of 0 means that the operation does not affect existing roughness. Harrows used as secondary tillage to create a seedbed are assigned 0.4 for tillage intensity to reflect that existing roughness has a significant effect on the roughness left by harrows. For example, the soil surface roughness after a harrow is greater when it follows a moldboard plow than when it follows a tandem disk used for secondary tillage. The tillage intensity effect is computed using:

$$R = (R_e - R_o)(1 - I) + R_o \qquad R_o \le R_e \qquad [8.23]$$

$$R = R_o \qquad R_o > R_e \qquad [8.24]$$

where: R = roughness after a soil disturbing operation, R_e = existing roughness immediately before the operation, I = tillage intensity, and R_o = the roughness left by the operation when applied to a smooth surface. Roughness values used in equations 8.23 – 8.24 have been adjusted for soil texture and biomass effects.

8.3.4. Ridges

The RUSLE2 assumption is that only soil disturbing operations create ridges.

Consequently, operations with a disturb soil process must be used to represent ridge creation.

The ridge input for the disturb soil process is initial ridge height. In contrast to soil surface roughness, the input ridge height is not adjusted for soil texture, soil biomass, existing ridges, or portion of the soil surface disturbed. For example, the ridge height left by a planter run on top of existing ridges depends on the existing ridge height. This effect is represented in RUSLE2 by having a set of planter descriptions in the RUSLE2 database for a range of ridge heights. A particular planter entry is selected from this input set based on the operations that precede the planter operation (see the RUSLE2 User's Reference Guide).

List of symbols

b = exponent in equation for distribution of buried residue left by an operation
B = buried material in a soil layer (mass/area)
B_{al} = live vegetation biomass (mass/area)
B_{br} = buried biomass in soil disturbance depth (mass/area)
B_{sr} = surface residue (mass/area)
c = daily cover-management subfactor
D = soil disturbance depth (length)
f_b = fraction of surface residue that is buried
$f_{b,r}$ = burial ratio for given residue type for reference soil disturbance depth and speed
f_d = fraction of the soil surface that is disturbed
f_f = fraction of existing standing residue that is flattened
f_n = faction of soil surfaced by non-erodible cover
f_{tl} = fraction of affected biomass that is left as standing residue
f_{lr} = fraction of above ground live biomass that is affected by operation
f_{sl} = fraction of affected biomass that is left as surface residue
f_u = fraction of the buried residue in soil disturbance depth that is resurfaced that is resurfaced
f_0 = fraction of soil surface covered by non-erodible cover immediately after an operation affects non-erodible cover (i.e., added or removed)
I = tillage intensity
m = cumulative buried residue normalized with depth (cumulative mass above depth in soil/total mass buried in soil disturbance depth)
N = number of observations
R = buried residue that is resurfaced from a soil layer (mass/area)
R = roughness after a soil disturbing operation (length)
R_e = existing roughness immediately before the operation (length)
R_o = the roughness left by the operation when applied to a smooth surface (length)
$s_{c,n}$ = net soil consolidation subfactor
$s_{c,u}$ = soil consolidation subfactor for the portion of soil surface not disturbed by operation
$s_{r,n}$ = net soil surface roughness subfactor immediately after a soil disturbing operation that occurs on day t
$s_{r,o}$ = soil surface roughness subfactor for disturbed portion of the soil surface immediately after the operation on day t
$s_{r,t}$ = soil surface roughness subfactor for undisturbed portion of the soil surface on day t
t = day on which an operation occurs
v_m = maximum operation speed (length/time)
v_r = reference speed (length/time)
v_s = operation speed (length/time)
y = depth in soil (length)
y_d = soil disturbance depth of operation (length)
$y_{e,n}$ = estimated value for the *nth* data point
y_m = the maximum soil disturbance depth for operation (length)
$y_{o,n}$ = observed value for the *nth* data point
y_{rc} = reference soil disturbance depth (length)

α_d = adjustment factor for depth
α_n = coefficient (days^{-1}) that describes rate of loss of non-erodible cover (time^{-1})
$\alpha_{,s}$ = adjustment factor for speed
δ= function that is minimized
ΔB = buried material that moves from *ith* soil layer to *(i+1)th* layer (mass/area)
ΔB_{sr} = surface residue transferred to the buried residue pool (mass/area)
ΔB_{sr} = standing residue added to surface residue biomass pool (mass/area)
ΔB_{tr} = biomass left as standing residue that is added to existing standing biomass pool (mass/area)
ΔB_u = residue that is resurfaced from soil disturbance depth (mass/area)
Δt_n = days since non-erodible cover was affected (time)
φ = fraction of buried material in the *ith* layer that is retained

Indices
j-1, j – before and after an operation
j – day
k - type of soil disturbance operation
n – data point

9. Vegetation

The input variables used to describe vegetation are biomass (dry basis) at maximum canopy cover and the temporal variables of root biomass (dry basis) in the upper 4-inch (100 mm) soil depth, canopy cover, effective fall height, and live ground cover. These variables are used to compute values for the temporal variables of the live root biomass by soil layer, dead root biomass produced by root sloughing, live above ground biomass, biomass produced by senescence that falls to the soil surface, and retardance. All of these variables are used to compute values for the cover-management subfactors (see **Section 6**), curve numbers used to compute runoff (see **Section 3.3.1.2**), and hydraulic resistance (see **Section 3.4.6**). The RUSLE2 User's Reference Guide describes selection of input values for variables used to describe vegetation.

9.1. Input of temporal variables

Values for the input temporal vegetation variables are often manually constructed and entered in RUSLE2 using values in the RUSLE2 core database as a guide (see RUSLE2 User's Reference Guide). This procedure works satisfactorily for simple vegetation descriptions for annual agricultural and horticultural crops and annual descriptions for mature perennial plant communities. However, creating and entering vegetation descriptions for long term vegetation from seeding to maturity is cumbersome and time consuming. RUSLE2 includes a long term vegetation tool that can be used to create long term vegetation descriptions (see RUSLE2 User's Reference Guide). A cubic spline procedure is used in this tool to fit a curve to key user input data points. RUSLE2 creates datasets of values from the fitted curve for use in vegetation descriptions (see Figure 9.2).

Temporal variables used to describe vegetation are assumed to vary linearly between the times in the data points entered for these variables. The time between data points should be sufficiently small to accurately represent non-linear variations.

9.2. Computed temporal vegetation variables

9.2.1. Live root biomass by soil layer

RUSLE2 uses input values for live root biomass in the upper 4-inch soil depth to compute daily live root biomass values in individual soil layers.

The literature was reviewed to obtain measured data for root biomass and its distribution in the soil at plant maturity for the major agricultural crops of corn, soybeans, cotton, and wheat; several vegetable crops; and several pasture/range plant communities (see list of references in the **subsection Root and Root:Top Growth Ratios References** in the **References Section**). The RUSLE2 equations for the distribution of live root biomass in the soil were derived from these data, especially the data by Long (1959). These equations are:

$$M_r = y[24.24y\exp(-5.50y) + 0.778] \qquad y \le 0.533333 \qquad [9.1]$$

$$M_r = 0.783391 + 0.147688(y - 0.533333) \qquad 0.533333 < y \le 2 \qquad [9.2]$$

$$M_r = 0 \qquad 2 < y \qquad [9.3]$$

here: M_r = cumulative root biomass (dry basis) above the depth y, y = Y/15, Y = depth (inches) in soil (Y = 0 at soil surface), and 15 = a reference depth (inches) used to normalize the depth variable y. A plot of these equations by 1 inch layer is shown in Figure 9.1.

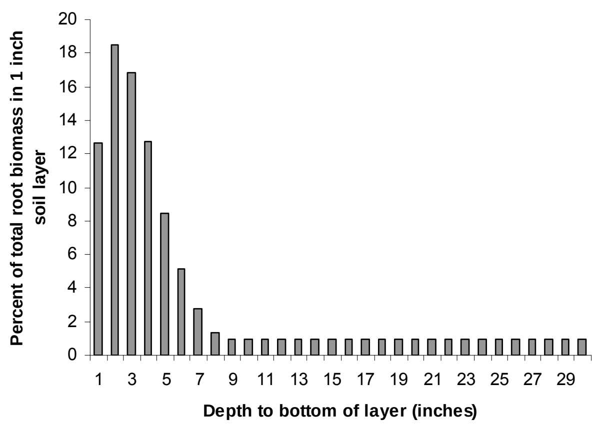


Figure 9.1. Fraction of total root biomass in 1 inch soil layers.

No data were found for measured root biomass in 1-inch soil layers. Accurately measuring roots is very difficult in soil layers as thin as 1-inch, especially near the soil surface. Preference was given to data where root biomass was measured in soil layers sufficiently thick to obtain accurate measurements, which is one of the reasons why the input value for root biomass is based on the upper 4-inch soil layer. This depth also contains the bulk of the roots that significantly affect rill-interrill erosion as discussed below.

The shape of the curve in Figure 9.1 within the upper 4-inch soil layer is based on judgment. A power equation gave the best fit to the observed data, but it was not used because a power equation form gives maximum root biomass density at the soil surface. The judgment is that root mass in the upper 1-inch layer is less than that at a slightly deeper soil depth. Soil moisture at the soil surface is reduced because of evaporation when soil surface (residue) cover is minimal, which in turn results in reduced root biomass near the soil surface. Increased surface residue reduces evaporation, which increases soil moisture at the soil surface. The form of equation 9.1, which represents reduced root biomass near the soil surface, was judged more appropriate overall for RUSLE2 than the power equation form. The shape of the curve in the upper 4-inch soil depth is of minimal consequence because RUSLE2 uses the average root biomass density in the upper 10-inch soil depth to compute soil biomass subfactor values (see Section **6.2.1**).

A major result from the literature review and data analysis was that rooting depth for the roots judged to have the most effect on rill-interrill erosion do not vary greatly among agricultural crops and pasture/range plant communities. However, the rooting depths for most vegetable crops were about one half of that for agricultural crops. A rooting depth of 30 inches was assumed in RUSLE2 for all plant communities, including vegetable crops. Other RUSLE2 assumptions based on data analysis were that 85 percent of live root biomass was above the 15 inch depth, the live root biomass distribution by depth was the same for all plant communities, and rooting depth does not temporally vary.

The adequacy of these RUSLE2 assumptions results partly from average live root biomass density in the upper 10 inch soil depth being used to compute values for the soil biomass subfactor (see **Section 6.5.2**). The RUSLE2 live root distribution described by equations 9.1 and 9.2 compute that 61 percent of the total live root biomass is in the upper 4-inch soil depth and 80 percent is in the upper 10-inch soil depth. The constant rooting depth assumption does not result in large errors for estimating the soil biomass subfactor because the input variable is the root biomass in the upper 4-inch soil depth that contains more than half of the total root biomass.[56] Furthermore, temporal live root biomass values given in the RUSLE2 Core Database (see the RUSLE2 User's Guide) were scaled from the values at plant maturity, which RUSLE2 accurately represents for most plant communities, to give expected erosion estimates for times before the vegetation reaches maturity.

These assumptions are in accordance with the RUSLE2 objective to provide a system where the major vegetation variables affecting rill-interrill erosion can be easily described and measured and values for variables used to describe vegetation can be easily entered in RUSLE2. The objective is to sufficiently represent vegetation for RUSLE2 to estimate the effects of vegetation for conservation and erosion control planning. The adequacy of RUSLE2 for conservation and erosion control planning is the criteria for judging these RUSLE2 relationships. **The RUSLE2 User's Reference Guide guidelines must be followed to ensure accurate RUSLE2 erosion estimates.**

9.2.2. Live root biomass becoming dead root biomass

RUSLE2 uses a single vegetation description on any particular day (see **Section 8.1.1**). An operation that includes a **kill vegetation** process transfers the entire live root biomass in each soil layer to the dead root biomass in the corresponding soil layer. RUSLE2 does not allow killing a portion of the live root biomass. That effect can be accomplished by using an operation that includes a **begin growth** process that instructs RUSLE2 to begin using values for a new vegetation description. RUSLE2 assumes that the difference between the live root biomass on the last day that a vegetation description is used and the live root biomass on day zero in the new vegetation description represents dead root biomass that is added to the existing root biomass. RUSLE2 assumes that a decrease in root biomass from one day to the next represents root sloughing (Reeder et al., 2001). Each daily decrease in live root biomass is added that day to the dead root biomass.

9.2.3. Live above ground biomass

---

[56] An RUSLE2 improvement would be to temporally vary rooting depth with plant community. The distribution of live root biomass with depth, Equations 9.1 and 9.2, would be assumed to the plant community and time invariant. The variable y would be normalized according to ½ of the temporally varying rooting depth rather than 15 inches.

RUSLE2 vegetation descriptions are divided into new growth, senescence, and regrowth periods, illustrated in Figure 9.2, to compute temporal values for live above ground biomass as a function of canopy cover.[57]

9.2.3.1. New growth period

A **new growth** period is the time during which particular canopy cover values are first reached in a vegetation description. For example, the canopy cover from the seeding date to the first canopy cover maxima is a new growth period as illustrated in Figure 9.2. A second new growth period occurs in the second year over the time that canopy cover increases from the value of the first local canopy cover maxima in the first year to the local canopy cover maxima in the second year, also illustrated in Figure 9.2. A similar third new growth period, not illustrated, occurs in the third year. A composite of plant materials including leaves and stems is assumed to be produced during new growth periods.

[57] The rules that RUSLE2 uses in handling vegetation biomass variables are described in the RUSLE2 user's Reference Guide.

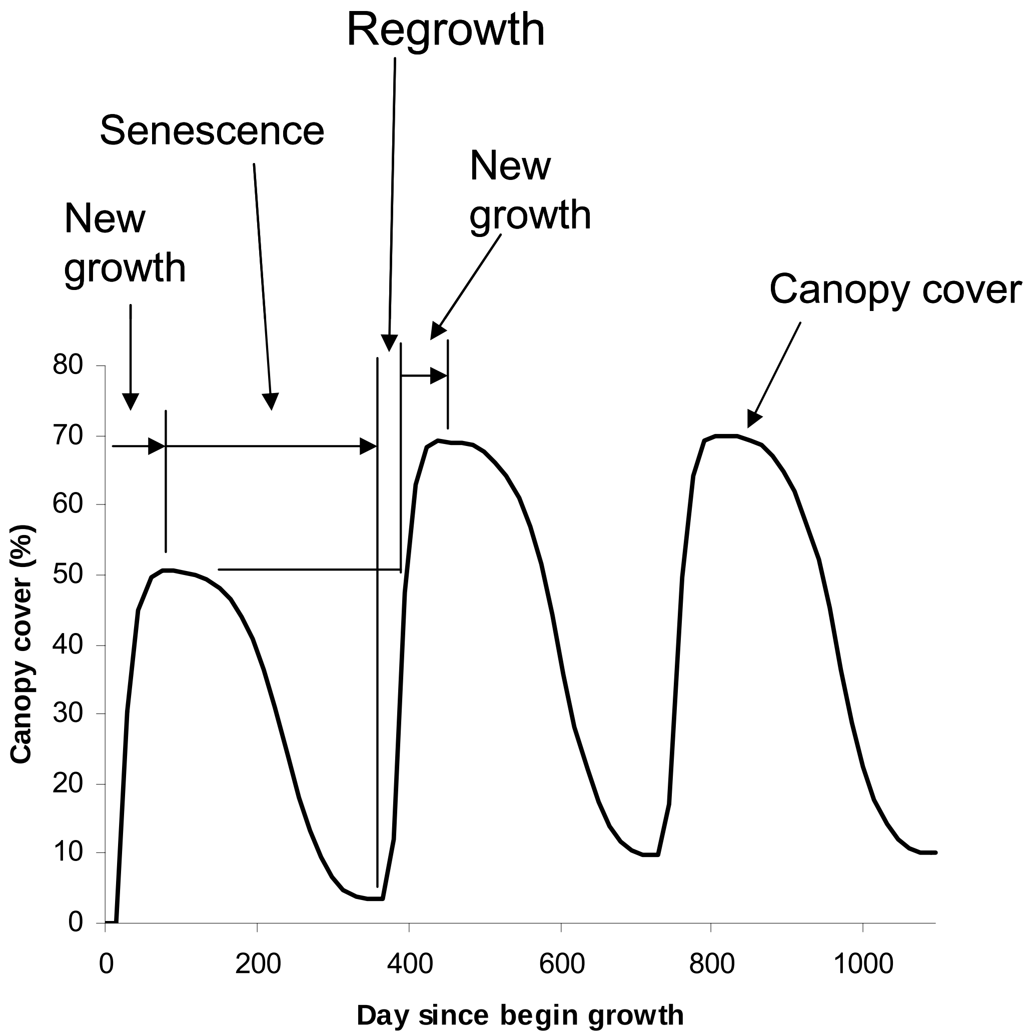


Figure 9.2. Vegetation growth periods used to compute live above ground biomass as a function of canopy cover.

The local canopy cover maxima that occurs in the third year for the vegetation description illustrated in Figure 9.2 is also the absolute canopy cover maxima description. The local canopy cover minima that occurs immediately after the absolute local canopy cover maxima is defined in RUSLE2 as the local absolute canopy cover minima corresponds to the absolute canopy cover maxima for the vegetation description, even though other local canopy cover minima are less than this canopy cover. Values for the absolute canopy maxim and minima and the corresponding live above ground biomass values for these canopy values are user RUSLE2 inputs.

Live above ground biomass is computed from canopy cover during a new growth period using:

$$B_l = B_{a,mx}(C/C_{amx})^{1.5} \quad [9.4]$$

where: B_l = live above ground biomass at time t during a new growth period, $B_{a,mx}$ = the live above ground biomass at absolute maximum canopy cover, C = canopy cover at time t, and C_{amx} = canopy cover at absolute maximum canopy cover.

9.2.3.2. Senescence period

A **senescence** period is the time over which canopy cover decrease in a vegetation description from a local canopy cover maxima to a local canopy cover minima as illustrated in Figure 9.2. The equation used to compute live above ground biomass for a senescence period is:

$$B_l = B_{i,mn} + (B_{i,mx} - B_{t,mn})[(C - C_{i,mn})/(C_{i,mx} - C_{i,mn})]^{1.5} \quad [9.5]$$

where: $B_{t,mn}$ = live above ground biomass at a local canopy cover minima, $B_{t,mx}$ = live above ground biomass at a local canopy cover maxima, $C_{i,mn}$ = canopy cover at a local minima, and $C_{it,mx}$ = canopy cover at a local maxima. The index i refers to canopy cover maxima-canopy cover minima combinations where canopy cover minima occur after the corresponding canopy cover maxima.

The live above ground biomass and canopy cover at local canopy cover minima must be on the curve given by:

$$B_{i,mn} = B_{a,mn}(C_{i,mn}/C_{a,mn})^{1.5} \quad [9.6]$$

where: $B_{a,mn}$ = the absolute minimum live above ground biomass and $C_{a,mn}$ = the absolute minimum canopy cover defined in **Section 9.2.3.1**. Values for live above ground biomass and canopy cover at local maxima must fall along the curve defined by equation 9.4.

The live above ground biomass-canopy cover curves for the new growth and the senescence periods are illustrated in Figure 9.3 for the first year of the vegetation description represented in Figure 9.2. The live above ground biomass for a given canopy cover during the senescence period is greater than that during the new growth period. Canopy cover loss during the senescence period is primarily by leaves falling to the soil surface. The biomass per unit canopy cover is much less for leaves than for the material, primarily stems, left standing during senescence. Each daily decrease in live above ground biomass is assumed to be biomass that falls and reaches the soil surface. This daily above ground biomass loss is added to the daily surface residue pool.

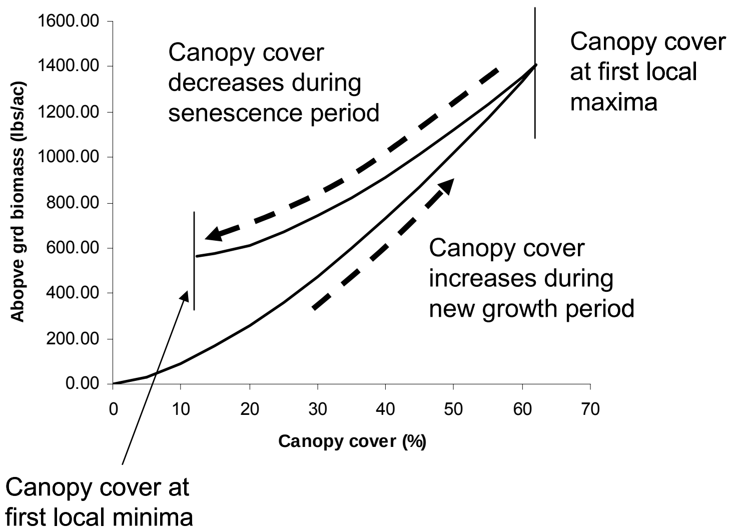


Figure 9.3. Live above ground biomass-canopy cover relationships for new growth and senescence periods during first year.

Equations 9.4 and 9.5 compute a decrease in live above ground biomass for a decrease in canopy cover. However, a decrease in live above ground biomass can occur with some plant communities with canopy cover remaining at 100 percent. An exponential equation form was evaluated to describe these plant communities. However, an exponential type equation was not used in RUSLE2 because such an equation can not be easily calibrated using the desired RUSLE2 inputs. Also, the exponential equation form did not give desired values for low canopy cover values.

Multiple vegetation descriptions can be used in RUSLE2 to describe significant change in live above ground biomass for no change in canopy cover. The inputs for these vegetation descriptions used during this period are selected so that RUSLE2 computes a significant change in live above ground biomass for very little change in canopy cover such as from 100 percent to 99.5 percent. Such small changes in canopy cover have essentially no effect on canopy subfactor values (see **Section 6.1**). Other vegetation descriptions are used for times that canopy cover changes rapidly.

9.2.3.3. Regrowth period

The **regrowth** period starts from the canopy cover and live above ground biomass at the last local minima that was reached in the RUSLE2 computations as illustrated in Figure 9.2. Equation 9.5 is used to compute live above ground biomass values for the regrowth period as the live above ground biomass-canopy cover relationship retraces the senescence curve as illustrated in Figure 9.4. Most of the live biomass added during this period is assumed to be leaves and other material that has low biomass for the canopy cover that it provides. The regrowth period ends when canopy cover becomes equal to the canopy cover value of the last local maxima. A new growth period begins at this point and continues until canopy cover becomes equal to the canopy cover of the next local maxima as illustrated in Figures 9.2 and 9.4. Equation 9.4 is used to compute values for live above ground biomass from canopy cover values during this new growth period. Once the next local maximum is reached, the next senescence period begins

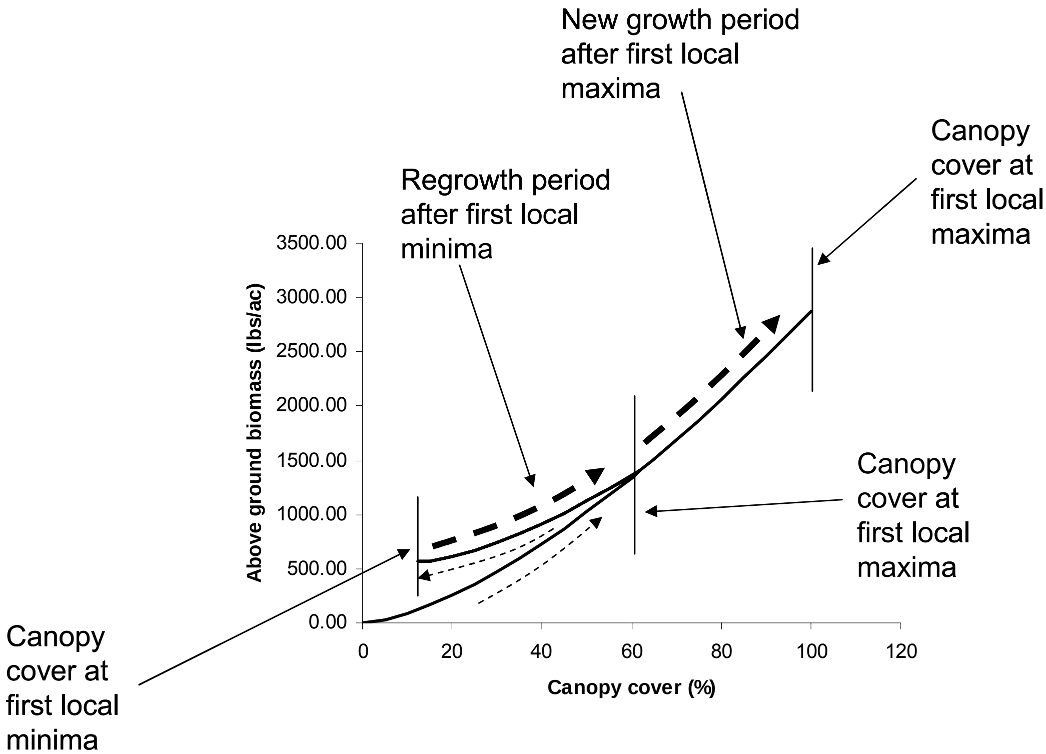


Figure 9.4. Live above ground biomass-canopy cover relationships for regrowth and new growth periods during second year.

where equation 9.5 is used to compute live above ground biomass values.

Computations for this sequence of vegetation periods are repeated until the end of the RUSLE2 computation period.

9.2.3.4. Special cases

9.2.3.4.1. Annual plant communities that experience senescence

Most agricultural crops are annual and are described with either a single new growth period or by a single new growth period and a senescence period. Soybeans and cotton are examples of crops that experience senescence.

9.2.3.4.2. Annual plant communities that experience a decrease in canopy cover without a corresponding decrease in live above ground biomass

RUSLE2 also represents vegetation (e.g., corn and wheat) where canopy cover decreases by leaves drooping instead of falling to the soil surface. In this special case, the live above ground biomass does not decrease as canopy cover decreases. However, RUSLE2 can not represent perennial (long term) vegetation (i.e., multiple sequences of new growth-senescence-regrowth periods in the vegetation description) that has these characteristics.

9.2.3.4.3. Operations that affect live vegetation

Operations that include begin growth, kill vegetation, and remove live biomass processes affect live above ground biomass. A **begin growth** process instructs RUSLE2 to begin using values from a new vegetation description. RUSLE2 assumes no relationship between live above ground biomass for the two vegetation descriptions although a relationship is assumed for live root biomass (see **Section 9.2.2**). The RUSLE2 assumption is that a decrease in live root biomass between the last day that a vegetation description is used to compute daily erosion and the live root biomass on day zero in the new vegetation description is biomass added to the existing dead root biomass pool. In contrast, no such connections are assumed for live above ground biomass. The RUSLE2 assumption is that the user explicitly uses operations to describe the fate of live above ground biomass between vegetation descriptions when a begin growth process is executed. Within the period represented by a vegetation description, the RUSLE2 assumption is that a decrease in canopy cover represents a senescence period and the decrease in live above ground biomass during a senescence period is daily added to the surface residue biomass pool.

Consequently, RUSLE2 assumes that a new growth vegetation period begins on day zero for a new vegetation description when a begin growth process is executed. This assumption applies to transplanted crops and to vegetation that regrows after hay harvest or mowing where canopy and live above ground biomass are greater than zero on day zero in the vegetation description. Similarly an operation that includes the **remove live biomass** process can leave live above ground biomass after the operation. RUSLE2 assumes that a new growth period begins immediately after the remove live biomass process is executed. The increase in live above ground biomass is assumed to be a composite of above ground plant components, including stems and leaves, during a new growth vegetation period in contrast to the increase in live above ground biomass being primarily leaves during the regrowth period that follows a senescence period.

A **kill vegetation** process transfers the entire live above ground biomass that exists on the day that the process is executed to the standing residue pool. The relation between standing residue biomass and canopy cover is given in **Section 9.2.3**.

9.2.4. Temporal standing live vegetation Manning's n

Standing vegetation contributes to total hydraulic resistance (see **Section 3.4**). The temporal contribution of standing live vegetation, not including live ground cover, to Manning's n is computed using:

$$n_{v,i} = n_{v,mx}(h_{f,i} / h_{f,mx})^{0.3} \qquad [9.7]$$

where: $n_{v,i}$ = the daily Manning's n contributed by live standing vegetation not including live ground cover, $n_{v,mx}$ = the maximum Manning's n contributed by live standing vegetation, not including live ground cover, during the period represented by the vegetation description, h_i = daily effective fall height, $h_{f,mx}$ = maximum effective fall height during the vegetation description, and i = subscript for day. Manning's n contributed by standing live vegetation is most affected by stems. Of the temporal input or computed variables used in a RUSLE2 vegetation description, Manning's n was assumed to be best related to effective fall height.

Maximum Manning's n for live standing vegetation for a vegetation description is computed from the user input vegetation retardance at maximum canopy cover. Vegetation retardance is a function of vegetation stem density and orientation of vegetation strips (rows) to the overland flow path (see **Section 3.4.6**). The live vegetation Manning's n when vegetation strips (rows) are on the contour (i.e., perpendicular to the overland flow path) is computed using equation 3.54. A Manning's n value for live standing vegetation for vegetation in rows up and downhill (i.e., parallel to the overland flow path) is computed using values in Table 3.9. The live standing vegetation Manning's n for the actual orientation of vegetation rows to the overland flow path (i.e., row grade) is computed using equation 3.55.

9.2.5. Temporal effective vegetation ridge height

Densely spaced stems of vegetation rows on the contour affect rill-interrill erosion much like soil ridges (see **Section 7.1.3.2**). An effective live vegetation ridge height is added to the soil ridge height to obtain an effective total ridge height used to compute values for the contouring subfactor in equation 7.6. The effect of live standing vegetation rows on erosion depends on row spacing. If row spacing is zero (i.e., the vegetation is not in rows and the plant stems are randomly spaced over the entire soil surface), orientation of vegetation rows to the overland flow path and row spacing has no meaning or effect on the contouring subfactor. The reduction in erosion (i.e., contouring effect) for a give effective live standing vegetation ridge height increases as vegetation row spacing increases and reaches a maximum at a narrow row width (i.e., a row spacing approximately ?? inches wide). The contouring effect of effective vegetation ridge height decreases as row spacing widens beyond the narrow row spacing. This effect is represented by values for the coefficient α given in Table 9.1.

The maximum effective live standing vegetation ridge height for contour vegetation strips (rows) for a vegetation description is computed using:

$$h_{v,mx} = 0.5\alpha R \qquad if\,(R > 7)R = 7 \qquad [9.8]$$

where: $h_{v,mx}$ = maximum effective live standing vegetation ridge height (inches) for the vegetation description when vegetation strips (rows) are on the contour, α = the coefficient that adjusts for row spacing, and R = the retardance class at maximum canopy cover in the vegetation description (see RUSLE2 User's Reference Guide).

Daily live standing vegetation ridge height is computed using:

$$h_{v,i} = h_{v,mx}(h_{f,i} / h_{f,mx})^{0.3} \qquad [9.9]$$

Table 9.1. Coefficient α values used to multiply maximum effective vegetation ridge height on contour to obtain effective vegetation ridge height for effect of row spacing

Row width	Coefficient α
Vegetation on ridges	0.25
Wide row	0.50
Moderate row spacing	0.75
Narrow row spacing	1.00
Very narrow row spacing	0.50
No rows (broadcast)	0.00

Like Manning's n for live standing vegetation, of the temporal vegetation variables, effective live vegetation ridge height is assumed to be most related to effective fall height.

9.3. Adjust input values for vegetation production (yield) level

Input values in RUSLE2 vegetation descriptions are functions of vegetation production (yield) level, and each RUSLE2 vegetation description applies to a particular production (yield) level. RUSLE2 compute values in a vegetation description for a new production (yield) level by adjusting values in a base vegetation description. The maximum canopy cover in the base vegetation description must be less than 100 percent. RUSLE2 can use a base vegetation description that has a maximum canopy cover of 100 percent to adjust for production (yield) levels greater than the production (yield) level for the base vegetation description, but RUSLE2 can not use a base vegetation description with a 100 percent maximum canopy cover to adjust to a lower production (yield) level.

Biomass values used in RUSLE2 computations are on a dry basis, but input values for vegetation production (yield) level are on a user defined basis. The user inputs information that RUSLE2 uses to convert production (yield) level value on the user defined basis to the dry basis needed for RUSLE2's computations (see RUSLE2 User's Reference Guide).

Multiple RUSLE2 vegetation descriptions can be used to compute erosion for a particular plant community over the period represented in the RUSLE2 computation (i.e., rotation duration, see RUSLE2 User's Reference Guide). For example, vegetation descriptions are used to describe a multiple year alfalfa hay production system. The first vegetation description describes the alfalfa crop from seeding to first hay harvest, the second vegetation description describes regrowth after each hay harvest in the first harvest year, the third vegetation description describes senescence and regrowth after senescence to the first hay harvest in the second harvest year, and so on. Input values such for live above ground biomass at maximum canopy apply to that particular vegetation description and not to the vegetation, such as the example alfalfa crop, as a whole over the RUSLE2 computation period.

9.3.1. Live above ground biomass at maximum canopy cover

A major vegetation input is live above ground biomass at maximum canopy cover for a particular vegetation description. When multiple vegetation descriptions are used to represent a particular vegetation, the live above ground biomass entered for each vegetation description is for the maximum canopy cover in that particular vegetation description.

The RUSLE2 assumption is that live above ground biomass at maximum canopy varies linearly as a function of production (yield) level. That is:

$$B_{l,mx} = a + bY_d \qquad [9.10\}$$

where: $B_{l,mx}$ = live above ground biomass (dry basis, mass/area) at maximum canopy cover for the vegetation description and Y_d = production (yield) level (dry basis, mass/area). The user provides inputs that RUSLE2 uses to convert production (yield) level in user units to biomass on a dry basis. These equations have the form:

$$Y_d = \beta Y_u \qquad [9.11]$$

where: Y_u = production level (yield) in user defined units and β = a conversion factor that RUSLE2 computes from user inputs. The values for the coefficients a and b in equation 9.10 are computed from user inputs for two live above ground biomass at maximum canopy cover-production (yield level) data points (see RUSLE2 User's Reference Guide).

9.3.1. Retardance at maximum canopy cover

Retardance for live vegetation at maximum canopy cover is computed from:

$$R = c + dY_u \qquad [9.12]$$

where: R = retardance at maximum canopy cover for a vegetation description and Y_u = production (yield) level in user defined units for the vegetation description. The user enters two input data points for retardance-production (yield) level that RUSLE2 uses to determine values for the coefficients c and d in equation 9.12. RUSLE2 uses eight retardance classes that vary with the degree that runoff is slowed for the vegetation grown in strips (rows) on the contour (see RUSLE2 User's Reference Guide). With the exception of the eight retardance class, retardance class values are assumed to be continuous when used computed from equation 9.12 and used in equation 3.54 to compute Manning's n values.

Vegetation descriptions are used to describe both live vegetation and fabric (silt) fences, gravel bag dams, and similar mechanical devices used on construction sites to trap and retain sediment on site (see RUSLE2 User's Reference Guide). The yield input for the vegetation description used to describe these devices is used to represent the degree that the installed device retards runoff. The eighth retardance class is reserved for conditions that provide extremely high retardance such as stiff grass hedges, fabric (silt) fences and gravel bag dams. RUSLE2 computes backwater length caused by vegetation strips and flow retarding devices as a function of Manning's n, which are computed from the retardance class for the vegetation description (see **Section 3.4.4**). RUSLE2 assigns a minimum backwater length of 3 ft for the extremely high retardance class but uses the backwater length computed for the other retardance classes. RUSLE2 assumes a maximum backwater length of 15 ft for all vegetation/mechanical retarding strips.

9.3.3. Temporal input vegetation variables

Simple equations are used in RUSLE2 to approximate the temporal variations in vegetation variables computed by the EPIC model (Williams et al., 1989).

9.3.1.1. Root biomass

Live root biomass values are assumed to vary linearly with live above ground biomass at maximum canopy cover. Live root biomass values for a new vegetation are computed as a function of production level (yield) using:

$$B_{r,n,j} = B_{r,b,j}(B_{l,mx,n} / B_{l,mx,b}) \qquad [9.13]$$

where: $B_{r,n,j}$ = root biomass value in the new vegetation description for the *jth* data point, $B_{r,b,j}$ = the corresponding root biomass value for the *jth* data point in the base vegetation description, and $B_{l,mx,b}$ = the live above ground biomass in the base vegetation description. A value for the live above ground biomass at maximum canopy $B_{l,mx,n}$ in the new vegetation description is computed by rearranging equation 9.11 and the production (yield) level value for the new vegetation description.

9.3.1.2. Canopy cover

The equation used to adjust canopy cover values for production (yield) level is:

$$C_{n,j} = C_{b,j}(B_{l,mx,n} / B_{l,mx,b})^{0.5} \qquad [9.14]$$

where: $C_{n,j}$ = canopy cover for *jth* data point the new vegetation description and C_b,j = the corresponding canopy cover value for the *jth* data point in the base vegetation description.

9.3.1.3. Effective fall height

The equation used to adjust effective fall height values for production (yield) level is:

$$h_{f,n,j} = h_{f,b,j}(B_{l,mx,n} / B_{l,mx,b})^{0.2} \qquad [9.15]$$

where: $h_{f,n.j}$ = effective fall value for the *jth* data point in the new vegetation description and $h_{f,b,j}$ = corresponding effective fall height value for the *jth* data point in the base vegetation description.

9.3.1.4. Live ground cover

The equation used to adjust live ground cover values as a function of production (yield) level is:

$$f_{\lg c,n,j} = f_{\lg c,b,j} (B_{l,mx,n} / B_{l,mx,b})^{0.5} \quad [9.16]$$

where: $f_{lgc,n,j}$ = live ground cover value for the *jth* data point in the new vegetation description and $f_{lgc,b,j}$ = corresponding live ground cover value for the *jth* data point in the base vegetation description.

9.3.1.4. Consumption water use

Consumption water use is used to compute how irrigation affects rill-interrill erosion by precipitation (see **Section 7.5**). Consumption water use is a function of production (yield) level. The equation used to adjust consumptive water use values as a function of production (yield) level is:

$$V_{wu,n,j} = V_{wu,b,j} (B_{l,mx,n} / B_{l,mx,b}) \quad [9.17]$$

where: $V_{wu,n,j}$ = consumptive water use value for the *jth* data point in the new vegetation description and $V_{wu,b,j}$ = corresponding values for consumptive water use value for the *jth* data point in the base vegetation description.

List of symbols

a = coefficient used to compute live above ground biomass at maximum canopy cover
b = coefficient used to compute live above ground biomass at maximum canopy cover
$B_{a,mn}$ = absolute minimum live above ground biomass (dry basis) (mass/area)
$B_{a,mx}$ = live above ground biomass at absolute maximum canopy cover (mass/area)
B_l = live above ground biomass (dry basis) at day t during a new growth period (mass/area)
$B_{l,mx}$ = live above ground biomass (dry basis) at maximum canopy cover for the vegetation description (mass/area)
$B_{l,mx,b}$ = live above ground biomass in base vegetation description (mass/area)
$B_{l,mx,n}$ = live above ground biomass at maximum canopy in new vegetation description
$B_{r,b,j}$ = the corresponding root biomass value for the *jth* data point in the base vegetation description (mass/area)
$B_{r,n,j}$ = root biomass value in the new vegetation description for the *jth* data point
$B_{t,mn}$ = live above ground biomass (dry basis) at a local canopy cover minima (mass/area)
$B_{t,mx}$ = live above ground biomass (dry basis) at a local canopy cover maxima (mass/area)
c = coefficient used to retardance from user input yield
C = canopy cover at day t (portion of soil surface covered)
$C_{a,mn}$ = absolute minimum canopy cover (portion of soil surface covered)
C_{amx} = canopy cover at absolute maximum canopy cover (portion of soil surface covered)
$C_{b,}j$ = canopy cover value for *jth* data point in base vegetation description (portion of soil surface covered)
$C_{i,mn}$ = canopy cover at a local minima (portion of soil surface covered)
$C_{it,mx}$ = canopy cover at a local maxima (portion of soil surface covered)
$C_{n,j}$ = canopy cover for *jth* data point in new vegetation description (portion of soil surface covered)
d = coefficient used to retardance from user input yield
$f_{lgc,n,j}$ = live ground cover value for *jth* data point in the new vegetation description (portion of soil surface covered)
$f_{lgc,b,j}$ = corresponding live ground cover value for *jth* data point in base vegetation description (portion of soil surface covered)
h_i = daily effective fall height
$h_{f,b,j}$ = corresponding effective fall height value for the *jth* data point in the base vegetation description (length)
$h_{f,n.j}$ = effective fall value for *jth* data point in new vegetation description (length)
$h_{f,mx}$ = maximum effective fall height during the vegetation description
$h_{v,mx}$ = maximum effective live standing vegetation ridge height for the vegetation description when vegetation strips (rows) are on the contour (length)
M_r = cumulative root biomass (dry basis) above the depth y (mass/area)
$n_{v,i}$ = daily Manning's n contributed by live standing vegetation not including live ground cover
$n_{v,mx}$ = maximum Manning's n contributed by live standing vegetation not including live ground cover
R = retardance class at maximum canopy cover in the vegetation description
$V_{wu,b,j}$ = corresponding values for consumptive water use value for *jth* data point in base

vegetation description (length)
$V_{wu,n,j}$ = consumptive water use value for *jth* data point in the new vegetation description (length)
y = normalized depth in soil from soil surface Y/15 inches
Y = depth in soil from soil surface (length)
Y_d = production (yield) level (dry basis, mass/area)
Y_u = production level (yield) in user defined units
15 = reference depth in inches for determining root mass distribution in soil

α = coefficient that adjusts for row spacing in computation of vegetation retardance
β = conversion factor that computes yield on dry basis from user inputs

Indices
i - day
i - refers to canopy cover maxima-canopy cover minima combinations where canopy cover minima occur after the corresponding canopy cover maxima
j – data point

10. Residue and dead roots

10.1. Description of residue and dead roots

Residue and dead roots are materials lost by decomposition. RUSLE2 includes standing residue, surface residue, and buried residue pools that account for material produced when live above ground biomass is converted to standing residue (**Sections 6.1 and 9.2.3.4.3**). RUSLE2 accounts for the movement of mass between these pools by harvest, tillage, ripping, and other operations that affect vegetation, residue, and soil (see **Section 8.2**). The RUSLE2 surface residue pool also includes material such as mulch, manure, and erosion control blankets applied to the soil surface (see **Section 6.2**). The RUSLE2 buried residue pool includes material such as manure and bio-solids in sewage sludge that are injected or incorporated into the soil (see **Sections 6.3 and 6.5**). Mass in the RUSLE2 dead root pool results from live root biomass associated with a vegetation description being transferred to the dead root biomass pool (see **Section 9.2.2**).

The general RUSLE2 assumption is that residue and dead roots are organic materials that decompose. RUSLE2 also describes the effects of non-organic material such as erosion control blankets and rock placed on the soil surface or incorporated into the soil. However, special inputs are used to represent non-organic material. For example, user inputs are selected so that the mass values used in the equation 6.48, the RUSLE2 equation for the soil biomass subfactor, are so small that values for the soil biomass subfactor are hardly affected when the assumption is that these materials have no effects on erosion when in the soil (see RUSLE2 User's Reference Guide).

10.2. Relation of portion of soil surface covered to residue mass

10.2.1. Equation for computing residue cover from residue mass

The fraction of the soil surface covered by material in direct contact with the soil surface is the major variable used to compute how ground cover (surface residue) affects rill-interrill erosion. However, RUSLE2 tracks surface residue by dry mass (mass/area). The RUSLE2 equation that computes portion of the soil surface covered by surface residue is:

$$f_{gc} = 1 - \exp(-\alpha B_s) \qquad [10.1]$$

where: f_{gc} = fraction of the soil surface covered by a particular residue type when no other residue type is present and B_s = surface residue mass (dry mass/area). RUSLE2 computes a value for the coefficient α using equation 10.1 and user entered values for the residue mass that provides 30, 60, or 90 percent cover.

The user assigns a residue description to each vegetation description and to eachoperation description that adds material to the soil surface used in a RUSLE2 computation (see **RUSLE2 User's Reference Guide**). For example, a corn-soybeans crop rotation involves two residue descriptions, one for corn and one for soybeans. The mass for each residue description is tracked separately. A daily ground cover value is computed with equation 10.1 for each residue description. A net ground cover value is used in equation 6.6 to compute a value for the ground cover subfactor, not the sum of the ground cover values computed with equation 10.1 for each residue description when multiple residue descriptions are involved. RUSLE2 takes into account the overlap of residue descriptions to compute net ground cover. The RUSLE2 assumption isthat the portion of material that overlaps underlying material has no effect on rill-interrill erosion. The computation of net ground cover is illustrated for crop residue or mulch applied to a soil surface with existing rock cover. The net ground cover for these two residue descriptions (i.e., crop residue or mulch and rock) is computed as:

$$f_{gc,n} = f_{gc,r} + f_{gc,m}(1 - f_{gc,r}) \qquad [10.2]$$

where: $f_{gc,n}$ = net ground cover (fraction), $f_{gc,r}$ = ground cover (fraction) computed with equation 10.1 provided by the rock surface residue cover assuming no other material is present, and $f_{gc,m}$ = ground cover (fraction) computed with equation 10.1 for crop residue or mulch assuming no other material is present. Equations 10.1 and 10.2 are used repeatedly to account for each residue description used in a particular RUSLE2 computation to compute a net ground cover value.

In some cases, a material is applied to soil surface that significantly affects erosion but does not affect erosion when incorporated into the soil. The mass values entered in the residue description for cover-mass data points can be scaled to be so small that the mass values used for the material when incorporated are so small that they have no effect on soil biomass subfactor values (see **Section 6.5**). Input values for mass of these materials applied to the soil must be accordingly scaled. The objective in these RUSLE2 applications in that RUSLE2 uses desired ground cover values to compute ground cover subfactor values using equation 6.6 but uses such small residue mass values so that soil biomass factor values computed with equation 6.48 are hardly affected if the material is incorporated into the soil.

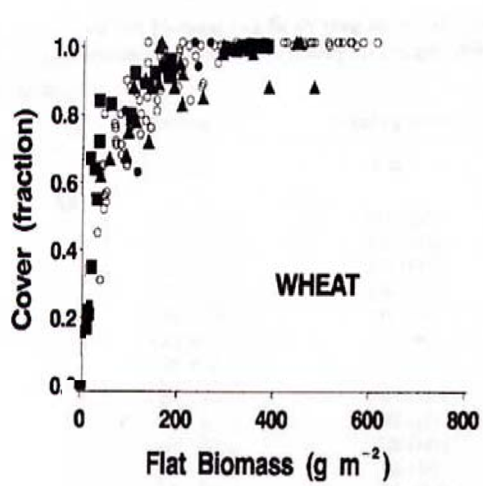


Figure 10.1. Measured data for relationship of residue cover to surface residue mass. (Source: Steiner et al., 2000).

Data reported in the literature for residue cover as a function of residue mass vary greatly from study to study and even within a particular study as illustrated by Figure 10.1. The values used in the RUSLE2 Core Database were chosen as representative values for conservation and erosion control planning, realizing that numerous studies give values different from the RUSLE2 values. For example, surface cover ranged from about 65 percent to 100% for a flat residue mass of about 1500 lbs/acre in the Steiner et al. (2000) study, which is significantly greater than the 58 percent that the RUSLE2 Core Database values compute. The RUSLE2 Core Database values are based on AH537 (Wischmeier and Smith, 1978) values, which were primarily derived from data reported by Mannering and Meyer (1963), Meyer and Mannering (1967) and Meyer et al. (1970).

Stott (1995) noted that α values for corn varied from about 0.00023 to 0.00045 acre/lbs for corn residue based on her measurements and data reported in the literature. She recommended that the 0.00023 acre/lbs value (60 percent cover at 4000 lbs/acre flat corn residue mass) be used for corn grown after the mid 1980's and that the RUSLE2 Core Database value of 0.00038 acre/lbs (60 percent cover at 2400 lbs/acre corn residue mass) be used for corn grown before the mid 1980's. RUSLE2 satisfactorily estimates flat residue cover at planting for a wide range of soil and conservation tillage methods as Table 10.1 shows, with the recognition that the corn in these studies was grown before the mid 1980's.

The RUSLE2 Core Database values for residue mass-residue cover relationships are recommended for routine RUSLE2 applications. When RUSLE2 users wish to use values for residue mass-cover other than those in the RUSLE2 Core Database, users should review and analyze data from multiple sources because of the great variability in these data within a study as illustrated in Figure 10.1 and between studies. RUSLE2 was calibrated using the values in the RUSLE2 Core Database. Unexpected serious error can occur when input values are improperly changed from those in the RUSLE2 Core Database (see the **RUSLE2 User's Reference Guide**).

10.2.2. Reasons for variability in the residue mass-residue cover relationship

A major reason for the variability in the residue mass-residue cover relationship is that crop residue, plant litter, and similar materials are composed of multiple plant components (e.g., leaves, stems, seed pods, and chaff) and pieces that vary in composition, geometry, size, mass, and surface area covered per unit dry mass. RUSLE2 uses a single residue description to represent residue as a composite of multiple components. Consequently, α in equation 10.1 is a function of the relative mass of each residue component in the composite and varies temporally as the relative mass of each residue component varies temporally. For example, the α value for corn and soybean residue immediately after harvest differs significantly from the α value several months later because leaves cover more area than do stems per unit mass and leaves decompose much more rapidly than do the stems. In contrast to corn and soybeans, field measured data at Bushland, Texas showed that α values for barley, oats, spring wheat, and winter wheat did not vary from 24 to 400 days after harvest (Steiner et al., 2000). However, data variability, as in all other studies of residue mass-residue cover, may have masked temporal changes in the residue mass-residue cover relationship.

Table 10.1. Measured and RUSLE2 estimated residue cover (percent) immediately after planting (Source: RUSLE2 User's Reference Guide)

Crop	Tillage system	Observed cover	Estimated cover	Reference
corn	spring disk	15	21	1
corn	fall chisel, spring disk	13	12	1
corn	spring disk, spring disk	27	18	2
corn	spring chisel, spring disk	22	11	2
corn	spring disk	15	21	2
corn	fall chisel, spring disk	13	12	2
soybeans	spring disk, spring disk	27	18	2
soybeans	spring chisel, spring disk	22	11	2
corn	spring disk	8	20	2
corn	spring disk, spring disk	5	7	2
corn	spring chisel, spring disk	7	3	2
corn	field cultivator	24	20	2
soybeans	spring disk, spring disk	11	8	2
soybeans	spring disk	15	22	2
soybeans	spring chisel, spring disk	11	4	2
corn	fall chisel, spring disk	33	26	3
corn	spring chisel, spring disk	19	19	4
corn	spring disk, spring disk	30	27	4
corn	fall chisel, spring disk, spring field cultivator	9	14	5
soybeans	fall chisel, spring field cultivator, spring field cultivator	9	5	5
corn	fall chisel, spring disk, spring field cultivator	16	14	6
soybeans	fall chisel, spring field cultivator, spring field cultivator	3	5	6
soybeans	spring disk, spring disk	9	7	7
soybeans	spring disk, spring disk	9	7	8
soybeans	spring disk	13	18	8

Table 10.1 (continued). Measured and RUSLE2 estimated residue cover (percent) immediately after planting
References:
1. Siemens, J. C., W. R. Oschwald.1976. Erosion from corn tillage systems. Trans. ASAE 19:69-72.
2. Dickey, E. C., D. P. Shelton, P. J. Jasa, T. R. Peterson. 1985. Soil erosion from tillage systems used in soybeans and corn resides. Trans. ASAE 28:1124-1129, 1140.
3. Lindstrom, M. J. and C. A. Onstad. 1984. Influence of tillage systems on soil physical parameters and infiltration after planting. J. of Soil and Water Cons. 39:149-152.
4. Laflen, J. M., J. L. Baker, R. O. Hartwig, W. F. Buchele, and H. P. Johnson. 1978. Soil and water losses from conservation tillage systems. Trans. ASAE 21:881-885.
5. McIsacc, G. F., J. K. Mitchell, and M. C. Hirschi. 1990. Contour and conservation tillage for corn and soybeans in the Tama Silt Loam Soil:hydraulics and sediment concentration.Trans. ASAE 33:1541-1550.
6. McIsaac, G. F., J. K. Mitchell, M. C. Hirschi, and L. K. Ewing. 1991. Conservation and contour tillage for corn and soybeans in the Tama silt loam soil:the hydrologic response. Soil and Tillage Research 19:29-46.
7. Shelton, D. P., P. J. Jasa, and E. C. Dickey. 1986. Soil erosion from tillage and planting systems used in soybean residue:Part I-influences of row spacing. Trans. ASAE 29:756-760.
8. Jasa, P. J., E. C. Dickey, and D. P. Shelton. 1986. Soil erosion from tillage and planting systems used in soybean residue:Part II-influences of row direction. Trans. ASAE 29:761-766.

The RUSLE2 assumption is that residue properties such as α in equation 10.1 are time invariant for the period represented by a residue description in a RUSLE2 computation. Consequently, equation 10.1 is a compromise and the values in the RUSLE2 Core Database used to compute α were chosen to compute erosion values appropriate for conservation and erosion control planning (see **RUSLE2 User's Reference Guide**). The input values that RUSLE2 uses to compute α values should be carefully selected to ensure that equation 10.1 gives the best erosion estimates for the time periods that have the greatest effect on average annual erosion. User entered values for a new residue description being added to a RUSLE2 database should be consistent with values in the RUSLE2 Core Database. Procedures described in the **RUSLE2 User's Reference Guide** must be followed.

In some cases, temporal changes in residue properties can be represented in RUSLE2 by using multiple residue descriptions during the RUSLE2 computation period. Using multiple residue descriptions requires using an operation that includes a **remove residue/cover process** to remove the existing material and another operation that includes an **add other cover process** that adds the removed material back to the soil surface using a new residue description. The computer mechanics of using RUSLE2 in this way is not convenient for routine conservation and erosion control planning. However, the procedure is mentioned to illustrate RUSLE2's capability for computing the effects of temporal variations of residue properties. Technical specialists for agencies using RUSLE2 in routine conservation planning can use this technique to evaluate the uncertainty in RUSLE2 erosion estimates resulting from the assumption that residue properties do not vary temporally (see **RUSLE2 User's Reference Guide**).

The importance of using recommended RUSLE2 inputs and following RUSLE2 procedures described in the RUSLE2 User's Reference Guide can not be over-emphasized, especially when making comparisons with the USLE, RUSLE1, and much of the historical data used to develop those models as well as RUSLE2. However, crop characteristics and yield, especially for corn, has changed greatly from the 20 bu/ac corn yield common in the 1930's data used to determine the AH282 and 537 soil loss ratio values, which were used to calibrate RUSLE2, to modern 200 bu/ac high production corn yields. The values in the RUSLE2 Core Database are considered adequate for evaluating modern crops and cropping practices, especially when RUSLE2 erosion computed values are being compared with values computed with the USLE or RUSLE1.

Consideration should be given to changing input values to represent modern crops and cropping practices in certain RUSLE2 applications. In doing so, the procedures described in the RUSLE2 User's Reference Guide should be carefully followed, and input values must be based on multiple data sources, not a single source. RUSLE2 was calibrated to compute expected erosion rates as a function of the principal variables affecting erosion. Therefore, RUSLE2 computation of what appears to be an erroneous cover value does not necessarily mean that RUSLE2's computed erosion values are erroneous.

Improper inputs without consideration of RUSLE2's calibration can result in very serious errors in RUSLE2 computed erosion values.

10.3. Decomposition of residue and dead roots

10.3.1. Description of equations

Both residue and dead roots are assumed to be lost over time as result of decomposition and other processes related to precipitation and temperature. The basic RUSLE1 decomposition equations are used in RUSLE2 [AH703 (Renard et al., 1997); Yoder et al., 1997; Stott, 1991; Stott et al., 1995], which are a simplification of the decomposition equations used in the erosion prediction model WEPP (Laflen et al., 1991; Flanagan and Nearing, 1995).[58] The main equation is:

$$B_i = B_{i-1} \exp(-\beta D) \qquad [10.3]$$

where: B_i = the mass in a particular residue/dead root pool after decomposition on the *ith*

[58] Also, see references listed in the **Decomposition Subsection** of the **References Section**.

day, B_{i-1} = the mass in the pool on a previous day, and D = the number of days in the period over which decomposition is being computed, which is a single day in RUSLE2 (i.e., D = 1 day in RUSLE2). The coefficient β is computed from:

$$\beta = \phi[\min(W_f, T_f)] \qquad [10.4]$$

where: φ = a decomposition coefficient (day^{-1}) that is a function of biomass type, W_f = a moisture function, and T_f = a temperature function. Equation 10.4 is based on the assumption that decomposition is limited by either moisture or temperature and is solely a function of the variable that limits decomposition on that date.

Moisture must be present for decomposition to occur. Daily precipitation is used in RUSLE2 as an indicator of moisture available for decomposition because RUSLE2 does not compute moisture in contact with material represented by the residue/dead root pools. Decomposition rate decreases if moisture decreases below a moisture content at which moisture does not limit decomposition. Values for the moisture function W_f are computed from:

$$W_f = P_i / P_b \qquad if\,(P_i / P_b > 1) W_f = 1 \qquad [10.5]$$

The 4.4 mm value used in RUSLE2 for P_b was determined by fitting the RUSLE2 decomposition equations to the field data identified in Table 10.1.

Decomposition rate also varies with temperature. Decomposition rate decreases as temperature decreases below 32 oC, the temperature at which decomposition rate is maximum. Similarly, decomposition rate decreases as temperature increases above the temperature of 32 oC. Values for the temperature function are computed from:

$$T_f = \frac{2(T+A)^2 (T_o + A)^2 (T+A)^4}{(T_o + A)^4} \qquad if\,(T < -10) T_f = 0 \qquad [10.6]$$

where: T = daily air temperature (oC), T_o = the optimum temperature (oC) for decomposition (32 oC), and A = 8 oC. The value for A was set so that when air temperature becomes less than – 10 oC, the temperature function is set to zero.[59] The reason that the temperature function does not become zero at a higher temperature, such as near 0 oC is that temperature varies between a minimum and maximum during the day and average temperature on a given day varies about the long-term average temperature for that day. Air temperature rather than soil temperature is used in the temperature function because soil temperature is not available in RUSLE2. Like precipitation, air temperature is an indicator variable rather than the actual temperature that the decomposing material experiences. Values for the RUSL>E2 decomposition coefficient φ differ from values for decomposition coefficient in similar equations used in other

---

[59] An adjustment should have been made to equation 10.6 to flatten the top of the curve around the 32 oC temperature for maximum decomposition to account for within day and year-to-year variation in temperature about the average daily temperature used in RUSLE2. See Schomberg et al. (??).

erosion prediction models such as WEPP (Stott et al., 1995), WEPS (Steiner et al., 1995), and RWEQ (Schomberg and Steiner, 1997).

The RUSLE2 composition coefficient φ can be expressed in terms of residue half life, which is defined as the time required for half of the residue mass to decompose at optimum temperature and moisture (i.e., $W_f = 1$ and $T_f = 1$). The relation of residue half life $D_{1/2}$ to the decomposition coefficient φ is given by:

$$D_{1/2} = -\ln(0.5)/\phi \qquad [10.7]$$

where: $D_{1/2}$ = residue half life (days) and ln(0.5) = 0.693.

Values for the decomposition coefficient φ were determined by fitting equations 10.3-10.6 to field data identified in Table 10.1.

The same decomposition coefficient φ values and moisture (W_f) and temperature (T_f) functions are used in RUSLE2 for buried and surface residue and dead roots. Also, RUSLE2 decomposition coefficient φ values and the W_f and T_f functions are assumed not to vary with depth in the soil, soil texture, soil management, or residue mass. The same W_f and T_f functions are used to estimate decomposition of standing residue, but the RUSLE2 decomposition coefficient φ value for standing residue is assumed to be 0.3 of that for surface and buried residue because moisture available for decomposition of standing residue is assumed to be much less than moisture available for decomposition of surface and buried residue (Douglas et al., 1980; Ghidey and Alberts, 1993; Steiner et al., 1994).[60]

10.3.2. Calibration of equations

Values for the daily precipitation P_b in equation 10.5 where the moisture function $W_f = 1$ for daily precipitation values greater than P_b and values for the decomposition coefficient φ were determined by fitting the decomposition data to measured data. Values resulting from that fitting are given in Table 10.2.

The fitting of the decomposition equations to the field data were done using long term average values for monthly precipitation and temperature rather than values for the precipitation and temperature that the residue experienced in the field experiments. Using long term-averages in these computations had a smoothing effect. Also, RUSLE2 is designed to use average daily precipitation regardless of whether precipitation actually occurs on a particular day, and thus values determined for P_b and φ are a function of that mathematical structure. The data preference for calibrating the decomposition equations in RUSLE2 is to have sufficient years of data for a particular residue type and placement so that the data represents the range of climatic conditions expected at that site over a 10 to 30 year period. Unfortunately, most residue decomposition studies involve only a

---

[60] The 0.3 values may be too high. Unfortunately, almost no adequate quality data seems to be available that can be used to determine decomposition coefficient values for standing stubble.

Table 10.2. Values for P_b and φ determined by fitting decomposition equations to measured decomposition data

Location	Crop	Daily precipition above which W_f = 1 P_b (mm)	Decomposition coefficient φ (day^{-1})	Placement
Columbia, MO	corn	3.2	0.010	buried, in bags
W. Lafayette, IN	corn	4.4 assumed	0.016	surface, determined from surface samples removed from no-till plots, not in bags
Columbia, MO	soybeans	3.6	0.029	buried, in bags
Holly Springs, MS	soybeans	10.0	0.015	surface, estimated from measured portion of soil surface covered
Holly Springs, MS	soybeans	2.7	0.013	surface, estimated from measured portion of soil surface covered
W. Lafayette, IN	wheat	4.2	0.0064	surface, determined from surface samples removed from no-till plots, not in bags
Bushland, TX	wheat	3.7	0.0081	surface, in bags
Twin Falls, ID	wheat	1.8	0.012	buried, in bags
Twin Falls, ID	wheat	4.4 assumed	0.021	buried, in bags
Pullman, WA	wheat	0.5	0.0099	surface, determined from surface samples removed from no-till plots, not in bags
Pullman, WA	wheat	0.5	0.0098	same
Pullman, WA	wheat	0.5	0.0097	same
Pullman, WA	wheat	4.4 assumed	0.019	same
Pullman, WA	wheat	4.4 assumed	0.019	same
Pullman, WA	wheat	4.4 assumed	0.019	same

single year. Therefore, the approach used in calibrating the RUSLE2 decomposition variables was to calibrate using average annual inputs using as many acceptable data sets at as many locations for a particular residue type as were available. The resulting calibrated values for the base daily precipitation P_b and residue decomposition coefficient φ are shown in Table 10.2. Equation 10.1 was used to estimate observed residue mass at Holly Springs, MS using measured values for portion of the soil surface covered by residue because measured residue mass values were not available. RUSLE2 Core Database values were selected by inspection of the values in Table 10.2. Illustrations of RUSLE2 computed values for residue decomposition are shown in **Section 10.Appendix 1** using RUSLE2 Core Database values..

The calibration values listed in Table 10.2 were determined by fitting the RUSE2 decomposition equations to the loss of residue over time, except for the residue decomposition coefficient value for Eucalypt forest litter. The decomposition coefficient value for the Eucalypt litter was determined by fitting RUSLE2 to measured data where surface residue (litter) accumulated over time following forest fire in the Southwestern Eucalypt forest (Birk and Simpson, 1980). The results for the Eucalypt forest are shown in Figure 10.2. This application illustrates RUSLE2 capability for computing the

Table 10.2 (continued). Values for P_b and φ determined by fitting decomposition equations to measured decomposition data

Location	Crop	Daily precipition above which W_f = 1 P_b (mm)	Decomposition coefficient φ (day^{-1})	Placement
Bushland, TX	alfalfa	4.4 assumed	0.015	surface, in bags
Holly Springs, MS	cotton	10.0	0.029	surface, estimated from measured portion of soil surface covered
Holly Springs, MS	cotton	3.0	0.010	same
Holly Springs, MS	cotton	2.7	0.026	same
Holly Springs, MS	cotton	2.7	0.011	same
Holly Springs, MS	cotton	2.7	0.029	same
Holly Springs, MS	cotton	2.7	0.006	same
Holly Springs, MS	cotton	6.3	0.011	same
Holly Springs, MS	cotton	5.4	0.017	same
Holly Springs, MS	cotton	4.9	0.007	same
Holly Springs, MS	cotton	6.6	0.03	same
Holly Springs, MS	cotton	5.0	0.012	same
SW Australia	Eucalypt litter	4.4 assumed	0.002	surface, determined from samples

accumulation of a surface litter layer where the biomass input is produced by aboveground senescence and a similar below ground biomass pool produced by root growth and death (root senescence, turnover).

Values for the decomposition coefficient φ recommended for use in RUSLE2 based on interpretation of the results presented in Table 10.2 and review of the literature are given in Table 10.3. These values are included in the RUSLE2 Core Database.

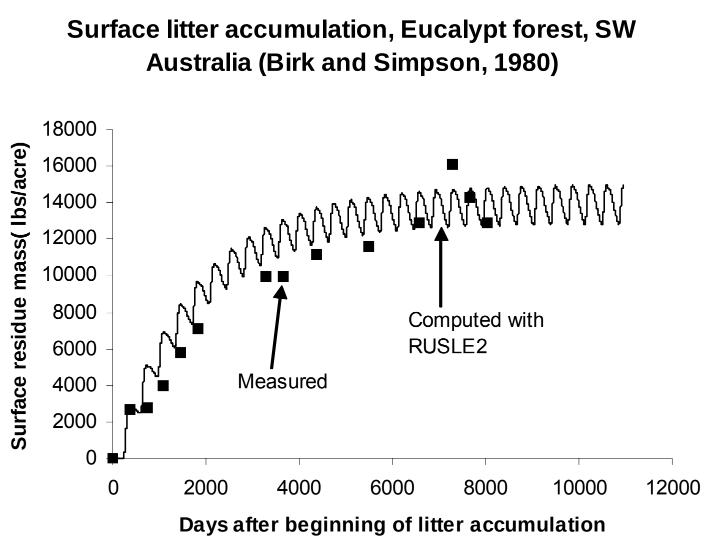


Figure 10.2. Computing the accumulation of a litter layer for an Eucalypt forest in Southwestern Australia.

10.3.3. Comments

RUSLE2's computations of ground (surface, flat) residue cover are scrutinized more intently than even the RUSLE2's computed erosion values. Surface residue cover is visible, easily measured,

Table 10.3. Recommended values for the decomposition coefficient φ in RUSLE2 with A = 8 oC and P_b = 4.4 mm based on fitting decomposition equations to measured data.

Crop	Decomposition Coefficient φ (day^{-1})
Alfalfa	0.015
Corn	0.016
Cotton	0.015
Sorghum	0.016
Wheat in Eastern US (soft white wheat)	0.008
Wheat in Northwest Wheat and Range Region (hard red wheat)	0.017

Note: If P_b = 0.5 mm, then φ = 0.01 day^{-1} for NWRR wheat

and is a major variable used in judging the adequacy of erosion control measures used on cropland. USDA-Natural resources Conservation Service (NRCS) standards and specifications for certain conservation practices require a minimum flat residue cover at planting (e.g., 30 percent). Therefore, the RUSLE2 decomposition procedures were carefully constructed to ensure that RUSLE2 computes appropriate surface residue cover values for conservation planning, as shown in Table 10.1. The RUSLE2 decomposition procedures were designed specifically for RUSLE2's use as a conservation planning tool, not for residue management and certainly not to advance residue decomposition science and modeling. The RUSLE2 intent is to capture main differences in loss of residue/dead roots between material types and locations in the context of estimating average annual erosion rates for comparison against a criteria such as the USDA-NRCS soil loss tolerance (T) values (Toy et al., 2002). For example, soybean residue decomposes more rapidly than does corn residue, and biomass decomposes much more rapidly in the southern US than in the northern US.

Decomposition data are highly varied, which required much judgment in the development of the RUSLE2 decomposition procedure and decomposition coefficient α values. The section describes the major judgments made in the development of the RUSLE2 decomposition procedure.

10.3.3.1. Residue characteristics

Residue produced by vegetation includes pieces having a wide range in geometry (e.g., fine and coarse roots; leaves and stems); multiple residue components (e.g. leaves, stems, seed pods, and chaff); variation in composition within stems/stalks (e.g., corn stalks having decomposition resistant outer shells and easily decomposed inside material); stems that decompose from the inside out without changing outside dimensions (e.g., wheat straw); temporal variation in properties that affect decomposition (e.g., tender young leaves that decompose much more rapidly than mature leaves); differences between above ground plant components and roots, and multiple species in plant communities (e.g., multiple plant species on rangeland and weeds on neglected pasture lands and landfills). RUSLE2 uses a single mass-cover coefficient (α) and decomposition coefficient (φ) to represent residue even though residue is composed of multiple components and pieces, each having their own α and φ values.

RUSLE2 decomposition coefficient φ values vary temporally because they are a function of the relative composition of residue component and pieces that decompose at different rates, which changes the relative composition of residue through time. Thus, the RUSLE2 decomposition coefficient values are a compromise. Consequently, RUSLE2 tends to compute residue mass values at times beyond one year that are less than measured values as illustrated in Figure 10.3. Priority was given to fitting RUSLE2 computed decomposition values within the first year after residue application. Thus, RUSLE2 most accurately estimates decomposition of the easily and rapidly decomposable portions of the residue. Most RUSLE2 applications involve a substantial annual input of biomass from crop production or senescence by permanent vegetation, which minimizes the impact of the errors in RUSLE2 decomposition estimates beyond one year after residue application.

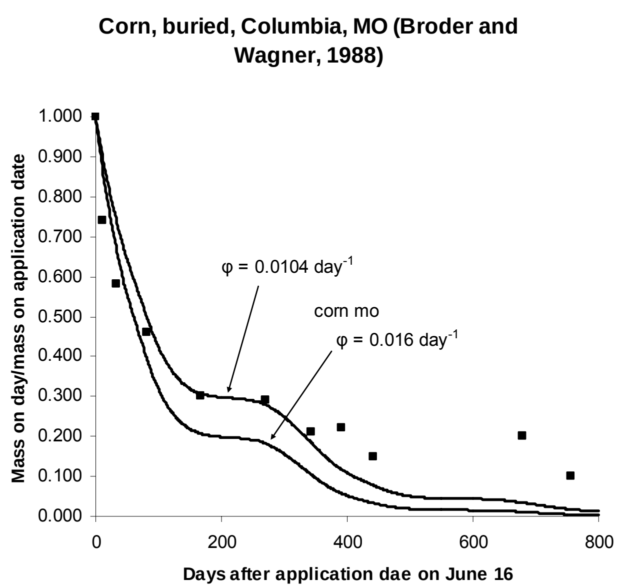


Figure 10.3. RUSLE2's estimate of residue decomposition over a 2-year period.

RUSLE2 assumes that both above ground (residue) and below ground (dead roots) plant parts decompose at the same rate and that surface residue and buried biomass decompose at the same rate. The fact different decomposition rates of surface and buried residue have been measured is recognized, which is illustrated in Figure 10.4. Differences such as the ones shown in Figure 10.4 may primarily result from measurement techniques than actual differences in decomposition. As Parker (1962) noted, a distinct boundary between surface residue and the soil surface and does not exist in many cropland situations. For example, only a portion of residue pieces are exposed in conventional and mulch-till forms of cropping systems where tillage buried a portion of the residue left from last year's harvest. Soil splash by raindrop impact and local deposition behind residue pieces bonds the residue to the soil (Brenneman and Laflen, 1982; Toy et al., 2002). Also, the

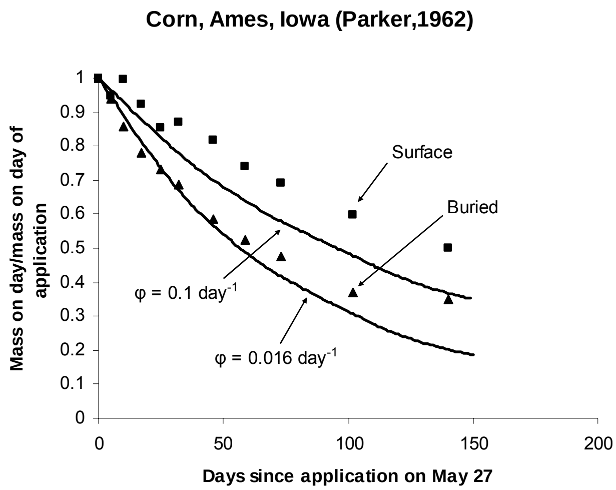


Figure 10.4. Difference in decomposition of residue in bags buried in the soil and placed on the soil surface.

boundary between residue and the soil is not distinct in long-term no-till cropping systems. Many studies (e.g., Parker, 1962; Schomberg et al., 1994) measure residue decomposition by placing bags of residue on the soil surface and burying them in the soil. The contact between residue and soil and supply of moisture to the residue, especially for the residue bags placed on the soil surface, does not seem to be comparable to that in actual fields. The significant difference in reported decomposition rates among research studies seems related to measurement technique (see **Section 10.3.3.2**).

The roots most important in RUSLE2 are the fine roots. A reasonable assumption is that the decomposition of fine roots is similar to buried residue.

Even if roots, buried residue, and surface residue decompose at different rates, the differences do not have great impact on RUSLE2 computed erosion values because RUSLE2 computed values for surface cover, surface and buried residue biomass, and root biomass were used to calibrate RUSLE2, especially the soil biomass subfactor (see **Section 6.5**), instead of measured values. Consequently, if the RUSLE2 equations and related coefficient values used to compute residue and root biomass are changed, RUSLE2's equations that relate erosion to biomass must be recalibrated. RUSLE2 was calibrated to give expected erosion values, and if a biomass change is made, for example, without recalibrating RUSLE2 with the new biomass values, the new RUSLE2 erosion values computed with the new biomass values may be erroneous.

The original RUSLE2 plan was to describe residue by its component parts. Using multiple residue description for each residue component would significantly improve RUSLE2's computations residue of decomposition and surface residue cover as a function of residue mass. Insufficient data exist for determining decomposition coefficient values for each plant residue component for the vast array of vegetations involved in RUSLE2 applications as a land use independent model.

Should future RUSLE2 developers determine that sufficient separate decomposition coefficient φ values are available for surface and buried residue and for roots, the RUSLE2 equations and computer code can be easily modified to use these separate decomposition coefficient values. RUSLE2 already uses a different decomposition coefficient value for standing residue than for surface and buried residue. Also, the capability of using multiple residue components can also be easily added to RUSLE2, which would significantly improve RUSLE2's accuracy when computing residue decomposition beyond 1 year after residue application.

Even if decomposition varies between surface and buried residue and between residue and roots, sufficient data are not available to reliably determine the required decomposition coefficient φ values for each placement of residue and for roots.

10.3.3.2. Differences in measured decomposition between studies reported in the literature

Measured decomposition differs greatly among published research studies, even after differences caused by location are considered. The illustrations in **Section 10.Appendix 1** show that RUSLE2 computed decomposition fits very well the measured data used to calibrate RUSLE2 and determine decomposition coefficient φ values. The differences between the fit to the measured values used to calibrate RUSLE2 and other measured values in Figure 10.5 represent differences in data between research studies.

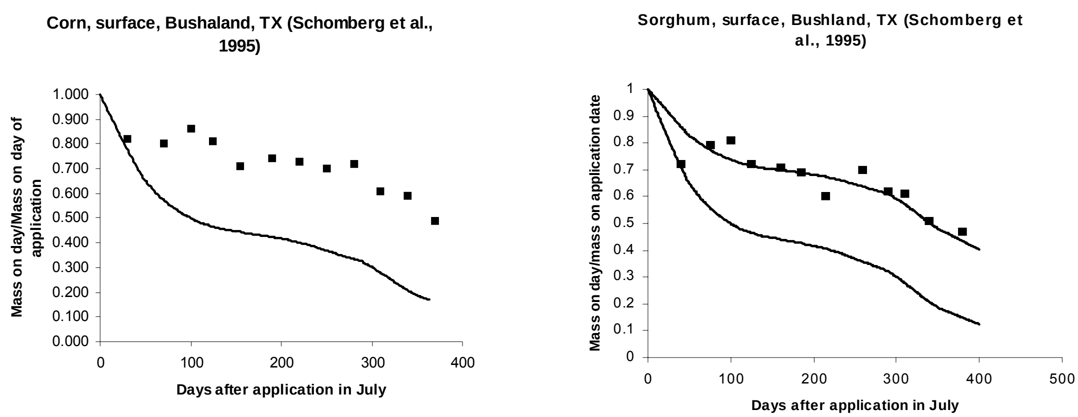


Figure 10.5. Comparison of decomposition of corn and sorghum at Bushland, Texas with RUSLE2 computed values using $\varphi = 0.016\ day^{-1}$ that fit decomposition data for corn at W. Lafayette, IN. $\varphi = 0.01\ day^{-1}$ fits the Bushland data.

Decomposition at Bushland, TX, illustrated in Figure 10.5, was measured using bags of residue placed on the soil surface while decomposition at W. Lafayette, IN was measured by taking residue samples of the residue as left after harvest. When decomposition was measured by sampling from the soil surface (Stenier et al., 1999), decomposition at Bushland, TX seemed to be consistent with data collected at W. Lafayette, IN. Each measurement technique has short comings. The sampling method used by Stott (1995) is considered superior to the bag method for RUSLE2 purposes. Similarly, the decomposition values determined from residue cover measurements measured at Holly

Springs, MS for cotton and soybeans is considered much superior to decomposition values determined by the bag method.

The Stott (1995) data were used to determine a decomposition coefficient φ value for corn. Similar measurements were not made for grain sorghum, but the decomposition coefficient value determined for corn is assumed in RUSLE2 to apply to grain sorghum based on the similarity in decomposition of corn and sorghum residue measured at Bushland by the bag method. That is, while the absolute decomposition values determined by the bag method are not considered acceptable for RUSLE2, the bag method is assumed to be useful for determining relative differences in decomposition in residue types.

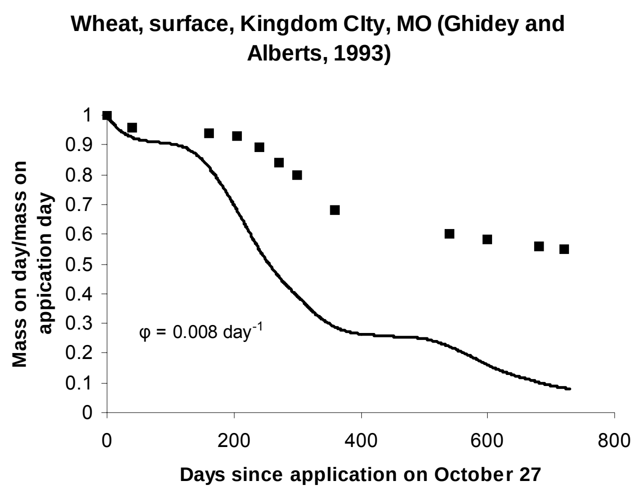


Figure 10.6. Difference in decomposition between that measured by Ghidey and Alberts (1993) and other data considered better for RUSLE2.

The Ghidey and Alberts (1993) dataset includes decomposition values for roots and buried, surface, and above surface residue. These data differ significantly from data considered best for RUSLE2 as illustrated in Figure 10.6. Using bags to measure residue decomposition and oven drying the residue at 65 oC for 24 hours before placing the residue in the field contributed to the differences illustrated in Figure 10.6.

Scientists differ in their opinion regarding the best measuring techniques and the best data for evaluating decomposition procedures in RUSLE2 and other erosion models (see **Section 10.3.3.4**). The criteria for conservation and erosion control planning is that RUSLE2 give reasonable estimates of average annual erosion and surface cover at planting, which RUSLE2 has been demonstrated to do (see **RUSLE2 User's Reference Guide**). Similar criteria are used for using RUSLE2 in erosion control planning for highly disturbed land for example.

10.3.3.3. Effect of loading (application) rate

Just as Steiner et al. (1999) found and Figure 10.7 illustrates, the decomposition coefficient φ is a function of residue mass initially added to the soil surface. If initial surface residue mass affects the decomposition coefficient, the decomposition coefficient must also be a function of surface residue mass at any time after the residue is added to the soils surface. Therefore, the basic structure of RUSLE2's decomposition equations (as well as similar equations in other erosion models) should be changed to reflect a

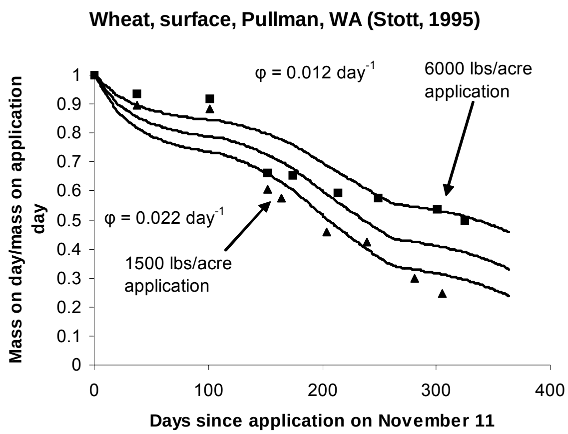


Figure 10.7. Affect of residue application rate on the decomposition coefficient φ.

temporally varying decomposition coefficient. The observed effect of initial residue mass on the decomposition function actually reflects the different decomposition rates among residue components, such as leaves, stems, and seed pods, and the different sized residue pieces. RUSLE2 assumes a composite residue where a single decomposition coefficient represents decomposition of the entire residue mass. The best way to deal with the initial mass effect on the residue decomposition coefficient reported by Steiner et al. (1999) is to represent individual residue components.

Certainly a case can be made that decomposition rate with the residue layer varies with height above the soil surface in the residue layer. Such an effect would cause the decomposition coefficient to be both a function of initial application residue rate and residue mass through time. The more important reason for the variation in the decomposition coefficient as a function of residue application rate is residue composition.

The RUSLE2decomposition coefficient φ is not varied by an internal function of residue application rate. Users can vary the decomposition coefficient in RUSLE2 by creating multiple residue descriptions, each having a different residue decomposition coefficient value, for a given residue type. The user selects the residue description that has the decomposition coefficient value considered appropriate for the residue application rate. Such an approach is not recommended for most conservation and erosion control planning RUSLE2 applications, however. The factors that affect residue decomposition have been sufficiently well determined by research to vary decomposition coefficient values, even for the major agricultural crops without considering the wide array of vegetations encountered in RUSLE2 applications. For

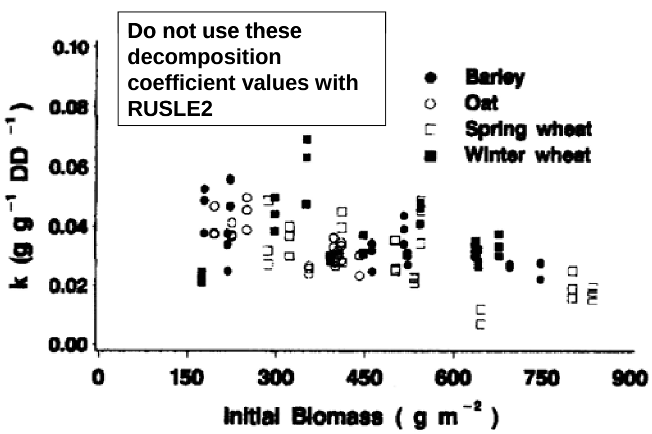


Figure 10.8. Variation of decomposition coefficient values from another decomposition model with residue application rate. (Source: Steiner et al., 1999)

example, how does residue application rate affect decomposition of wheat straw mulch blown onto a construction site in comparison to wheat straw left in a no-till crop field? Does residue application rate affect decomposition differently for conventional tillage than for mulch-tillage or no-tillage? Does residue application rate affect decomposition differently when the residue is corn, wheat, hay, litter on rangelands, or Eucalypt forest litter? Much additional empirical data along with improved representation of residue components and improved decomposition model structure are needed before the RUSLE2 decomposition coefficient is an internal function of residue application rate.

The variability in decomposition data, like that illustrated in Figure 10.8 must be significantly reduced. The overall trend in those data is that the decomposition coefficient decreases with increases in the residue application rate. However, decomposition coefficient values for winter wheat increase between 170 g/m^2 and 360 g/m^2 application rates rather than decrease. The range in decomposition coefficient values over these residue application rates is greater than the difference from low to high decomposition coefficient values for the overall trend. Evaluating the adequacy of a decomposition model or comparing decomposition models, like the attempt by Schomberg and Steiner, (1997) will be impossible until a database is developed that all residue modelers accept as the basis for calibrating and evaluating residue decomposition models. In contrast to Steiner et al.'s (1999) opinions, other decomposition modeling advancements are much more important than making the RUSLE2 decomposition coefficient a function of residue application rate.

10.3.3.3. Effect of irrigation on residue decomposition

RUSLE2 does not compute erosion directly caused by irrigation. However, RUSLE2 does compute rill-interrill erosion as affected by irrigation increasing vegetation production (crop yield), soil erodibility, and decomposition. RUSLE2's accuracy for estimating increased decomposition caused by irrigation was assessed using data from Schomberg et al. (1994). From 5 mm to 336 mm of irrigation water was added during the study year, which was comparable to 305 mm of natural precipitation. The average annual precipitation at Bushland, TX is approximately 480 mm.

Figure 10.9 shows measured and RUSLE2's computed values for decomposition of surface alfalfa residue and buried grain sorghum residue as a function of observed precipitation and water applied by sprinkler irrigation (Schomberg et al., 1994). The middle curves in Figure 10.9 show decomposition computed with RUSLE2 using long term average values for precipitation and temperature and the RUSLE2 Core Database value for the decomposition coefficient φ determined using long-term averages for precipitation and temperature rather than measured values (see **Section 10.3.2**).

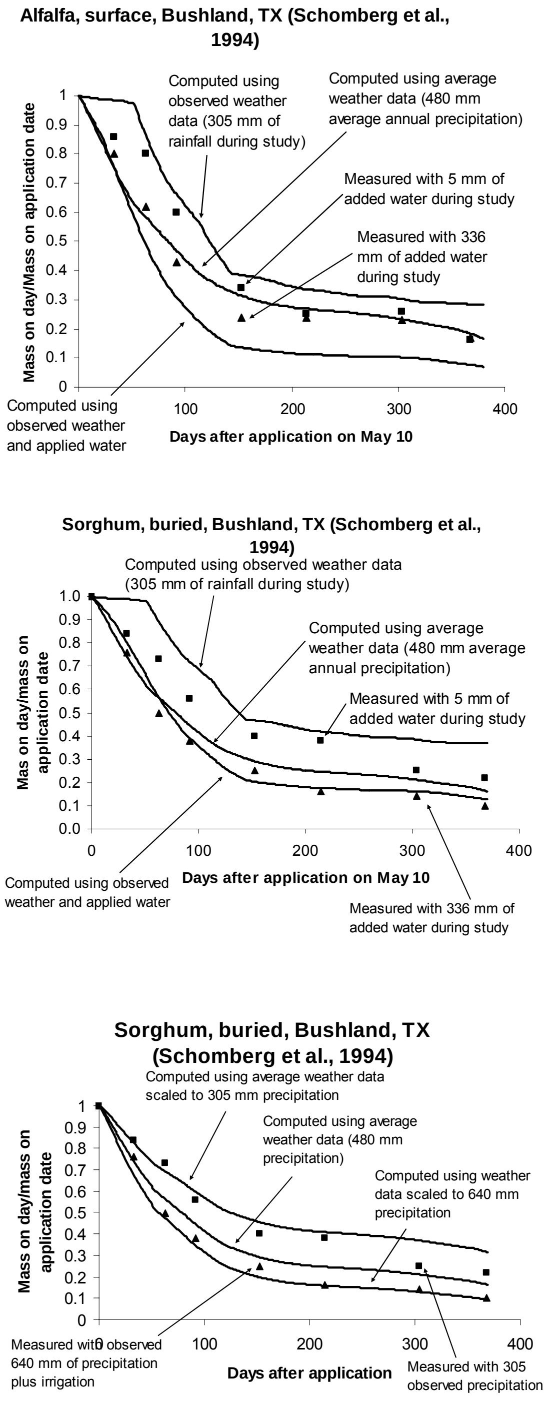


Figure 10.9. Effect of irrigation on decomposition of alfalfa and sorghum residue and alternate ways of computing decomposition with RUSLE2 for irrigation

The measured effect of irrigation-applied water on decomposition was much less for the alfalfa residue than for sorghum and wheat residue in the Schomberg et al. (1994) study. In another study (Schomberg and Steiner, 1995), alfalfa residue decomposed with irrigation similar to sorghum and wheat residue, which emphasizes the variability in residue data and why multiple data sources should be considered when selecting decomposition and other coefficient values for residue.

Based on the results shown in Figure 10.9, RUSLE2 accurately computes residue decomposition as affected by irrigation in combination with natural precipitation using long term average weather data values and irrigation water that is assumed to be applied smoothly over the growing season or over the year as in the Schomberg et al. (1994) study. RUSLE2 does not compute decomposition well using observed weather data, especially with the irregular timing of precipitation in low rainfall areas like Bushland, TX.

These results confirm the importance of using long term weather data to calibrate RUSLE2's decomposition equations and to determine decomposition coefficient values rather than using observed data (see **Section 10.3.2**). These results also show that decomposition of both surface and buried residue is a dampened process that does not react quickly to changes or irregularities in precipitation or temperature. Surface residue apparently continues to decompose longer after a water-application event that seems to have been assumed in some decomposition models (Schomberg and Steiner, 1997).

An important question is whether residue decomposes the same per unit water added by irrigation as it does by unit water added by natural rainfall. Decomposition may be less per unit water applied by sprinkler irrigation than applied by natural rainfall. Water droplets in the irrigation-applied water have very low impact energy in comparison to natural rainfall. Thus, natural rainfall splashes many more soil particles that increase the contact between the soil and the residue (Foster et al., 1985) than does sprinkler irrigation applied water. Irrigation-applied water may also wash away soil particles previously bonded to the residue by rainfall. Also, deposition of sediment produced interrill-rill erosion (Brenneman and Laflen,1982) increases soil bonding between residue and soil that does not occur with irrigation-applied water at low residue application rates.

The judgment is that RUSLE2 satisfactorily estimates the effect of sprinkler irrigation-applied water when long term average input values are used. In addition to results in comparing RUSLE2 estimates with measured values in the Schomberg et al. (1994) study, this conclusion is also supported by RUSLE2 computed decomposition values comparing well with measured data from locations having widely different precipitation (e.g., Griffin, GA and Bushland, TX as illustrated in **Section 10.Appendix 1**).

10.3.3.3. Special considerations for the NWRR and Req zones

The climate in the Northwest Wheat and Range Region (NWRR), which is within the larger Req zone (see **RUSLE2 User's Reference Guide**), differs significantly from the climate in non-Req areas. An example is the relationship for monthly precipitation amount to number of precipitation events (see Figure 10.11). Consequently, should the decomposition equations and coefficient values differ for the NWRR and the entire Req zone from those for other regions? To evaluate this possibility, the base moisture P_b value in the moisture function (W_f, equation 10.5) was determined by fitting the decomposition equations specifically to decomposition data collected at Pullman, WA. A P_b value of 0.54 mm produced improvement for some data sets as illustrated in Figure 10.10, but not for all data sets. When 0.5 mm is used for P_b in equation10.5, RUSLE2 computes decomposition being controlled throughout the entire year by the temperature function (T_f, equation 10.6) at Pullman, WA. When P_b = 4.4 mm, RUSLE2 computes that decomposition is controlled by the moisture function from May through October. Computing that decomposition is controlled by moisture when average monthly precipitation is as low as 0.45 inches (11 mm) in July and 0.64 inches (16 mm) in August seems more appropriate

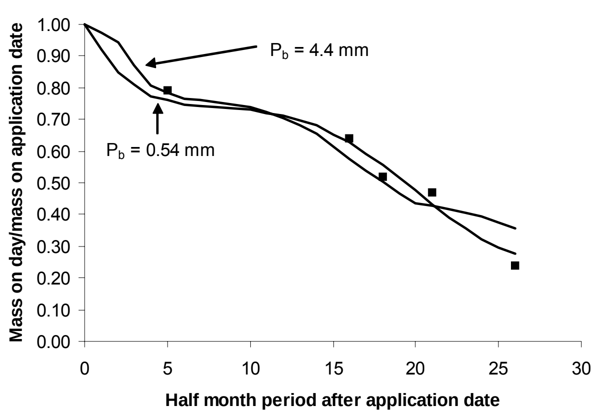


Figure 10.10. Effect of changing the base daily precipitation P_b value in the moisture function used to compute residue decomposition.

than the temperature function controlling during these dry months.

Decomposition coefficient φ values determined for wheat using P_b = 0.54 mm are essentially the same as decomposition coefficient values determined for wheat in other reasons using P_b = 4.4 mm. Consequently, the difference in decomposition coefficient values in Table 10.1 between the NWRR and other regions may not be related to wheat varieties as assumed, but related to having an appropriate description of the moisture function W_f for the NWRR.

The recommendation is that 4.4 mm be used for P_b for the NWRR and Req zone along with the decomposition coefficient values given in Table 10.2 until additional research is conducted. This additional decomposition research for the Req zone, including the NWRR, can be conducted simultaneously with additional research needed on other RUSLE2 Req relationships throughout the Req zone, especially for locations outside of the central Washington to northern Idaho and Northeastern Oregon region.

10.3.3.4. Comparison of RUSLE2 and RWEQ decomposition estimates

The RWEQ wind erosion and RUSLE2 water erosion prediction technologies use comparable structures and both were originally intended for the same purpose of guiding conservation planning in the USDA-Natural Resources Conservation Service (NRCS) field offices. The decomposition components in RUSLE2 and RWEQ are similar but have important differences. During the development of RUSLE2, the USDA-NRCS placed a high priority on RUSLE2 and RWEQ and later RUSLE2 and WEPS computing comparable residue cover estimates. Although USDA clients may not know the expected residue cover values that these models should compute, these clients readily recognize differences in values computed by the models and question differences when none should exist. Such differences cause the creditability of the models, the conservation planning to suffer greatly. Although the NRCS adopted WEPS rather than RWEQ for field office conservation planning, the differences between residue cover values computed by RUSLE2 and WEPS remains an important concern.

10.3.3.4.1. Structure

To study the differences caused by decomposition model structure, decomposition was computed with the RUSLE2 and RWEQ decomposition equations where the initial residue mass on October 15was the same for both models. The RWEQ decomposition coefficient was adjusted until both RUSLE2 and RWEQ computed the same residue mass on May 15, which represents residue cover immediately after corn planting. Residue cover immediately after planting is used in conservation planning and in compliance checking of conservation plans by NRCS field office personnel. Therefore, each model should give the same residue cover value at planting.

The results are shown in **Section 10.Appendix 2**. The computations for Tucson, AZ differed from the other locations. Both models start with the same residue mass on January 1. The RWEQ decomposition coefficient value was adjusted so that RUSLE2 and RWEQ computes the same residue value on July 1, which is the start of the rainy season. The locations represented in **Section 10.Appendix 2** correspond with locations where decomposition data were collected that were used in the calibration and evaluation of RUSLE2, except for the Tucson, AZ location. The Spokane, WA location was used rather than Pullman, WA because climate data for Pullman, WA were not in the RWEQ database.

The figures in **Section 10.Appendix 2** illustrate that RUSLE2 computes more decomposition during the winter months and less decomposition during the summer months than does RWEQ. This difference is caused by RUSLE2 using the minimum of its moisture and temperature functions (equation 10.4) rather than multiplying them as does RWEQ (Schomberg and Steiner, 1997). Both WEPS (Steiner et al., 1995) and WEPS (Stott et al., 1995) use the minimum function like RUSLE2.

Using the minimum of the moisture and temperature functions as in RUSLE gives results that are judged to be qualitatively better that produced by multiplying the moisture and temperature functions as in RWEQ. The RUSLE2 form is judged to better fit the decomposition data illustrated in Section 10.Appendix 1 that does the RWEQ form, especially at Spokane (Pullman), WA. Although RUSLE2 was not fitted to decomposition data for Tucson, AZ, the RUSLE2 form is judged to be better for Tucson, AZ than the RWEQ form. The Gregory et al. (1985) decomposition model was originally used in RUSLE2, but it was replaced with a modification of the WEPP decomposition model (Stott, 1991; Stott et al., 1995) because the Gregory et al. model was also judged to compute too little decomposition in the winter months and too much in the summer months. Furthermore, RUSLE2 using the minimum of the moisture and temperature functions provides commonality with the WEPS model that is used by the USDA-NRCS in its field offices.

10.3.3.4.2. Moisture function

The RUSLE2 and RWEQ moisture functions differ. RUSLE2 uses a moisture function that increases linearly to a maximum of 1 when long-term average daily precipitation equals or exceeds 4.4 mm. The RWEQ moisture function varies linearly with the ratio of number of precipitation events in a period to the number of days in the period. The Schomberg and Steiner (1997) justification for using number of precipitation events is that surface residue does not remain moist long after a precipitation event, which conceptually implies that residue moisture content following a precipitation event is independent of the event's precipitation amount, which seems questionable. The moisture retained by residue depends greatly on residue type and mass. This assumption also seems questionable during fall and spring periods when evaporation is reduced but the moisture function is limiting in equation 10.4. Also, the assumptions seems questionable for mulch-till and no-till cropping systems where the soil-residue interface is not well defined and surface residue pieces are partially covered by soil.

Number of precipitations events in a given period actually serves as a surrogate for precipitation amount as illustrated in Figure 10.11, which shows that precipitation amount is highly correlated with number of precipitation events in a period. Therefore, using number of precipitation events in RUSLE2 that uses long term monthly averages provides no fundamental improvement in RUSLE2's decomposition estimates.

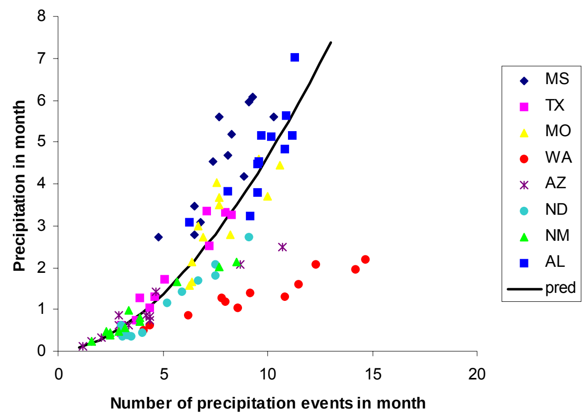


Figure 10.11. Relation of average monthly precipitation to number of precipitation events in a month.

A problem with using number of precipitation events as a RUSLE2 input is spatial variability as evidenced significant differences in number of precipitation events in the RWEQ database for Minneapolis, MN and for St. Cloud, MN, which are only about 75 miles apart. Long term average monthly precipitation amount is spatially more stable than number of precipitation events. Data on number of precipitation events are much less available than long term monthly precipitation values, such as those that were easily found and used to compute decomposition in SW Australia (see Figure 10.2) and Canada (see **Section 10.Appendix 1**).

The residue moisture content that determines decomposition apparently does not vary as greatly as might be assumed. Also, dew may provide a significant moisture source, even on very hot days (Heilman et al;, 1992)). Decomposition of surface residue does not seem to vary temporally as much as expected, which is perhaps the reason that very good fits are obtained when the RUSLE decomposition equations using long-term average monthly precipitation and temperature values are fitted to measured decomposition for a particular year.

Given RUSLE2's satisfactory performance in computing decomposition as illustrated in **Section 10.Appendix 1**, the fact that RWEQ's moisture function is closely related to precipitation amount, and the practical advantage of long-term monthly precipitation, RUSLE2's moisture function is judged superior to RWEQ's moisture function, especially for computing decomposition of buried residue and roots, which is not done in RWEQ.

10.3.3.4.3. Temperature function

RUSLE2's and RWEQ's temperature functions use the same basic equation. RUSLE2 computes an average daily value for its temperature function using the long-term average daily temperature. RWEQ computes a temperature function value each for the daily maximum and minimum temperatures and averages the resulting temperature function values to obtain a daily temperature function value. To compensate for using long-term average daily temperature in RUSLE2, the value for A in equation 10.6 was chosen so that RUSLE2 computes decomposition for a long term average daily temperature as low as -10 oC. The RWEQ approach is superior at high temperatures. An adjustment is needed to flatten the RUSLE2 temperature function around the optimum temperature, T_o in equation 10.6. The best approach would be to replace the RUSLE2 temperature function as described by Schomberg et al. (2002).

The end result is that the RUSLE2 computed temperature function values at high temperatures were not a significant factor in the **Section 10.Appendix 2**examples. In each example, the moisture function was limiting rather than the temperature function when temperatures were high. At low temperatures, the temperature function was limiting, where RUSLE2's temperature function is judged adequate. Schomberg et al. (2002) found no improvement in the fit of RUSLE2 computed decomposition to measured data with their improved temperature function. However, their new temperature required a decomposition coefficient φ value of 0.0048 day^{-1} in comparison to 0.0041 day^{-1} for the temperature function described by equation 10.6. The important result is that decomposition coefficient values are highly model and moisture and temperature function dependent as illustrated in this example and illustrated in **Section 10.3.3.3**.

A decomposition equation developed for another model or another moisture function or temperature function can not be used in RUSLE2.

10.3.3.4.4. Calibration

Differences between the data sets used to calibrate RUSLE2 and RWEQ accounts for all of the differences reported by Schomberg and Steiner (1997) between decomposition values computed by RUSLE2 and RWEQ. As Schomberg and Steiner (1997) show, both RUSLE2 and RWEQ give similar results when fitted to the same data. The data sets used to calibrate RWEQ and RUSLE2 were very different (see **Section 10.3.2**). Had the same data sets been used to calibrate both models, RUSLE2 and RWEQ would have given similar results, except for the structural difference in RUSLE2 using a minimum of the moisture and temperature functions and RWEQ multiplying those functions (see Section **10.3.3.4.1)**. The variability within most residue decomposition data sets often prevents showing that one model is statistically better than another model.

If the priority that RUSLE2 and WEPS give similar residue cover estimates is still an important objective, decomposition data must be identified that best represents field conditions that would be used to calibrate both RUSLE2 and WEPS.

10.3.3.5. Summary comments on decomposition computations

The RUSLE2 decomposition equations use simple inputs so that RUSLE2 is convenient for use in conservation and erosion control planning. The purpose is not to accurately model residue decomposition processes in a research context. RUSLE2 users must be aware of RUSLE2 procedure and how to select RUSLE2 inputs to best represent residue for the particular application. Input values described in the RUSE2 User's Reference Guide and in the RUSLE2 core database were chosen to ensure that RUSLE2 is adequate for conservation and erosion control planning. RUSLE2 is a complex procedure that involves many mathematical relationships with numerous interactions. Input values must be carefully selected to avoid RUSLE2 computing erroneous erosion values when adjusting RUSLE2 inputs to obtain a desired value for a particular variable such as the portion of the soil surface covered by residue. Avoid changing a single variable such as the decomposition coefficient so that RUSLE2 computes an expected surface residue cover immediately before harvest.

Although not often convenient for conservation and erosion control planning, multiple residue descriptions can be used in RUSLE2 to compute how temporal variations in residue properties and residue components decomposing at differing rates affect RUSLE2 erosion estimates. Such analyses can be used to evaluate uncertainty in RUSLE2 erosion estimates. This procedure is described in **Sections 9.2.3.2 and 10.2** the RUSLE2 User's Reference Guide.

The RUSLE2 User's Reference Guide describes steps that should be observed in adjusting RUSLE2 input related to values computed for portion of the soil surface covered by residue.

10.4. Standing residue

10.4.1. Decomposition

Certain operations convert live vegetation to standing residue. A portion of the standing residue is assumed to fall each day and become surface residue. Also, standing residue decomposes daily. This decomposition is computed using equations 10.3-10.6 but with a decomposition coefficient that is 0.3 of that used to compute decomposition of surface residue because reduced moisture is assumed to be available for decomposition of standing residue.

RUSLE2 computes the decomposition of a unit stem mass assumed to represent the decomposition at the base of stems of standing residue using equations 10.3-10.6 and the same decomposition coefficient value used to compute decomposition of surface residue. That is, decomposition at the stem base is assumed to occur at the same rate as decomposition of surface residue.

The portion of the standing residue mass that remains standing over time is assumed to be related to the portion of the unit stem base mass that remains over time. The RUSLE2 equation for this relationship is:

$$\gamma_t = -2.62\gamma_s^3 + 4.57\gamma_s^2 - 0.95\gamma_s \quad [10.8]$$

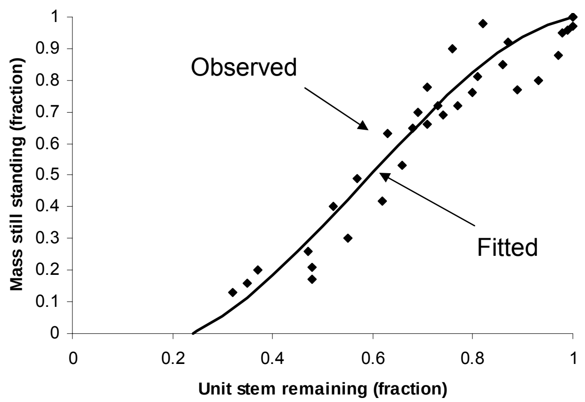


Figure 10.2. Relation of standing residue mass to computed unit stem base mass.

where: γ_t = portion (fraction) of standing residue mass that remains and γ_s = portion (fraction) of the unit stem base mass that remains. Equation 10.8 was derived by fitting to measured wheat data collected in Texas, Oregon, and North Dakota as illustrated in Figure 10.2 (Steiner et al., 1994).

10.4.2. Canopy cover-mass relationship

During the live period for a vegetation description, canopy cover is the known variable, which is used to estimate temporal values for live above ground biomass. Once live above ground biomass is transferred to standing residue, the known variable is standing residue mass computed with equation 10.8 and the standing live above ground biomass converted to standing residue on the conversion date.

RUSLE2 canopy cover for standing residue using:

$$f_t = \mu B_t^{1/1.5} \quad [10.9]$$

where: f_t = canopy cover provided by the standing residue and B_t = the standing residue biomass. A value for the coefficient μ is determined from:

$$\mu = f_{t,o} / B_{t,o}^{1/1.5} \quad [10.10]$$

where: $f_{t,o}$ and $B_{t,o}$ = canopy cover and biomass, respectively, when the standing residue is created.

10.4.3. Manning's n, effective vegetation ridge height, and effective fall height

Values for the Manning's n and effective ridge height for standing residue are computed from:

$$n_{t,i} = n_{t,o}(B_{t,i} / B_{t,o}) \quad [10.11]$$

$$h_{t,i} = h_{t,o}(B_{t,i} / B_{t,o}) \quad [10.12]$$

where: $n_{t,i}$ = the standing residue Manning's n on the *ith* day, $n_{t,o}$ = the live vegetation Manning's n on the day that the standing residue was created, $B_{t,i}$ = standing residue mass on the *ith* day, $B_{t,o}$ = standing residue mass on the day the standing residue was created, $h_{t,i}$ = effective standing residue ridge height on the *ith* day, and $h_{t,o}$ = effective ridge height of the live vegetation on the day that the standing residue was created. The effective ridge height for standing residue is computed from:

$$h_{f,i} = h_{f,o}(f_{t,i} / f_{t,o}) \qquad [10.13]$$

where: $h_{f,i}$ = the effective fall height on the *ith* day, $h_{f,o}$ = the effective fall height for the vegetation on the day that the standing residue was created, $f_{t,i}$ = canopy cover on the *ith* day, and $f_{t,o}$ = the canopy cover of the vegetation on the day that the standing residue was created.

While RUSLE2 uses a single vegetation description on any given day, RUSLE2 tracks multiple standing residue descriptions. RUSLE2 assumes that the Manning's n for standing residue and that the effective ridge height for each standing residue description are the respective sums of the values for each standing residue description. The net effective fall height is weighted by the canopy cover for each standing residue description. These values are independent of corresponding values for live vegetation.

This approach for representing a composite of vegetation and multiple standing residues description should involve interactions similar to those assumed for overlapping ground cover. However, the RUSLE2 procedure is judged to be satisfactory for conservation and erosion control planning. Only a few residue descriptions are used in most cover-management descriptions and most standing residue is removed by tillage or other operations.

List of symbols

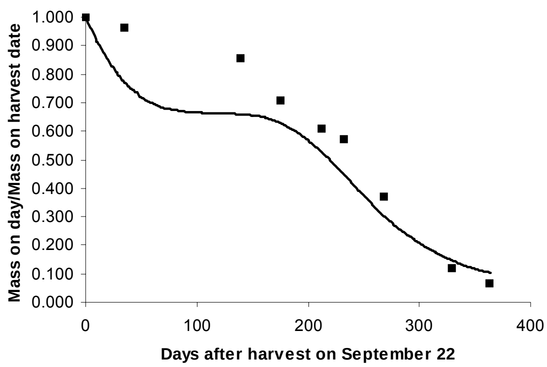
A = a reference temperature in temperature function used to compute decomposition (8 oC)
B_i = mass (dry basis) in a particular residue/dead root pool after decomposition on *ith* day
B_s = surface residue mass (dry mass/area)
B_t = standing residue biomass (dry basis) (mass/area)
$B_{t,o}$ = standing residue biomass (dry basis) on day when standing residue is created (mass/area)
D = number of days in period over which decomposition is being computed
$D_{1/2}$ = residue half life (time)
f_{gc} = portion of soil surface covered by a particular residue type as represented by a particular residue description when no other residue type is present
$f_{gc,m}$ = ground cover for crop residue or mulch assuming no other material is present (portion of soil surface covered)
$f_{gc,n}$ = net ground cover (portion of soil surface covered)
$f_{gc,r}$ = ground cover provided by the rock surface residue cover assuming no other material is present (portion of soil surface covered)
f_t = canopy cover provided by the standing residue (portion of soil surface covered)
$f_{t,o}$ = canopy cover provided by standing residue on day that standing residue is created (portion of soil surface covered)
$h_{f,i}$ = effective fall height of standing residue on the *ith* day (length)
$h_{f,o}$ = effective fall height for the vegetation on day that the standing residue was created (length)
$h_{t,i}$ = effective standing residue ridge height on *ith* day (length)
$h_{t,o}$ = effective ridge height of live vegetation on day that the standing residue was created (length)
$n_{t,i}$ = standing residue Manning's n on *ith* day
$n_{t,o}$ = live vegetation Manning's n on day that the standing residue was created
P_b = base daily precipitation (4.4 mm) in moisture function used to compute decomposition (length)
P_i = daily precipitation (length)
T = daily air temperature (oC)
T_f = temperature function used to compute decomposition
T_o = optimum temperature for decomposition (32 oC)
W_f = moisture function used to compute decomposition

γ_s = portion of the unit stem base mass (dry basis) that remains
γ_t = portion of standing residue mass (dry basis) that remains
μ = coefficient in equation used to compute canopy cover from standing biomass
φ = decomposition coefficient that is a function of biomass type ($time^{-1}$)

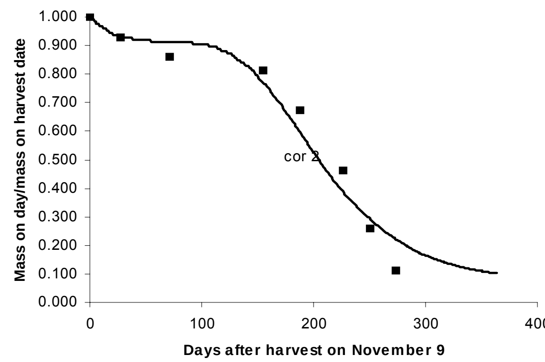
Indices
i - day

Section 10.Appendix 1. Illustrations of RUSLE2 decomposition estimates with measured field data.

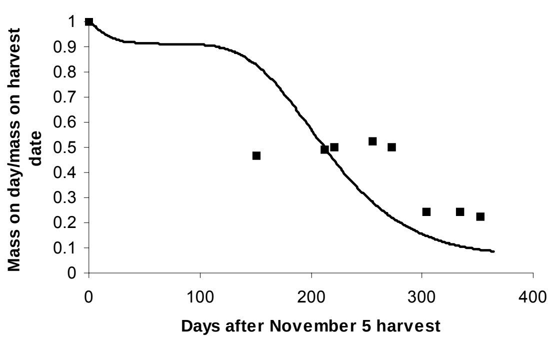
Corn, surface,after conventional tillage, W. Lafayette, IN (Stott, 1995)



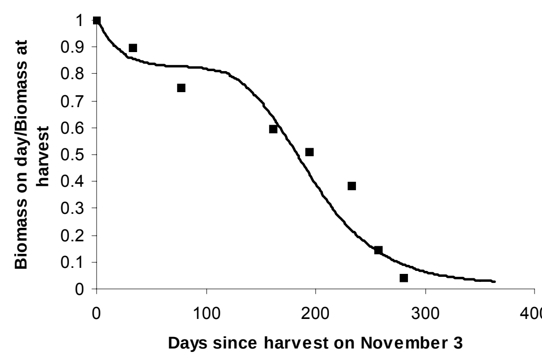
Corn, surface, after 1st yr no-till, W. Lafayette, IN (Stott, 1995)



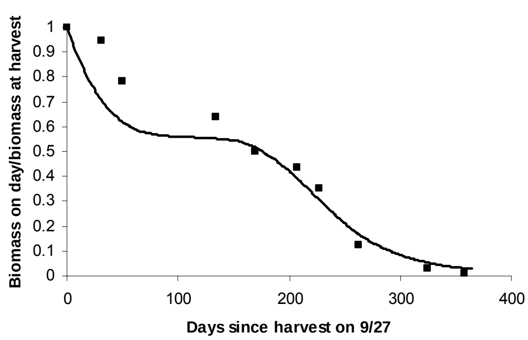
Corn, surface and buried, after till plant, Treynor, IA (Alberts and Schrader, 1980)



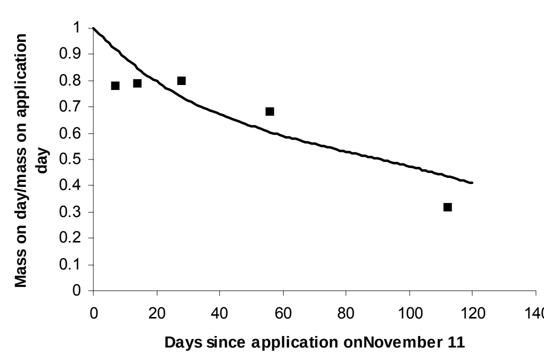
Soybeans, surface, W. Lafayette, IN (Stott, 1995)



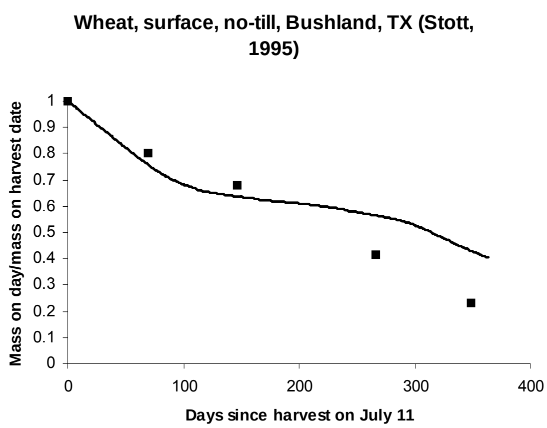
Soybeans, surface, W. Lafayette, IN, (Stott, 1995)

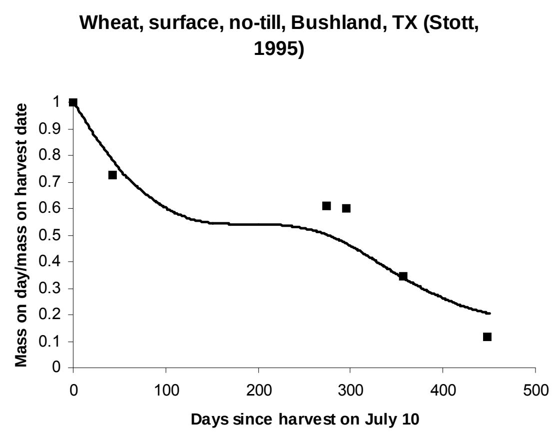


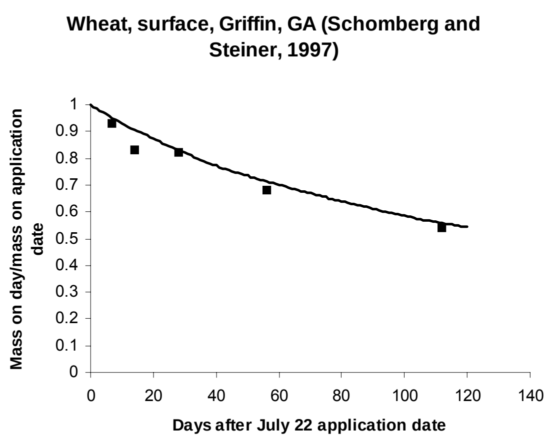
Soybeans, surface, Griffin, GA (Schomberg and Steiner, 1997, pre-publication draft)

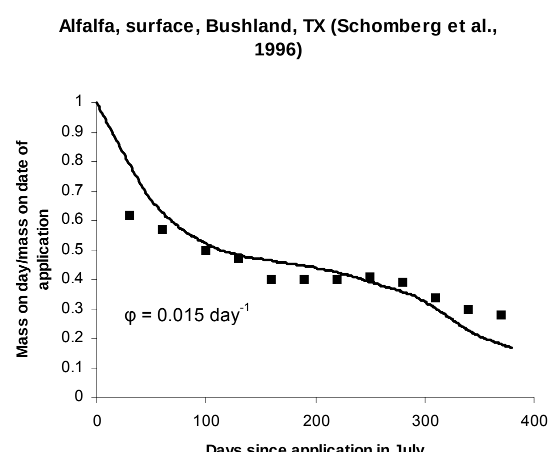


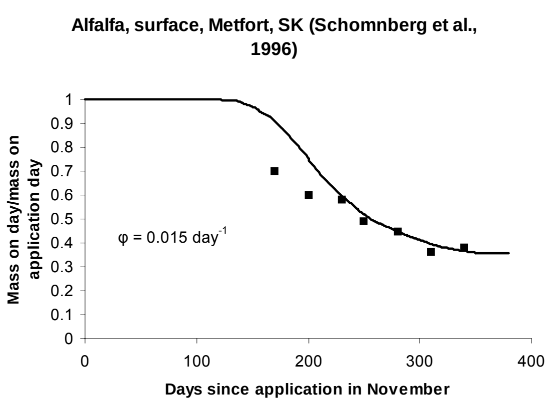
Section 10.Appendix 1 (continued). Illustrations of RUSLE2 decomposition estimates with measured field data.

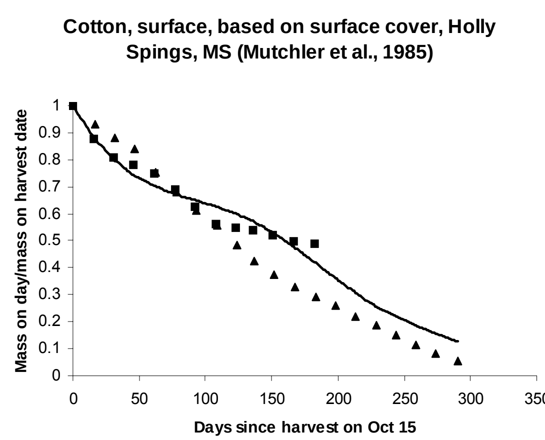




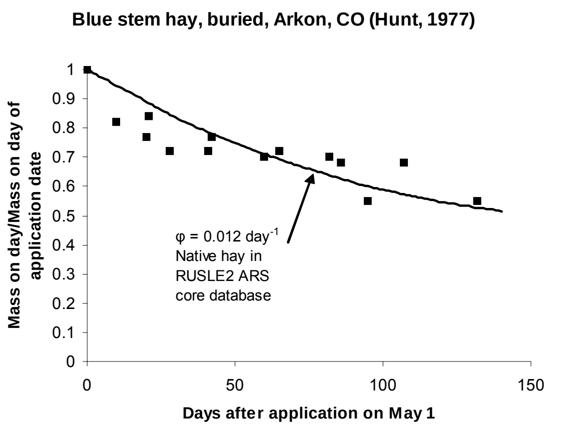


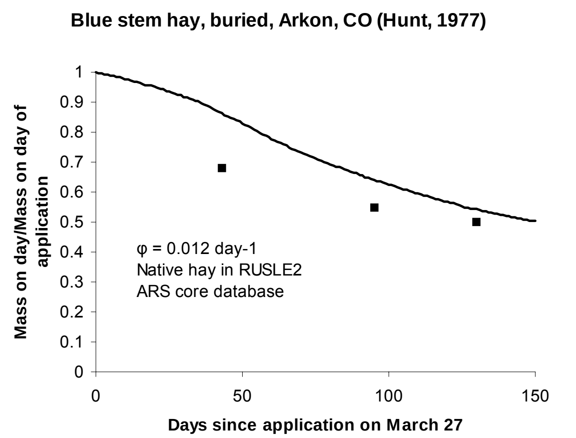




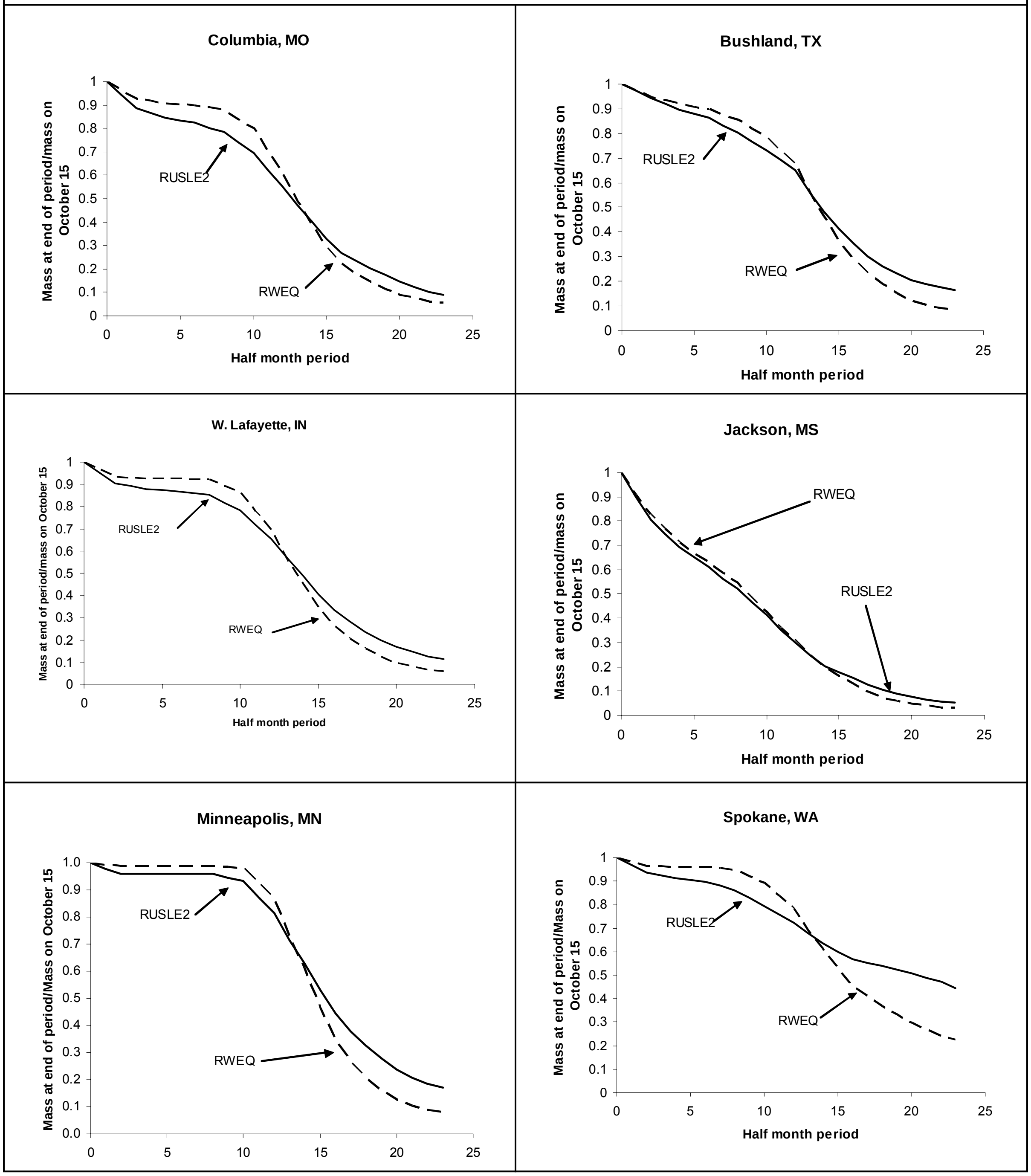


Section 10.Appendix 1 (continued). Illustrations of RUSLE2 decomposition estimates with measured field data.

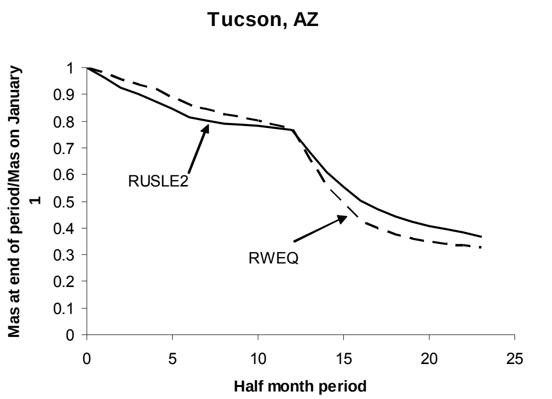




Section 10.Appendix 2. Comparison of decomposition computed with RUSLE2 and RWEQ equations to compare model structure.



Section 10.Appendix 2 (continued). Comparison of decomposition computed with RUSLE2 and RWEQ equations to compare model structure.



11. Summary

References

RUSLE2 User's Reference Guide

Alberts, E.E. and W.D. Schrader. 1980.Cornstalk decomposition on a till-planted watershed. Agronomy Journal. 72:709-712.

Alonso, C.V., W.H. Neibling, and G.R. Foster. 1981. Estimating sediment transport capacity in watershed modeling. Transactions of the American Society of Agricultural Engineers 24(5):1211-1220, 1226.

Bengston, R.I. and G. Sabbage. 1988. USLE P-factor for subsurface drainage in a hot, humid climate. ASAE Paper 88-2122. American Society of Agricultural Engineers. St. Joseph, MI.

Birk, E.M. and R.W. Simpson. 1980. Steady state and the continuous input model of litter accumulation and decomposition in Australian Eucalypt forests. Ecology. 6:481-485.

Bonta, J.V. and W.R. Hamon. 1980. Preliminary evaluations of a sediment pond draining a surface mined watershed. Symposium on Surface Mining Hydrology, Sedimentology, and Reclamation. University of Kentucky. Lexington, KY. 371-381.

Borst, H.L.., A.G. McCall, and F.G. Bell. 1945. Investigations in erosion control and reclamation of eroded land at the Northwest Appalachian Conservation Experiment Station, Zanesville, Ohio, 1934-42. Technical Bulletin 888. U.S. Department of Agriculture, Washington, DC.

Box, J.E., Jr. 1981. The effects of slaty fragments on soil erosion by water. Soil Science Society of America Journal. 45:111-116.

Box, Jr, J.E. and E.N. Bui. 1993. Growing corn roots effects on interrill soil erosion. Soil Science Society of America Journal. 57:1066-1070.

Brenneman, L.G. and J.M. Laflen. 1982. Modeling sediment deposition behind corn residue. Transactions of the American Society of Agricultural Engineers. 25:1245-1250.

Broder, M.W. and G.H. Wagner. 1988. Microbial colonization and decomposition of corn, wheat, and soybean residue. Soil Science Society of America Journal. 52:112-117.

Brown, L.C., and G.R. Foster. 1987. Storm erosivity using idealized intensity distributions. Transactions of American Society of Agricultural Engineers 30(2):379-386.

Brown, L.C., G.R. Foster, and D.B. Beasley. 1989. Rill erosion as affected by incorporated crop residue and seasonal consolidation. Transactions of American Society of Agricultural Engineers 32:1967-1978, 1979.

Brown, L.C., R.K. Wood, and J.M. Smith. 1992. Residue management and demonstration and evaluation. Applied Engineering in Agriculture. 8:333-339.

Browning, F.M., R.A. Norton, A.G. McCall, and F.G. Bell. 1948. Investigations in erosion control and reclamation of eroded land at the Missouri Valley Loess Conservation Experiment Station, Clarinda, Iowa, 1931-42. Technical Bulletin 959. U.S. Department of Agriculture, Washington, DC.

Chapman, G. 1948of raindrops and their striking force at the soil surface in a red pine plantation. Transactions of the American Geophysical Union. 29:664-670.

Chow, V.T., 1959. Open-channel hydraulics. McGraw-Hill Book Co. New York, NY.

Cogo, N.C., W.C. Moldenhauer, and G. R. Foster. 1984. Soil loss reduction from conservation tillage practices. Soil Science Society of American Journal 48(2):368-373.

Colvin, T. S. and J. E. Gilley. 1987. Crop residue - soil erosion combatant. Crops and Soils 39:7-9.

Cooley, K.R. 1980. Erosivity values for individual design storms. Journal of Irrigation and Drainage. American Society of Civil Engineers 106:136-145.

Copley, T.L., L.A. Forrest, A.G. McCall, and F.G. Bell. 1944. Investigations in erosion control and reclamation of eroded land at the Central Piedmont Conservation Experiment Station, Statesville, North Carolina, 1930-40. Technical Bulletin 873. U.S. Department of Agriculture, Washington, DC.

Daly, C., G. Taylor, and W. Gibson. 1997. The PRISM approach to mapping precipitation and temperature, 10th Conf. on Applied Climatology, American. Meteorological Society.

Dabney, S.M., Meyer, L.D., Harmon, W.C., Alonso, C.V., and Foster, G.R. 1995. Runoff and soil loss from cotton plots with and without stiff-grass hedges. Transactions of the American Society of Agricultural Engineers. 38:1719-1729.

Desmet, P.J.J. and G. Govers. 1996. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. Journal of Soil and Water Conservation Service 51:427-433.

Dickey, E.C., C.R. Fenster, J.M. Lalen, an R.H. Mickelson. 1983. Effects of tillage on soil erosion in a wheat-fallow rotation. Transactions of the American Society of Agricultural Engineers. 26:814-820.

Dickey, E.C., D.P. Shelton, P.J. Jasa, and T.R. Peterson. 1985. Soil erosion from tillage systems used in soybean and corn residues. Transactions of the American Society of Agricultural Engineers. 28:1124-1129, 1140.

Douglas, Jr., C.L., R.R. Allmaras, P.E. Rassmussen, R.E. Ramig, and N.C. Roager, Jr. 1980. Wheat straw composition and placement effects on decomposition in dryland agriculture of the Pacific Northwest. Soil Science Society of America Journal. 44:833-83.

Dissmeyer, G.E. and G.R. Foster. 1981. Estimating the cover-management factor (C) in the universal soil-loss equation for forest conditions. Journal of Soil and Water Conservation 36:235-240.

Elliot, W.J., J.M. Laflen, K.D. Kohl, K.D. 1989. Effect of soil properties on soil erodibility. ASAE Paper 89-2150. American Society of Agricultural Engineers. St. Joseph, MI.

El-Swaify, S.A. and E.W. Dangler. 1976. Erodibilities of selected tropical soils in relation to structural and hydrologic properties. In: Soil Erosion: Prediction and Control. Soil and Water Conservation Society of America. Ankeny, IA. pp. 105-114.

Fennessey, L.A.J. and A.R. Jarrett. 1997. Influence ofprincipal spillway geometry and permanent pool depth on sediment retention of sedimentation basins. Transactions of the American Society of Agricultrual Engineers. 40:53-59.

Finkner, S.C., M.A. Nearing, G.R. Foster, and J.E. Gilley. 1989. A simplified equation for modeling sediment transport capacity. Transactions of American Society of Agricultural Engineers 32(5):1545-1550.

Flanagan, D.C., G.R. Foster, W.H. Neibling, and J.P. Burt. 1989. Simplified equations for filter strip design. Transactions of American Society of Agricultural Engineers 32(6):2001-2007.

Flanagan, D.C. and M.A. Nearing (editors). 1995. Technical Documentation, USDA-Water Erosion Prediction Project (WEPP). NSERL Report No. 10. National Soil Erosion Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture. Washington, D.C.

Formanek, G.E, E. Ross, and J. Istok. 1987. Subsurface drainage for erosion reduction on croplands of northwestern Oregon. In: Irrigation Systems of the 21st Century. Proceeding Irrigation Division Specialty Conference. American Society of Civil Engineers. New York, NY. pp. 25-31.

Foster, G.R. and L.D. Meyer. 1972. Transport of soil particles by shallow flow. Transactions of the American Society of Agricultural Engineers 15(1):99-102.

Foster, G.R. and L.D. Meyer. 1975. Mathematical simulation of upland erosion by fundamental erosion mechanics. *In:* Present and Prospective Technology for Predicting

Sediment Yields and Sources. ARS-S-40 U.S. Department of Agriculture. pp. 190-204.

Foster, G.R., L.D. Meyer, and C.A. Onstad. 1977a. An erosion equation derived from basic erosion principles. Transactions of the American Society of Agricultural Engineers 20(4):678-682.

Foster, G.R., L.D. Meyer, and C.A. Onstad. 1977b. A runoff erosivity factor and variable slope length exponents for soil loss estimates. Transactions of the American Society of Agricultural Engineers 20(4):683-687.

Foster, G.R. L.J. Lane, J.D. Nowlin, J.M. Laflen, and R.A. Young. 1980. A model to estimate sediment yield from field sized areas: Development of model. *In:* CREAMS - a field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. Vol. I: Model Documentation. Conservation Research Report No. 26. U.S. Department of Agriculture. . pp. 36-64.

Foster, G.R., L.J. Lane, and J.D. Nowlin. 1980. A model to estimate sediment yield from field sized areas: Selection of parameter values. *In:* CREAMS - a field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. Vol. II: User Manual. Conservation Research Report No. 26. U.S. Department of Agriculture. pp. 193-281

Foster, G.R., W.H. Neibling, S.S. Davis, and E.E. Alberts. 1980. Modeling particle segregation during deposition by overland flow. *In:* Proceedings of Hydrologic Transport Modeling Symposium. American Society of Agricultural Engineers. St. Joseph, MI. pp. 184-195.

Foster, G.R. and V.A. Ferreira. 1981. Deposition in uniform grade terrace channels. *In:* Crop Production with Conservation in the 80's. American Society of Agricultural Engineers. St. Joseph, MI. pp. 185-197.

Foster, G.R., L.J. Lane, J.D. Nowlin, J.M. Laflen, and R.A. Young. 1981. Estimating erosion and sediment yield on field sized areas. Transactions of the American Society of Agricultural Engineers 24(5):1253-1262.

Foster, G.R., D.K. McCool, K.G. Renard, and W.C. Moldenhauer. 1981. Conversion of the universal soil loss equation to SI metric units. Journal of Soil and Water Conservation 36:355-359.

Foster, G.R. 1982. Modeling the erosion process. Chapter 8. *In:* Hydrologic Modeling of Small Watersheds. C.T. Haan, H.P. Johnson, D.L. Brakensiek, eds. American Society of Agricultural Engineers. St. Joseph, MI. pp. 297-382.

Foster, G.R., C.B. Johnson, and W.C. Moldenhauer. 1982. Critical slope lengths of unanchored cornstalk and wheat straw residue. Transactions of the American Society of Agricultural Engineers 25(4):935-939, 947.

Foster, G.R. C.B. Johnson, and W.C. Moldenhauer. 1982. Hydraulics of failure of unanchored cornstalk mulches for erosion control. Transactions of the American Society of Agricultural Engineers 25(4):940-947.

Foster, G.R., L.J. Lane, W.R. Osterkamp, and D.W. Hunt. 1982. Effect of discharge on rill erosion. Paper No. 82-2572. American Society of Agricultural Engineers. St. Joseph. MI.

Foster, G.R., F. Lombardi, and W.C. Moldenhauer. 1982. Evaluation of rainfall-runoff erosivity factors for individual storms. Transactions of the American Society of Agricultural Engineers 25(1):124-129.

Foster, G.R. and R.E. Highfill. 1983. Effect of terraces on soil loss: USLE P factor values for terraces. Journal of Soil and Water Conservation 38:48-51.

Foster, G.R. 1985. Understanding ephemeral gully erosion (concentrated flow erosion). *In:* Soil Conservation, Assessing the National Resources Inventory. National Academy Press. Washington, D.C. pp. 90-125.

Foster, G.R., G.C. White, T.E. Hakonson, and M. Dreicer. 1985. A model for splash and retention of sediment and soil-borne contaminants on plants. Transactions of the American Society of Agricultural Engineers 28(5):1511-1520.

Foster, G.R., R.A. Young, and W.H. Neibling. 1985. Sediment composition for nonpoint source pollution analyses. Transactions of the American Society of Agricultural Engineers 28(1):133-139, 146.

Foster, G.R., R.A. Young, M.J.M. Römkens, and C.A. Onstad. 1985. Processes of soil erosion by water. *In:* Soil Erosion and Crop Productivity. American Society of Agronomy, Crop Science Society of America, Soil Science Society of America. R.F. Follett and B.A. Stewart, eds. Madison, WI. pp. 137-162.

Foster, G.R., G.A. Weesies, K.G. Renard, J.P. Porter, and D.C. Yoder. 1997. Support practice factor "P". *In:* A Guide to Conservation Planning with the Revised Soil Loss Equation (RUSLE). Agriculture Handbook 703. U.S. Department of Agriculture. Chapter 6.

Fournier, F. 1960. Climat et Erosion. Universitaries de France, Paris.

Ghidey, F., J. M. Gregory, T. R. McCarty, and E. E. Alberts. 1985. Residue decay evaluation and prediction. Transactions of the American Society of Agricultural Engineers. 28:102-105.

Gilley, J.E., S.C. Finkner, R.G. Spomer, and L.N. Mielke. 1986. Runoff and erosion as affected by corn residue. I. Total losses. Transactions of the American Society of

Agricultural Engineers. 29:157-160.

Gilley, J.E. and S.C. Finkner. 1991. Hydraulic roughness coefficients as affected by random roughness. Transactions of the American Society of Agricultural Engineers. 34:897-903.

Gilley, J.E. and E.R. Kottwitz. 1994. Darcy-Weisbach roughness coefficients for surfaces with residue and gravel cover. Transactions of the American Society of Agricultural Engineers. 38:539-544.

Gilley, J.E. and E.R. Kottwitz. 1995. Darcy-Weisbach roughness coefficients for selected crops. Transactions of the American Society of Agricultural Engineers. 37:467-471.

Govers, G. 1991. Rill erosion on arable land in central Belgium: Rates, control, and predictability. Catena. 18:133-135.

Graf, W.H. 1971. Hydraulic of Sediment Transport. McGraw Hill. New York, NY.

Gregory, J.M., T.R. McCarty, F. Ghidey, and E.E. Alberts. 1985. Derivation and evaluation of residue decay equation. Transactions of the American Society of Agricultrual Engineers. 28:98-101.

Ghidey, F. and E.E. Alberts. 1993. Residue type and placement effects on decomposition: Field study and model evaluation. Transactions of the American Society of Agricultural Engineers. 36:1611-1617.

Gunn , R. and Kinzer, G.D. 1949. The terminal velocity of fall for water droplets. Jounral of Meteorology. 6:243-248.

Haan, C.T., B.J. Barfield and J.C. Hayes. 1994. Design hydrology and sedimentology for small catchments. Academic Press, New York, NY.

Hanna, H.M., S.W. Melvin, and R.O. Pope. 1995. Tillage implement operational effects on residue cover. Applied Engineering in Agriculture. 11:205-210.

Hayes, J.C., B.J. Barfield, and R.I. Barnhisel. 1984. Performance of grass filters under laboratory and field conditions. Transactions of the American Society of Agricltrual Engineers 27:1321-1331.

Hays, O.E. and O.J. Attoe. 1957. Control of runoff and erosion on Almena silt loam in Wisconsin. ARS 41-16. U.S. Department of Agriculture, Washington, DC.

Hays, O.E., A.G. McCall, and F.G. Bell. 1949. Investigations in erosion control and reclamation of eroded land at the Upper Mississippi Valley Conservation Experiment Station near LaCrosse, Wisconsin, 1933-43. Technical Bulletin 973. U.S. Department of Agriculture, Washington, DC.

Heilman, J.L., K.J. McInnes, R.W. Gesch, and R.J. Lascano. 1992. Evaporation from ridge-tilled soil covered with herbicide-killed winter wheat. Soil Science Society of America Journal. 56:1278-1286.

Hill, H.O., W.J. Peevy, A.G. McCall, and F.G. Bell. 1944. Investigations in erosion control and reclamation of eroded land at the Blackland Conservation Experiment Station Temple, Texas, 1931-41. Technical Bulletin 859. U.S. Department of Agriculture, Washington, DC.

Hill, P.R. and D.E. Stott. 2000. Corn residue retention by a combination chisel plow. Soil Science Society of America Journal. 64:293-299.

Hollinger, S. E., J. R. Angel, and M.l A. Palecki. 2002. Spatial Distribution, Variation, and Trends in Storm Precipitation Characteristics Associated with Soil Erosion in the United States. Contract report CR 2002-08. Illinois State Water Survey. Champaign, IL

Hood, G.W. and R.P. Bartholomew. 1956. Soil and water conservation studies in the Ozark Highlands of Arkansas. Agricultural Experiment Station Bulletin 563. University of Arkansas.

Johnson, R.R. 1988. Soil engaging tool effects on surface residue and roughness with chisel-type implements. Soil Science Society of America Journal.52:237-243.

Kay, B.D. and A.J. VanderBygaart. 2002. Conservation tillage and depth stratification of porosity and soil organic matter. Soil and Tillage Research. 66:107-118.

Knisel, W. G. (editor). 1980. CREAMS : a field scale model for Chemicals, Runoff, and Erosion from Agricultural Management Systems. Conservation Research Report 26. U.S. Department of Agriculture, Washington, DC.

Laflen, J.M., H.P. Johnson, and R.C. Reeve. 1972. Soil loss from tile outlet terraces. Journal of Soil and Water Conservation. 27:74-77.

Laflen, J.M., W.C. Moldenhauer, and T.S. Colvin. 1980. Conservation tillage and soil erosion on continuously row-cropped land. In: Crop Production with Conservation in the 80's. American Society of Agricultural Engineers. St. Joseph, MI. pp. 121-133.

Laflen, J.M. and T.S. Colvin. 1981. Effect of crop residues on soil loss from continuous row cropping. Transaction of the American Society of Agricultural Engineers. 24:605-609.

Laflen, J.M., G.R. Foster, and C.A. Onstad. 1985. Simulation of individual-storm soil loss for modeling the impact of soil erosion on crop productivity. Individual-storm soil loss. Chapter 26. *In:* Soil Erosion and Conservation. S.A. El-Swaify, W.C. Moldenhauer, and Andrew Lo, eds. Soil Conservation Society of America. Ankeny, IA.

pp. 285-295.

Laflen, J.M., W.J. Elliot, J.R. Simanton, C.S. Holzhey, and K.D. Kohl. 1991. WEPP: soil erodibility experiments for rangeland and cropland soils. Journal of Soil and Water Conservation. 46:39-44.

Laflen, J.M., L.J. Lane, and G.R. Foster. 1991. WEPP-A new generation of erosion prediction technology. Journal of Soil and Water Conservation 46(1):34-38.

Lattanzi, A.R., L.D. Meyer, and M.F. Baumgardner. 1974. Influence of mulch rate and slope steepness on interrill erosion. Soil Science Society of America Proceedings. 38:946-950.

Lu, J.Y., W.H. Neibling, G.R. Foster, and E.A. Cassol. 1988. Selective Transport and Deposition of Sediment Particles by Shallow Flow. Transactions of American Society of Agricultural Engineers 31(4):1141-1147.

Lyles, L. and J. Tatarko. 1987. Precipitation effects on ridges created by grain drills. Journal of Soil and Water Conservation. 42:269-271.

Mannering, J.V. and L.D. Meyer. 1963. Effects of various rates of surface mulch reduce soil erosion and runoff velocity. Soil Science Society of America Proceedings. 27:84-86.

Mannering, J.V., C.B. Johnson, and L.D. Meyer. 1968. Effect of cropping intensity on erosion and infiltration. Agronomy Journal. 60:206-209.

Mannering, J.V. 1981. The use of soil loss tolerance as a strategy for soil conservation. In: Soil Conservation: Problems and Prospects. R.P.C. Morgan (ed), John Wiley and Sons, Inc., NY. pp. 337-349.

McCool, D.K., L.C. Brown, G.R. Foster, C.K. Mutchler, and L.D. Meyer. 1987. Revised slope steepness factor for the Universal Soil Loss Equation. Transactions of American Society of Agricultural Engineers (30)4:1387-1396.

McCool, D.K., G.R. Foster, C.K. Mutchler, and L.D. Meyer. 1989. Revised slope length factor for the Universal Soil Loss Equation. Transactions of American Society of Agricultural Engineers 32(5):1571-1576.

McCool, D.K., M.T. Walter, and L.G. King. 1995. Runoff index values for frozen soil areas of the Pacific Northwest. J. Soil and Water Conservation. 50: 466-469.

McCool, D.K., G.R. Foster, and G.A. Weesies. 1997. Slope length and steepness factors (LS). Chapter 4. *In:* Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook 703. U.S. Department of Agriculture. Washington, DC.

McCool, D. K., G. R. Foster, A. H. Ingersoll, R. C. McClellan, and R. W. Rickman.

2002. Cover-Management Enhancements for RUSLE2 in the Pacific Northwest USA. Vol. II, p. 513-517. In: Proceedings of the 12th Conference of the International Soil Conservation Organization, Beijing, China. 2002.

McCormack, D.E. and K.K. Young. 1981. Technical and societal implications of soil loss tolerance. 364-376, In: Soil Conservation: Problems and Prospects. R.P.C. Morgan (ed), John Wiley and Sons, Inc., NY.

McGregor, K.C., R.L. Bengtson, and C.K. Mutchler. 1988. Effects of surface straw on interrill runoff and erosion of Grenada silt loam soil. Transactions of the American Society of Agricultural Engineers. 31:111-116

McGregor, K.C., R.L. Bengston, and C.K. Mutchler. 1990. Surface and incorporated wheat straw effects on interrill runoff and soil erosion. Transaction of the American Society of Agricultural Engineers. 33:469-474.

McGregor, K.C., R.L. Bingner, A.J. Bowie, and G.R. Foster. 1995. Erosivity index values for northern Mississippi. Transactions of the American Society of Agricultural Engineers. 38:1039-1047.

McGregor, K.C., S.M. Dabney, and J.R. Johnson. 1999. Runoff and soil loss from cotton plots with and without stiff-grass hedges. Transactions of the American Society of Agricultural Engineers. 42:361-368.

Meyer, L.D., and J.V. Mannering. 1967. Tillage and land modification for water erosion control. In: Proceeding ASAE-ASA-SCSA Tillage Conference. American Society of Agricultural Engineers. St. Joseph, MI. 58-62.

Meyer, L.D., W.H. Wischmeier, and G.R. Foster. 1970. Mulch rates required for erosion control on steep slopes. Soil Science Society of American Proceedings 34(6):928-931.

Meyer, L.D., W.H. Wischmeier, and W.H. Daniel. 1971. Erosion, runoff, and revegetation of denuded construction sites. Transactions of the American Society of Agricultural Engineers. 138-141.

Meyer, L.D., C.B. Johnson, and G.R. Foster. 1972. Stone and woodchip mulches for erosion control on construction sites. Journal Soil and Water Conservation 27(6):264-269.

Meyer, L.D., G.R. Foster, and M.J.M. Römkens. 1975. Source of soil eroded by water from upland slopes. *In:* Present and Prospective Technology for Predicting Sediment Yields and Sources. ARS-S-40. U.S. Department of Agriculture. pp. 177-189.

Meyer, L.D., G.R. Foster, and S. Nikolov. 1975. Effect of flow rate and canopy on rill erosion. Transactions of the American Society of Agricultural Engineers 18(5):905-911.

Meyer, L.D. and M. A. Ports.1976. Prediction and control urban erosion and sedimentation. Proceedings of National Symposium on Urban Hydrology, Hydraulics, and Sedimentation. Bulletin 111. University of Kentucky. Lexington, KY. pp. 323-331.

Meyer, L.D., W.C. Harmon, and L.L. McDowell. 1980. Sediment sizes eroded from crop row sideslopes. Trans. ASAE. 23: 891-898.

Meyer, L.D. and W. C. Harmon. 1985. Sediment losses from cropland furrows of different gradients. Trans. ASAE. 28: 448-453, 461.

Meyer, L.D. and W.C. Harmon. 1989. How row-sideslope length and steepness affect interrill erosion. Transactions of the Society of Agricultural Engineers. 32:639-644.

Mutchler, C.K., R.E. Burwell, and L.C. Staples. 1976. Runoff and Soil Losses from Barnes Soils in the Northwestern Corn Belt. ARS NC-36. U.S. Department of Agriculture.

Mutchler, C.K. 1970. Splash of a waterdrop at terminal velocity. Science 169:1311-1312.

Mutchler, C.K. and R.A. Young. 1975. Soil detachment by raindrops. 113-117, In: Present and Prospective Technology for Predicting Sediment Yields and Sources. ARS-S-40. U.S Dept of Agriculture, Science and Education Administration. Washington, DC.

Mutchler, C.K., C.E. Murphree, and K.C. McGregor. 1982. Subfactor method for computing C-factors for continuous cotton. Transactions of the American Society of Agricultural Engineers. 25:327-332.

Mutchler, C.K. and K.C. McGregor. 1983. Erosion from low slopes. Water Resources Research. 19:1323-1326.

Mutchler, C.K. and C.E. Carter. 1983. Soil erodibility variation during the year. Transactions of the American Society of Agricultural Engineers. 26:1102-1104, 1108.

Mutchler, C.K. and C.E. Murphree, Jr. 1985. Experimentally derived modifications of the USLE. In: Soil Erosion and Conservation. S.A. El-Swaify, W.C. Moldenhauer, and A. L (editors). Soil and Water Conservation Society, Ankeny , IA. pp. 523-527.

Nearing, M.A., G.R. Foster, L.J. Lane, and S.C. Finkner. 1989. A process-based soil erosion model for USDA Water Erosion Prediction Project technology. Transactions of American Society of Agricultural Engineers 32(5):1587-1593.

Neibling, W.H. and G.R. Foster. 1982. Transport and deposition of naturally eroded sediment by shallow flow. Paper No. 82-2088. American Society of Agricultural Engineers. St. Joseph, MI.

Parker, D.T. 1962. Decomposition in the field of buried and surface-applied cornstalk residue. Soil Science of America Proceeding 26:559-562.

Reeder, J.D., C.D. Franks, and D.G. Michunas. 2001. Root biomass and microbial processes. In: The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect. R.K. Follett, J.M. Kimble, and R. Lal (eds). Lewis Publisher, Boca Raton, FL.

Renard, K.G. and G. R. Foster. 1983. Soil conservation: Principles of erosion by water. Agronomy Monograph no. 23. *In:* Dryland Agriculture. American Society of Agronomy. Madison, WI. pp. 155-176.

Renard, K.G. and J.R. Freimund. 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. Journal of Hydrology 157:287-306.

Renard, K.G., G.R. Foser, G.A. Weesies, D.K. McCool, and D.C. Yoder (coordinators). 1997. Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook 703. U.S. Department of Agriculture. Washington, DC.

Richardson, C.W., G.R. Foster, and D.A. Wright. 1983. Estimation of erosion index from daily rainfall amount. Transactions of the American Society of Agricultural Engineers 26(1):153-156, 160.

Römkens, M.J.M., D.W. Nelson, and C.B.Roth. 1975. Soil erosion on selected high clay subsoils. Journal of Soil and Water Conservation. 30:173-176.

Römkens, M.J.M., C.B. Roth, and D.W. Nelson. 1977. Erodibility of selected clay soubsoils in relation to physical and chemical properties. Soil Science Society of America Journal. 41:954-960.

Romkens, M.J.M., R.A. Young, J.W.A. Poesen, D.K.McCool, S.A. El-Swaify, and J.M. Bradford. 1997. Soil erodibility factor. In: Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). Agriculture Handbook 703. U.S. Department of Agriculture, Washington, DC.

Roth, C.B. and D.W. Nelson, and M.J.M. Römkens. 1974. Prediction of subsoil erodibility using chemical, mineralogical and physical parameters. EPA 660/2-74-043. U.S. Department of Environmental Protection, Washington, DC. 111 pp.

Schomberg, H.H. and J.L. Steiner. 1995. Comparison of residue decomposition models used in erosion prediction. Pre-publication copy. Agricultural Research Service. U.S. Department of Agriculture. Bushland, TX.

Schomberg, H.H. and J.L. Steiner. 1997. Comparison of residue decomposition models used in erosion prediction. Agronomy Journal 89:911-919.

Schomberg, H.H. G.R. Foster, J.L. Steiner, and D.E. Stott. 2002. An improved temperature function for modeling crop residue decomposition. Transactions of the American Society of Agricultural Engineers. 45:1415-1422.

Schwab, G.O., R.K. Frevert, T.W. Edminster, and K.K. Barnes. 1966. Soil and Water Conservation Engineering. John Wiley and Sons, New York, NY. pp. 542-559.

Schwab, G.O. and J.L. Fouss. 1967. Tile flow and surface runoff from drainage systems with corn and grass cover. Transactions of the American Society of Agricultural Engineers. 10:492-493, 496.

Schwab, G.O. 1976. Tile or surface drainage for Ohio's heavy soils? Ohio Report. March-April. Ohio Agricultural Experiment Station. Columbus, OH.

Shelton, C. H. and J. F. Bradley. 1987. Controlling erosion and sustaining production with no-till systems. Tennessee Farm and Home Science. Winter:18-23.

Simanton, J.R., E. Rawitz, andE.D. Shirley. 1984. The effects of rock fragments on erosion on semiarid rangeland soils. In: Erosion and Productivity of Soils Containing Rock Fragments. Chapter 7, Special Publication 13. Soil Science Society of American. Madison, WI. Pp. 65-72.

Simanton, J.R., M.A. Weltz, and H.D. Larson. 1991. Rangeland experiments to parameterize the water erosion prediction project model: vegetation canopy cover effects. Journal of Range Management. 44:276-282.

Skaggs, R.W., A Nassehzadeh-Tabrizi, and G.R. Foster. 1982. Subsurface drainage effects on erosion. Journal of Soil and Water Conservation 37:167-172.

Smith, D.D., D.M. Whitt A.W. Zingg, et al. 1945. Investigations in erosion control and reclamation of eroded Shelby and related soils at the Conservation Experiment Station, Bethany, Missouri, 1932-42. Technical Bulletin 883. U.S. Department of Agriculture, Washington, DC.

Spaeth, Jr., K.E. F.B. Pierson, M.A. Weltz, and W.H. Blackburn. 2003. Evaluation of USLE and RUSLE estimated soil loss on rangeland. Journal of Range Management. 56:234-246.

Steiner, J.L. H.H. Schomberg, C.L. Douglas, Jr., and A.L. Black. 1994. Standing stem persistence in no-tillage small-grain fields. Agronomy Journal. 86:76-81.

Steiner, J.L., H.H. Schomberg, and P.W. Unger. 1995. Residue decomposition submodel. In: Wind Erosion Prediction System (WEPS), Technical Documentation, L.J. Hagan et al. (ed). Wind Erosion Research Unit, Agricultural Research Service, U.S. Department of Agriculture, Washington, DC. pp. D1-D12.

Steiner, J.L., H.H. Schomberg, P.W. Unger, and J. Cresap. 1999. Crop residue decomposition in no-tillage small-grain fields. Soil Science Society of America Journal 63:1817-1824.

Steiner, J.L., H.H. Schomberg, P.W. Unger, and J. Cresap. 2000. Biomass and residue cover relationships of fresh and decomposing small grain residue. Soil Science of America Journal. 64:2109-2114.

Stott, D.E. 1995. Analysis of RUSLE decomposition and mass-to-cover parameters. Unpublished report. National Soil Erosion Research Laboratory, U.S. Department of Agriculture, Agricultural Research Service, W. Lafayette, IN.

Swanson, N. P., Dedrick, A. R., Weakley, H. E., Haise, H. R. 1965. Evaluation of mulches for water-erosion control. Transactions of the American Society of Agricultural Engineers. 8:438-440.

Swanson, N.P., A.R. Dedrick, and A.E. Dudeck. 1967. Protecting steep construction slopes against water erosion. Highway Research Record 206. Highway Research Board. Washington, DC. pp. 46-52.

Toy, T.J. and G.R. Foster (coeditors). 1998. Guidelines for the use of the Revised Universal Soil Loss equation (RUSLE1.06) on mined lands, construction sites, and reclaimed lands. USDI-Office of Surface Mining. Denver. CO.

Toy, T.J. and G.R. Foster. 2000. Estimating Rill-interrill erosion on converging and diverging hillslopes. Unpublished report submitted to National Sedimentation Laboratory, U.S. Department of Agriculture.

Toy, T.J., G.R. Foster, and K.G. Renard. 2002. Soil Erosion: Processes, Prediction, Measurement, and Control. John Wiley and Son, New York, NY.

U.S. Environmental Protection Agency (USEPA). 1976a. Effectiveness of surface mine sedimentation ponds. EPA-600/2-76-117. Environmental Protection Technology Series. Washington, D.C.

U.S. Environmental Protection Agency (USEPA). 1976ba. Erosion and Sediment Control: Surface mingin in the Easter U.S. EPA-25/3-76-006. Environmental Protection Agency Technology Transfer Seminar Publication. Washington, D.C.

Van Klaveren, R.W. and D.K. McCool. 1998. Erodibility and critical shear stress of a previously frozen soil. Transactions of the American Society of Agricultural Engineers. 41:1315-1321.

Van Liew, M.W. and K.E. Saxton. 1983. Slope steepness and incorporated residue effects on rill erosion. Transactions of the American Society of Agricultural Engineers. 26: 1738-1743.

Vigil, M. F. and D. Sparks. 2004. Factors affecting the rate of crop residue decomposition under field conditions. Conservation tillage Fact Sheet #3-95. U.S. Department of Agriculture, Washington, DC.

Wagner, L.E. and R.G. Nelson. 1995. Mass reduction of standing and flat crop residue by selected tillage implements. Transactions of the American Society of Agricultural Engineers. 38:419-427.

Williams, J.R., C.A. Jones, J.R. Kiniry, and D.A. Spanel. 1989. The EPIC crop growth model. Transactions of the American Society of Agricultural Engineers. 32:497-511.

Wischmeier, W.H. and D.D. Smith. 1958. Rainfall energy and its relationship to soil loss. Transactions of American Geophysical Union. 39: 285-291.

Wischmeier, W.H. and D.D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: A guide for selection of practices for soil and water conservation. Agriculture Handbook 282. U.S. Department of Agriculture, Washington, DC.

Wischmeier, W.H. and J.V. Mannering. 1969. Relation of soil properties to its erodibility. Soil Science Society of American Proceedings. 33:131-137.

Wischmeier, W.H., C.B. Johnson, and B.V. Cross. 1971. A soil erodibility monograph for farmland construction sites. Journal of Soil and Water Conservation. 26: 189-193.

Wischmeier, W.H. 1975. Estimating the soil loss equation's cover and management factor for undisturbed areas. In: Present and prospective technology for predicting sediment yields and sources. ARS-S40. U.S. Department of Agriculture. Washington, D.C. pp. 118-124.

Wischmeier, W. H. 1978. Conservation tillage to control water erosion. In: Conservation Tillage: The Proceedings of a National Conference. Soil and Water Conservation Society. Ankeny, IA. pp. 133-141.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall-erosion losses: A guide to conservation planning. Agriculture Handbook (AH) 537. U.S. Dept. of Agriculture, Washington, DC.

Yoder, D.C., J.P. Porter, J.M. Laflen, J.R. Simanton, K.G. Renard, D.K. McCool, and G.R. Foster. 1997. Cover-management factor (C). In: A Guide to Conservation Planning with the Revised Soil Loss Equation (RUSLE). Agriculture Handbook 703. U.S. Department of Agriculture. Chapter 5.

Young, R.A. and C. K. Mutchler. 1969. Soil and water movement in small tillage channels. Transactions of the American Society of Agricultural Engineers. 12:543-545.

Young, R.A. and C.K. Mutchler. 1977. Erodibility of some Minnesota soils. Journal of

Soil and Water Conservation. 32:180-182.

Contouring References:

Borst, H.L.., A.G. McCall, and F.G. Bell. 1945. Investigations in erosion control and reclamation of eroded land at the Northwest Appalachian Conservation Experiment Station, Zanesville, Ohio, 1934-42. Technical Bulletin 888. U.S. Department of Agriculture, Washington, DC.

Browning, F.M., R.A. Norton, A.G. McCall, and F.G. Bell. 1948. Investigations in erosion control and reclamation of eroded land at the Missouri Valley Loess Conservation Experiment Station, Clarinda, Iowa, 1931-42. Technical Bulletin 959. U.S. Department of Agriculture, Washington, DC.

Daniel, H.A., H.M. Elwell, and M.B. Cox. 1943. Investigations in erosion control and reclamation of eroded land at the Red Plains Conservation Experiment Station, Guthrie, Oklahoma, 1930-40. Technical Bulletin 837. U.S. Department of Agriculture. Washington, D.C.

Diseker, E.G. and R.E. Yoder. 1936. Sheet erosion studies on Cecil clay. Bulletin 245. Alabama Agricultural Experiment Station. Auburn, University. Auburn, AL.

Hays, O.E., A.G. McCall, and F.G. Bell. 1949. Investigations in erosion control and reclamation of eroded land at the Upper Mississippi Valley Conservation Experiment Station near LaCrosse, Wisconsin, 1933-43. Technical Bulletin 973. U.S. Department of Agriculture, Washington, DC.

Hill, H.O., W.J. Peevy, A.G. McCall, and F.G. Bell. 1944. Investigations in erosion control and reclamation of eroded land at the Blackland Conservation Experiment Station Temple, Texas, 1931-41. Technical Bulletin 859. U.S. Department of Agriculture, Washington, DC.

Hood, G.W. and R.P. Bartholomew. 1956. Soil and water conservation studies in the Ozark Highlands of Arkansas. Agricultural Experiment Station Bulletin 563. University of Arkansas.

Jamison, V.C., D.D. Smith, and J.F. Thornton. 1968. Soil and water research on a claypan soil. Technical Bulletin 1379. U.S. Department of Agriculture. Washington, D.C.

Jasa, P. J., E. C. Dickey, and D. P. Shelton. 1986. Soil erosion from tillage and planting systems used in soybean residue: Part II - influences of row direction. Transactions of the American Society of Agricultural Engineers. 29:761-766.

Knoblauch, H.C. and J.L. Hayes. 1940. The effect of contour cultivation on runoff. Transactions of the American Geophysical Union. 21:499-504.

Lamb, Jr., J., J.S. Andrews, and A.F. Gustafson. 1944. Experiment in the control of soil erosion in southern New York. Bulletin 811. New York Agricultural Experiment Station. Cornell University, Ithaca, NY.

McGregor, K.C., J.D. Greer, G.E. Gurley, and G.C. Bolton. 1969. Runoff and sediment production from north Mississippi Loessial soils. Bulletin 777. Mississippi Agricultural Experiment Station. Mississippi State University. Starkville, MS.

McIsaac, G, F., Mitchell, J. K., Siemans, J.C., Hummel, J. W. 1987. Row cultivation effects on runoff, soil loss and corn grain yield. Transactions of the American Society of Agricultural Engineers. 30:125-128,136.

Moldenhauer, W.C. and W.H. Wischmeier. 1960. Soil and water losses and infiltration rates on Ida silt loam as influenced by cropping systems, tillage practices, and rainfall characteristics. Soil Science Society of America Proceedings. 24:409-413.

Nichols, M.L. and H.D. Sexton. 1932. A method of studying soil erosion. Agricultural Engineering. 13:101-103.

Smith, D.D., D.M. Whitt A.W. Zingg, et al. 1945. Investigations in erosion control and reclamation of eroded Shelby and related soils at the Conservation Experiment Station, Bethany, Missouri, 1932-42. Technical Bulletin 883. U.S. Department of Agriculture, Washington, DC.

Van Doren, C.A., R.S. Stauffer, and E.H. Kidder. 1950. Effect of contour farming on soil loss and runoff. Soil Science Society of America Proceedings. 15:413-417.

Young, R.A., C.K. Mutchler, and W.H. Wischmeier. 1964. Influence of row direction and type of vegetal cover on the soil-loss relationship. Transactions of the American Society of Agricultural Engineers. 7:316-317, 320.

Decomposition References:

Alberts, E.E. and W.D. Schrader. 1980.Cornstalk decomposition on a till-planted watershed. Agronomy Journal. 72:709-712.

Broder, M.W. and G.H. Wagner. 1988. Microbial colonization and decomposition of corn, wheat, and soybean residue. Soil Science Society of America Journal. 52:112-117.

Birk, E.M. and R.W. Simpson. 1980. Steady state and the continuous input model of litter accumulation and decomposition in Australian Eucalypt forests. Ecology. 6:481-485.

Broder, M.W. and G.H. Wagner. 1988. Microbial colonization and decomposition of corn, wheat, and soybean residue. Soil Science Society of America Journal. 52:112-117.

Collins, H.P., L.F. Elliot, and R.I. Papendick. 1986. 1990. Wheat straw decomposition and changes in decomposition during field exposure. Soil Science Society of America Journal. 54:1013-1016.

Douglas, Jr., R.R. Allmaras, P.E. Rasmussen, R.E. Ramg, and N.C. Roager, Jr. 1980. Wheat straw composition and placement effects on decompoisition in dryland agriculture of the Pacific Northwest. Soil Science Society of America Journal. 44:833-837.

Douglas, Jr., C.L. and R.W. Rickman. 1992. Estimating crop residue decomposition from air temperature, initial nitrogen content, and residue placement. Soil Science Society of America Journal. 56:272-278.

Ghidey, F., J. M. Gregory, T. R. McCarty, and E. E. Alberts. 1985. Residue decay evaluation and prediction. Transactions of the American Society of Agricultural Engineers. 28:102-105.

Ghidey, F. and E.E. Alberts. 1993. Residue type and placement effects on decomposition: Field study and model evaluation. Transactions of the American Society of Agricultural Engineers. 36:1611-1617.

Hunt, H.W. 1977. A simulation model for decomposition in grasslands. Ecology 58:469-484.

McGregor, K.C. and C.K. Mutchler 1983. C Factors for no-till and reduced-till corn. Transactions of the American Society of Agricultural Engineers. 26:785-788.

Mutchler, C.K. and J.D. Greer.. 1984. Reduced tillage for soybeans. Transactions of the American Society of Agricultural Engineers. 27:1364-1369.

Mutchler, C.K. L.L. McDowell, and J.D. Greer. 1985. Soil loss cotton with conservation tillage. Transactions of the American Society of Agricultural Engineers. 28:160-163, 168.
.
Mutchler, C.K. and L.L. McDowell. 1990. Soil loss cotton with winter cover crops. Transactions of the American Society of Agricultural Engineers. 33:432-436.

Murphree, C.E. and C.K. Mutchler. 1980. Cover and management factors for cotton. Transactions of the American Society of Agricultural Engineers. 23:585-588, 595.

Parker, D.T. 1962. Decomposition in the field of buried and surface-applied cornstalk residue. Soil Science Society of America Proceedings. 26:559-562.

Schomberg, H.H., J.L. Steiner, and P.W. Unger. 1994. Decomposition and nitrogen dynamics of crop residues: Residue quality and water effects. Soil Science Society of America Journal. 58:372-381.

Schomberg, H.H. and J.L. Steiner. 1995. Comparison of residue decomposition models used in erosion prediction. Pre-publication copy. Agricultural Research Service. U.S. Department of Agriculture. Bushland, TX.

Schomberg, H.H., J.L. Steiner, S.R. Evett, and A.P. Moulin. 1996. Climatic influence on residue decomposition prediction in the Wind Erosion Prediction System. Theoretical and Applied Climatology. 54:5-16.

Schomberg, H.H. and J.L. Steiner. 1997. Comparison of residue decomposition models used in erosion prediction. Agronomy Journal 89:911-919.

Smith, J.H. and R.E. Peckenpaugh. 1986. Straw decomposition in irrigated soil: Comparison of twenty three cereal straws. Soil Science Society of America Journal. 50:928-932.

Steiner, J.L., H.H. Schomberg, P.W. Unger, and J. Cresap. 1999. Crop residue decomposition in no-tillage small-grain fields. Soil Science Society of America Journal 63:1817-1824.

Stott, D.E., H.F. Stroo, L.F. Elliott, R.I. Papendick, and P.W. Unger. Wheat residue loss from fields under no-till management. Soil Science Society of America Journal. 54:92-98.

Stott, D.E. 1991. RSMAN: A tool for soil conservation education. Journal of Soil and Water Conservation. 46:332-333.

Stott, D.E. 1995. Analysis of RUSLE decomposition and mass-to-cover parameters. Unpublished report. National Soil Erosion Research Laboratory, U.S. Department of Agriculture, Agricultural Research Service, W. Lafayette, IN.

Stott, D.E., E.E. Alberts, and M.A. Weltz. 1995. Residue decomposition and management. Chapter 9. In: Technical Documentation, USDA-Water Erosion Prediction Project (WEPP). (D.C. Flanagan and M.A. Nearing, editors). NSERL Report No. 10. National Soil Erosion Research Laboratory, Agricultural Research Service, U.S. Department of Agriculture. Washington, D.C.

Van Doren, Jr., D.M., W.C. Moldenhauer, and G.B. Triplett, Jr. 1984. Influence of long-term tillage and crop rotation on water erosion. Soil Society of America Journal 48:636-640.

Weaver, J.E. 1947. Rate of decomposition roots and rhizomes of certain range grasses in undisturbed prairie soils. Ecology. 28:221-240.

No-Till and other Conservation Tillage References:

Adams, J. E. 1974. Residual effects of crop rotations on water intake, soil loss, and sorghum yield. Agronomy Journal 66:299-304.

Alberts, E. E., R. C. Wendt, and R. E. Burwell. 1985. Corn and soybean cropping effects on soil losses and C-factors. Soil Science Society of America Journal 49:721-728.

Andraski, B. J., D. H. Mueller, and T. C. Daniel. 1985. Effects of tillage and rainfall date on water and soil losses. Soil Science Society of America Journal 49:1512-1517.

Baker, J. L. and Laflen, J. M. 1983. Runoff losses of nutrients and soil from ground fall-fertilized after soybean harvest. Transactions of the American Society of Agricultural Engineers. 26:1122-1127

Blevins, R. L., W. W. Frye, P. L. Baldwin, S. D. Robertson. 1990. Tillage effects on sediment and soluble nutrient losses from a Maury Silt Loam Soil. Journal of Environmental. Quality. 19:683-686.

Blough, R. F., A. R. Jarrett, J. M. Hamlett, and M. D. Shaw. 1990. Runoff and erosion rates from slit, conventional, and chisel tillage. Transactions of the American Society of Agricultural Engineers. 33:1882-1888.

Burwell, R. E. and L. A. Kramer. 1983. Long-term annual runoff and soil loss from conventional and conservation tillage of corn. Journal of Soil and Water Conservation. 38:315-319.

Cogo, N. P., W. C. Moldenhauer, and G. R. Foster. 1984. Soil loss reductions from conservation tillage practices. Soil Science Society of America Journal. 48:368-373.

Comis,D.L. 1984. Tennessee researchers find no-till, double-cropped soybeans cut erosion. Soil and Water Conservation News. 5:10.

Dabney, S. M., C. E. Murphree, and L. D. Meyer. 1993. Tillage, row spacing, and cultivation affect erosion from soybean cropland. Transactions of the American Society of Agricultural Engineers. 36:87-94.

Dick, W. A., McCoy, E. L., Edwards, W. M., and Lal, R. 1991. Continuous application of no-tillage to Ohio Soils. Agronomy Journal. 83:65-73.

Dickey, E. C., C. R. Fenster, J. M. Laflen, and R. H. Mickelson. 1983. Effects of tillage on soil erosion in a wheat-fallow rotation. Transactions of the American Society of Agricultural Engineers. 27:814-820.

Dickey, E. C., D. P. Shelton, P. J. Jasa, and T. R. Peterson. 1984. Tillage, residue and erosion on moderately sloping soils. Transactions of the American Society of Agricultural Engineers. 27:1093-1099.

Dickey, E. C., D. P. Shelton, Paul J. Jasa, and Thomas R. Peterson. 1985. Soil erosion from tillage systems used in soybeans and corn residues. Transactions of the American Society of Agricultural Engineers. 28:1124-1129, 1140.

Diezman, M. M., S. Mostaghimi, V. O. Shanholtz, J. K. Mitchell. 1987. Size distribution of eroded sediment from two tillage systems. Transactions of the American Society of Agricultural Engineers. 30:1642-1647.

Gilley, J. E., Finkner, S. C., Varvel, G. E. 1986. Runoff and erosion as affected by sorghum and soybean residue. Transactions of the American Society of Agricultural Engineers. 29(6):1605-1610.

Gilley, J. E., Finkner, S.C., Spomer, R. G., and Mielke, L. N. 1986. Runoff and erosion as affected by corn residue: Part 1. Total losses. Transactions of the American Society of Agricultural Engineers. 29:157-161.

Gilley, J. E., Finkner, S. C., and Varvel, G. E. 1987. Slope length and surface residue influences on runoff and erosions. Transactions of the American Society of Agricultural Engineers. 30:148-152.

Hairston, J. E., J. O. Sanford, H. C. Hayes, and L. L. Reinschmiedt. 1984. Crop yield, soil erosion, and net returns from five tillage systems in the Mississippi Blackland Prairie. Journal of Soil and Water Conservation. 39:391-395.

Hamlett, J. M., J. L. Baker, S. C. Kimes, H. P. Johnson. 1984. Runoff and sediment transport within and from small agricultural watersheds. Transactions of the American Society of Agricultural Engineers. 27:1355-1363, 1369.

Harrold, L. L., G. B. Triplett, Jr., and W. M. Edwards. 1970. No-tillage corn - characteristics of the system. Agricultural Engineering. 51:128-131.

Harrold, L. L., and W. M. Edwards. 1972. A severe rainstorm test of no-till corn. Journal of Soil and Water Conservation. 27:30.

Harrold, L. L. and W. M. Edwards. 1974. No-tillage system reduces erosion from continuous corn watersheds. Transactions of the American Society of Agricultural Engineers. 17:414-416.

Jasa, P. J., E. C. Dickey, and D. P. Shelton. 1986. Soil erosion from tillage and planting systems used in soybean residue: Part II - influences of row direction. Transactions of the American Society of Agricultural Engineers. 29:761-766.

Jasa, P.J., and E.C. Dickey. 1991. Subsoiling, contouring, and tillage effects on erosion and runoff. Applied Engineering in Agriculture. 7:81-85.

Jones, J.N., J. E. Moody, G. M. Shear, W. W. Moschler, and J. J. Lillard.1968. The no-tillage system for corn. Agronomy Journal. 60:17-20.

Kramer, L. A. 1986. Runoff and soil loss by cropstage from conventional and conservation tilled corn. Transactions of the American Society of Agricultural Engineers. 29:774-779.

Laflen, J. M., J. L. Baker, R. O. Hartwig, W. F. Buchele, and H. P. Johnson. 1978. Soil and water losses from conservation tillage systems. Transactions of the American Society of Agricultural Engineers. 21:881-885.

Laflen, J. M. and T. S. Colvin. 1981. Effects of crop residue on soil loss from continuous row cropping. Transactions of the American Society of Agricultural Engineers. 24:605-609.

Laflen, J. M., Moldenhauer, .W. C., and Colvin, T. S. 1981. Conservation tillage and soil erosion on continuously row-cropped land. In Crop Production with Conservation in the 80's. American Society of Agricultural Engineers. St. Joseph, MI. pp. 121-133.

Laflen, J. M.and T. S. Colvin. 1982. Soil and water loss from no-till, narrow-row soybeans. Paper no. 82-2023. American Society of Agricultural Engineers. St Joseph, MI.

Langdale, G. W., A. P. Barnett, R. A. Leonard, and W. G. Fleming. 1979. Reduction of soil erosion by the no-till system in the Southern Piedmont. Transactions of the American Society of Agricultural Engineers. 21:82-86, 92.

Langdale, G. W., M. C. Mills, and A. W. Thomas. 1992. Use of conservation tillage to retard erosive effects of large storms. Journal of Soil and Water Conservation. 47:257-260.

Langdale, G. W., L. T. West, R. R. Bruce, W. P. Miller, and A. W. Thomas. 1992. Restoration of eroded soil with conservation tillage. Soil Technology. 5:81-90.

Lindstrom, M. J. and C. A. Onstad. 1984. Influence of tillage systems on soil physical parameters and infiltration after planting. Journal of Soil and Water Conservation. 39:149-152.

Lindstrom, M. J., W. B. Voorhees, and C. A. Onstad. 1984. Tillage system and residue cover effects on infiltration in Northwestern Cornbelt soils. Journal of Soil and Water Conservation. 39:64-67.

Mannering, J. V., Meyer, L. D., and Johnson, C.B. 1966. Infiltration and erosion as affected by minimum tillage for corn. Soil Science Society of America Proceedings. 30:101-105.

McGregor, K. C., J. D. Greer, and G. E. Gurley. 1975. Erosion control with no-till cropping practices. Transactions of the American Society of Agricultural Engineers. 18:918-920.

McGregor, K. C. and J. D. Greer. 1982. Erosion control with no-till and reduced-till corn for silage and grain. Transactions of the American Society of Agricultural Engineers. 25:154-159.

McGregor, K. C. 1983. C factors for no-till and conventional-till soybeans from plot data. Transactions of the American Society of Agricultural Engineers. 26:1119-1122.

McGregor, K. C. and C. K. Mutchler. 1983. C factors for no-till and reduced-till corn. Transactions of the American Society of Agricultural Engineers. 26:785-788, 794.

McGregor, K. C. and C. K. Mutchler. 1992. Soil loss from conservation tillage for sorghum. Transactions of the American Society of Agricultural Engineers. 35(6):1841-1845.

McIsaac, G, F., Mitchell, J. K., Siemans, J.C., Hummel, J. W. 1987. Row cultivation effects on runoff, soil loss and corn grain yield. Transactions of the American Society of Agricultural Engineers. 30:125-128,136.

McIsaac, G. F., Mitchell, J. K., and Hirschi, M. C. 1988. Runoff and sediment concentration from conservation tillage for corn and soybeans under simulated rainfall. Paper no. 88-2595. American Society of Agricultural Engineers. St. Joseph, MI.

McIsaac, G. F., Mitchell, J. K., and Hirschi, M.C. 1990. Contour and conservation tillage for corn and soybeans in the Tama Silt Loam Soil: hydraulics and sediment concentration. Transactions of the American Society of Agricultural Engineers. 33:1541-1550.

McIsaac, G. F., M.C. Hirschi, and J. K. Mitchell. 1991. Nitrogen and phosphorus in eroded sediment from corn and soybean tillage systems. Journal of Environmental Quality 20:663-670.

McIsaac, G. F., J. K. Mitchell, M.C. Hirschi, and L. K. Ewing. 1991. Conservation and contour tillage for corn and soybeans in the Tama silt loam soil: the hydrologic response. Soil and Tillage Research. 19:29-46.

McIsaac, G. F, and Mitchell, J. K. 1992. Annual variation in runoff and erosion from simulated rainfall on corn and soybean tillage systems. Paper no.91-2016. American Society of Agricultural Engineers. St. Joseph, MI.

McIsaac,G. F.,and Mitchell, J. K. 1992. Temporal variation in runoff and soil loss from simulated rainfall on corn and soybeans. Transactions of the American Society of Agricultural Engineers. 35:465-472.

Meyer, L. D. and J. V. Mannering. 1961. Minimum tillage for corn: its effect on infiltration and erosion. Transactions of the American Society of Agricultural Engineers. 42:72-75.

Mills, W. C., A. W. Thomas, and G. W. Langdale. 1986. Estimating soil loss probabilities for Southern Piedmont cropping-tillage systems. Transactions of the American Society of

Agricultural Engineers. 29:948-955.

Mills, W. C., A. W. Thomas, and G. W. Langdale. 1992. Seasonal and crop effects on soil loss and rainfall retention probabilities: an example from the U.S. Southern Piedmont. Soil Technology. 5:67-79.

Moldenhauer, W. C., W. G. Lovely, N. P. Swanson, and H. D. Currence. 1971. Effect of row grades and tillage systems on soil and water losses. Journal of Soil and Water Conservation. 26:193-195.

Moldenhauer, W. C., G. W. Langdale, W. Frye, D. K. McCool, R. I. Papendick, D. E. Smika, and D. W. Fryrear. 1983. Conservation tillage for erosion control. Journal of Soil and Water Conservation. 38:144-151.

Mostaghimi, S., Dillaha, T. A., and Shanholtz, V. O. 1986. Influence of tillage systems and residue levels on runoff, sediment, and phosphorus losses. Transactions of the American Society of Agricultural Engineers. 31:128-132.

Mueller, D. H., R. C. Wendt, and T. C. Daniel. 1984. Soil and water losses as affected by tillage and manure application. Soil Science Society of America Journal. 48:896-900.

Mutchler, C. K., Murphree, C. E., and McGregor, K. C. 1982. Subfactor method for computing C factors for continuous cotton. Transactions of the American Society of Agricultural Engineers. 25(2):327-332.

Mutchler, C. K. and J. D. Greer. 1984. Reduced tillage for soybeans. Transactions of the American Society of Agricultural Engineers. 27:1364-1369.

Mutchler, C. K., L. L. McDowell, J. D. Greer. 1985. Soil loss from cotton with conservation tillage. Transactions of the American Society of Agricultural Engineers. 28:160-163, 168.

Mutchler, C. K. and L. L. McDowell. 1990. Soil loss from cotton with winter cover crops. Transactions of the American Society of Agricultural Engineers. 33:432-436.

Onstad, C. A. 1972. Soil and water losses as affected by tillage practices. Transactions of the American Society of Agricultural Engineers. 15:287-289.

Salehi, F., A. R. Pesant, and R. Lagace. 1991. Validation of the universal soil loss equation for three cropping systems under natural rainfall in Southeastern Quebeck. Canadian Agricultural Engineering. 33:11-16.

Seta, A.K., R.L. Blevins, W.W. Frye, and B.J. Barfield. 1993. Reducing soil erosion and agricultural chemical losses with conservation tillage. Journal of Environmental Quality. 22:661-665.

Shelton, C. H., F. D. Tomkins, and D. D. Tyler. 1983. Soil erosion from five soybean tillage systems. Journal of Soil and Water Conservation. 38:425-428.

Shelton, C. H. and J. F. Bradley. 1987. Controlling erosion and sustaining production with no-till systems. Tennessee Farm and Home Science. Winter:18-23.

Shelton, D. P., P. J. Jasa, E. C. Dickey. 1986. Soil erosion from tillage and planting systems used in soybean residue: Part I - influences of row spacing. Transactions of the American Society of Agricultural Engineers. 29:756-760.

Siemens, J. C., W. R. Oschwald. 1976. Erosion from corn tillage systems. Transactions of the American Society of Agricultural Engineers.19:69-72.

Siemens, J. C. and W. R. Oschwald. 1978. Corn-soybean tillage systems: erosion control, effects on crop production, costs. Transactions of the American Society of Agricultural Engineers. 21:293-302.

Sloneker, L. L. and W. C. Moldenhauer. 1977. Measuring the amounts of crop residue remaining after tillage. Journal of Soil and Water Conservation. 32:231-236.

Stein, O. R., W. H. Neibling, T. J. Logan, and W. C. Moldenhauer. 1986. Runoff and soil loss as influenced by tillage and residue cover. Soil Science Society of America Journal. 50:1527-1531.

Sturgul, S. J., Daniel, T. C., and Mueller, H. D. 1990. Tillage and canopy cover effects on interill erosion from first-year alfalfa. Soil Science Society of America Journal. 54:1733-1739.

Van Doren, D. M., W. C. Moldenhauer, and G. B. Triplett. 1984. Influence of long-term tillage and crop rotation on water erosion. Soil Science Society of America Journal. 48:636-640.

Wendt, R. C. and R. E. Burwell. 1985. Runoff and soil losses for conventional, reduced, and no-till corn. Journal of Soil and Water Conservation. 40:450-454.

West, L. T., W. P. Miller, G. W. Langdale, R. R. Bruce, J. M. Laflen, A. W. Thomas. 1991. Cropping system effects on interrill soil loss in the Georgia Piedmont. Soil Science Society of America Journal. 55:460-466.

Wischmeier, W. H. 1978. Conservation tillage to control water erosion. In: Conservation Tillage: The Proceedings of a National Conference. Soil and Water Conservation Society. Ankeny, IA. pp. 133-141.

Wood, S. D. and A. D. Worsham. 1986. Reducing soil erosion in tobacco fields with no-tillage transplanting. Journal of Soil and Water Conservation 41:193-196.

Yoo, K. Y. and J. T. Touchton. 1988. Surface runoff and sediment yield from various tillage systems of cotton. Transactions of the American Society of Agricultural Engineers. 31:1154-1158.

Yoo, K. Y. and E. W. Rochester. 1989. Variation of runoff characteristics under conservation tillage systems. Transactions of the American Society of Agricultural Engineers. 32:1625-1630.

Yoo, K. Y. and J. T. Touchton. 1989. Runoff and soil loss by crop growth stage under three cotton tillage systems. Journal of Soil and Water Conservation. 44:225-228.

Zhu, J. C., C. J. Gantzer, S. H. Anderson, E. E. Alberts. 1989. Runoff, soil, and nutrient losses from no-till soybean with winter cover crops. Soil Science Society of America Journal. 53:1210-1214.

Redistribution of Material in Soil by Soil Disturbing Operations References:

Allmaras R.R., S.M. Copeland, P.J. Copeland, and M. Oussible. 1996. Spatial relations between oat residue and ceramic spheres when incorporated sequentially by tillage. Soil Science Society of America Journal. 60:1209-1216.

Juzwik, J., D.L. Stenlund, R.R. Allmaras, S.M. Copeland, and R.E. McRoberts. 1997.Incorporation of tracers and dazomet by rotary tillers and a spading machine. Sol and Tillage Research. 41:237-248.

Staricka, J.A., P.M. Burford, R.R. Allmaras, and W.W. Nelson. 1990. Tracing the vertical distribution of simulated shattered seeds as related to tillage. Agronomy Journal. 82:1131-1134.

Staricka, J.A., R.R. Allmaras, and W.W. Nelson. 1991. Spatial variation of crop residue incorporated by tillage. Soil Science Society of America Journal. 53:1668-1674.

Staricka, J.A., R.R. Allmaras, W.W. Nelson, and W.E. Larson. 1992. Soil aggregate longevity as determined by the incorporation of ceramic spheres. Soil Science Society of America Journal. 56:1591-1597.

Stenlund, D.L., J. Juzwik, R.R. Allmaras, and S.M. Copeland. 1997. Incorporation of surface-applied materials by tillage implements. General Technical Report PNW 365. Forest Service. U.S. Department of Agriculture, Washington, D.C. pp 29-30.

Root and Root:Top Growth Ratios References

Arnon. I. 1975. Mineral Nutrition of Maize. International Potash Institute. Bern-Worblaufen, Switzerland.

Buyanovsky, G.A. and G.H. Wagner. 1986. Post-harvest residue input to cropland. Plant and Soil. 93:57-65.

Dalrymple, R.L. and D.D. Dwyer. 1967. Root and shoot growth of five range grasses. Journal of Range Management. 20:141-145.

Foth, H.D. 1962. Root and top growth of corn. Agronomy Journal. 54:49-52.

Kramer, J./ and J.E. Weaver. 1936. Relative Efficiency of Roots and Tops of Plants in Protecting the Soil from Erosion. Bulletin 12. Conservation and Survery Division, University of Nebraska, Lincoln, NE.

Long, O.H. 1959. Root studies on some farm crops in Tennessee. Bulletin 301. Agricultural Experiment Station. University of Tennessee, Knoxville, TN. 42 pp.

Raper, Jr., C.D. and S.A. Barber. 1970. Rooting systems of soybeans. I. Difference in root morphology among varieties. Agronomy Journal. 62:581-584.

Taylor, R.S. Plant Root Systems: Their Function and Interaction with the Soil. Chapters 2 and 4. MCGraw-Hill Book Company. New York, NY.

Wallace, A., S.A. Bamburg, and J.W. Cha. 1974. Quantitative studies of roots of perennial plants in the Mojave Desert. Ecology. 55:1160-1162.

Weaver, J.E. and G.W. Harmon. 1935. Quantity of Living Plant Materials in Prairie Soils in Relation to Run-Off and Soil Erosion. Bulletin 8. Conservation and Survey Division. University of Nebraska. Lincoln, NE.

Strip Cropping References:

Borst, H.L.., A.G. McCall, and F.G. Bell. 1945. Investigations in erosion control and reclamation of eroded land at the Northwest Appalachian Conservation Experiment Station, Zanesville, Ohio, 1934-42. Technical Bulletin 888. U.S. Department of Agriculture, Washington, DC.

Hays, O.E. and O.J. Attoe. 1957. Control of runoff and erosion on Almena silt loam in Wisconsin. ARS 41-16. U.S. Department of Agriculture, Washington, DC.

Hays, O.E., A.G. McCall, and F.G. Bell. 1949. Investigations in erosion control and reclamation of eroded land at the Upper Mississippi Valley Conservation Experiment Station near LaCrosse, Wisconsin, 1933-43. Technical Bulletin 973. U.S. Department of Agriculture, Washington, DC.

Hill, H.O., W.J. Peevy, A.G. McCall, and F.G. Bell. 1944. Investigations in erosion control and reclamation of eroded land at the Blackland Conservation Experiment Station Temple, Texas, 1931-41. Technical Bulletin 859. U.S. Department of Agriculture, Washington, DC.

Hood, G.W. and R.P. Bartholomew. 1956. Soil and water conservation studies in the Ozark Highlands of Arkansas. Agricultural Experiment Station Bulletin 563. University of Arkansas.

McGregor, K.C., S.M. Dabney, and J.R. Johnson. 1999. Runoff and soil loss from cotton plots with and without stiff-grass hedges. Transactions of the American Society of Agricultural Engineers. 42:361-368.

Smith, D.D., D.M. Whitt A.W. Zingg, et al. 1945. Investigations in erosion control and reclamation of eroded Shelby and related soils at the Conservation Experiment Station, Bethany, Missouri, 1932-42. Technical Bulletin 883. U.S. Department of Agriculture, Washington, DC.