Science Documentation

Revised Universal Soil Loss Equation
Version 2

(RUSLE2)

(for the model with release date of May 20, 2008)

USDA-Agricultural Research Service

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Acknowledgements

RUSLE2 was developed cooperatively by the USDA-Agricultural Research Service (ARS), the USDA-Natural Resources Conservation Service (NRCS), and the Biosystems Engineering and Environmental Science Department of the University of Tennessee. Each project participant maintains a RUSLE2 Internet site directed toward their specific interests. Consult these sites for a list of the employees of these organizations who contributed to the development of RUSLE2. Contributors from several other organizations also participated in the development of RUSLE2.

The USDA-ARS was responsible for providing the erosion science on which RUSLE2 is based including the mathematical equations used in RUSLE2, core data values used to calibrate RUSLE2, scientific documentation, and a user's reference guide for RUSLE2.

The USDA-NRCS was the principal client for RUSLE2. The NRCS provided information to ensure that RUSLE2 could be easily used in their local field (district) offices. The NRCS also developed an extensive RUSLE2 operational (working) database, primarily for cropland. The NRCS has developed RUSLE2 templates and user guides specifically for their purposes.

The University of Tennessee participated in the development of the mathematical equations used in RUSLE2, developed the computer science used in RUSLE2, and developed the RUSLE2 computer program. They also developed user guides and other RUSLE2 information for their clients.

The interests and needs of a wide variety of other users were considered during RUSLE2's development. RUSLE2 was developed to be land-use independent to give RUSLE2 the widest applicability range possible and to accommodate the needs of these users.

This RUSLE2 Science Documentation was reviewed by USDA-Natural Resources Conservation Service technical specialists from several disciplines; Kenneth G. Renard (retired), USDA-Agricultural Research Service, Tucson, Arizona; and Seth Dabney, USDA-Agricultural Research Service, Oxford, Mississippi.

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 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 alternative erosion control practices 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 wherever 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://www.ars.usda.gov/Research/docs.htm?docid=6010. Additional information is also available on RUSLE2 Internet sites maintained by the USDA-Natural Resources Conservation Service and the University of Tennessee.

Each chapter in this document stands alone with its own list of symbols given at the end of the chapter. Symbols are defined on their occurrence. Refer to the list of symbols at the end of each chapter because symbol usage differs between chapters.

RUSLE2 uses mathematical equations from several disciplines. In most cases, the symbols that are common in a given discipline are used in this document, which results in the same symbol being used for multiple variables, even within the same chapter. Using the typical symbol for a given variable was considered to be more useful than having a unique symbol for each variable.

Also, topics overlap between chapters. The topics within and between chapters are organized according to the mathematical structure of RUSLE2 rather than along a user oriented structure, which is followed in the RUSLE2 User Reference Guide. Consequently, the mathematical representation of key variables such as residue may be discussed in several places in this document. Cross references to other sections where this variable is discussed are included for the major variables.

Disclaimer

The purpose of RUSLE2 is to guide and assist erosion-control planning. Erosion-control planners should consider information generated by RUSLE2 to be only one set of information used to make an erosion-control decision. RUSLE2 has been verified and validated, and every reasonable effort has been made to ensure that RUSLE2 works as described in RUSLE2 documentation available from the USDA-Agricultural Research Service. However, RUSLE2 users should be aware that errors may exist in RUSLE2 and exercise due caution in using RUSLE2.

Similarly, this RUSLE2 Science Documentation has been reviewed by erosion scientists and RUSLE2 users. These reviewers' comments have been faithfully considered in the revision of this document.

Every reasonable effort has been made to ensure that this document is accurate. The USDA-Agricultural Research Service alone is responsible for this document's accuracy and how faithfully the RUSLE2 computer program represents the information in this document.

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 amount
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 for each day of the year, 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	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 not 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 under a location name in the climate component of RUSLE2 database

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 contouring component of RUSLE2 database; 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-*management* description	Values for variables that describe cover-management, includes dates, *operation* descriptions, *vegetation* descriptions, vegetation production levels (yields), external *residue* descriptions and amount applied, cover-*management* descriptions named and saved in the management component of RUSLE2 database
Cover-management subfactors	Cover-management subfactor values used to compute detachment (sediment production) by multiplying subfactor values; subfactor values vary through time as cover-management conditions vary temporally
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 affect erosion
Soil consolidation	Represents how a mechanical disturbance affects erosion;, erosion decreases over time after last disturbance as the soil consolidates (soil consolidation as used in RUSLE2 represents soil particles rebonding during soil wetting and drying; rebonding process is not

	to occur by mechanical compaction)
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 a 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 curve number values as a 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 transported by runoff 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 convert monthly precipitation and temperature values to daily values assuming that daily values vary linearly; daily precipitation values sum to equal monthly values, average daily monthly temperature values equals average monthly temperature 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 and dense particles and leaving the sediment load with increased portion of fine and less dense particles
Enrichment ratio	Ratio of specific surface area 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 average annual rainfall erosivity at a location; closely related to rainfall amount and intensity; monthly erosivity is average sum of individual storm values in month, annual erosivity is average sum of values in year; storm rainfall amount must be ½ inch 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 produced by vegetation
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 (effective)	Effective fall height is the effective height from which waterdrops fall from canopy; depends on canopy shape, canopy density gradient from bottom to top of canopy, 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
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 or 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 (steepness)
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 the temporal vegetation variables of live root biomass in upper 4 inches, canopy cover, effective fall height, and live ground cover; values are in a *vegetation* description in the vegetation component of the RUSLE2 database
Hortonian overland flow	Overland flow 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 hydraulic element flow path component of 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 the hydraulic element system component of the 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 occur where terraces cross concentrated flow areas; impoundments drains through risers into underground pipe
Incorporated biomass	Biomass incorporated (buried) in the soil by a *soil disturbing* operation; also biomass added to the soil by decomposition of surface biomass; amount added by decomposition of surface material is function of soil consolidation subfactor
Inherent organic matter	Soil organic matter content in unit-plot condition
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 having 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 (see operation processes)
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 occurs 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 provided by vegetation (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 over a constant rooting depth of 10 inches for all vegetation types and plant growth stages; 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, 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, any arbitrary date, or only for the annual cycle of 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 vegetation 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 input selections are made for each segment
NRCS curve number method	Mathematical procedure used in RUSLE2 to compute runoff; a daily runoff value is computed using the 10 yr-24 hr precipitation amount and temporally curve number values that vary as cover-management 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 used to represent common farm and construction activities such as plowing, blading, vehicular or animal traffic, and mowing; also used to represent burning and natural processes such as 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
Operation description	Information used to describe an operation, named and stored in the operations component of the RUSLE2 database
Operation processes	An operation is described by a sequence of processes; used to describe 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) surface	Mechanically disturbs soil; required to bury surface residue; resurfaces buried residue; required to create roughness and ridges; required to place 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 and standing 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 portion of nonerodible cover
Operation speed	Surface residue buried by a soil disturbing operation is a function of operation speed
Overland flow path	Path taken by overland flow on a smooth soil 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 (profile) description	Includes values for steepness, names for *soil* and cover-*management* descriptions for segments along an overland flow path; a uniform overland flow path (profile) is where steepness, soil, or cover-management 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; a complex profile is a combination of convex, concave, and/or uniform sub-profiles or where soil and/or cover-management vary along the overland flow path

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 inverse of 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; named and saved in plan component of 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 (overland flow path); includes names for location, topography, soil, cover-management, and support practices used to make a particular RUSLE2 computation, named and stored in profile component of RUSLE2 database
Profile shape	See overland flow path description
Rainfall (storm) energy	Computed as sum of products of unit rainfall 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) 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 path; 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 is much greater than in summer period; winter effect is much greater than in other regions because of a greatly increased soil erodibility; effect partially results from an elevated soil water content, increased runoff, 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 (external residue) 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 applied material like rock that does not decompose
Residue description	Values used to describe residue, named and stored in the residue component of the RUSLE2 database
Residue type	Refers to fragility and geometric residue characteristics; affects residue amount buried and resurfaced by 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 decrease 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* description are repeated in a cycle; length of cycle is rotation duration; list of operation descriptions are repeated in RUSLE2 until computed 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 pass, first *operation* descriptions in cover-*management* description establish initial conditions
Rotation duration	Time (length of cycle) before the list of *operation* descriptions in a rotation type cover-*management* description repeats; 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 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 amount; 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 runoff's 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 cover; 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 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 effect	Represents how wetting/drying and other processes cause soil erodibility to decrease over time following a mechanical soil disturbance; increase in soil bulk density (mechanical compaction) not the major cause of reduced soil erodibility; affects runoff, accumulation of biomass in upper 2 inch soil layer, and soil biomass effectiveness
Soil consolidation subfactor	See cover-management subfactors
Soil description	Describes inherent soil properties that affect erosion, runoff, and sediment characteristics at point of detachment on unit plot conditions, named and saved in the soil component of the 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 must 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 credited 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 *description*	Support practice, describes porous barriers, named and stored in the strip/barrier component of 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, named and save in subsurface drainage component of RUSLE2 database
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 soil surface 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 soil surface roughness; standard deviation of surface elevations measured on a 1 inch 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 an 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	Energy content of rainfall per unit of rainfall; function of rainfall 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, flow retardance, and biomass-yield information; named and stored in the vegetation component of the 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; used to compare erosion computer for profile descriptions; named and saved in the worksheet component of the RUSLE2 database

Rusle 2 Science Documentation

1. ABOUT RUSLE2

1.1. 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) at various locations, soils, cover-management systems, vegetations, residues, operations, porous strips and barriers, flow interceptors including diversions and terrace channels and small impoundments, subsurface drainage systems, irrigation systems, overland flow paths, worksheets, and plan views (collections of overland flow paths). A single overland flow path is the basic RUSLE2 computational unit. Erosion can be compared in a worksheet for multiple erosion control alternatives for a single overland flow path or multiple overland flow paths. A plan view is used to compute erosion on overland flow areas in spatially complex landscapes.

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 user requirements as the principal RUSLE2 client and 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 designed to meet several requirements, many of which affected RUSLE2's science and the equations. These requirements included:

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

2) Be easy to use.

3) Be robust so that computed erosion values are not overly sensitive to small changes in variables where input values involve considerable uncertainty. Helps ensure good estimates when extrapolated beyond range of data used to derive RUSLE2.

4) Input values are physically meaningful to typical RUSLE2 users and directly measurable where possible.

5) Not require resources beyond those available at the field office level, especially for the USDA-Natural Resources Conservation Service that is the primary RUSLE2 user.

6) Produce useful information for conservation and erosion control planning that is consistent with the resources (i.e., expertise, time, effort, and other costs) required to implement and use RUSLE2.

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.

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

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

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

11) Be an evolution of the USLE and RUSLE1.

12) Be thoroughly and carefully reviewed and evaluated to ensure that RUSLE2 performs acceptably.

13) Recommendations on how to best apply RUSLE2 would be a part of the RUSLE2 development and documentation.

1.3. Major guiding principles used to develop RUSLE2 science

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

1) The USLE is accepted in term of its conceptual basis, equation structure, empirical derivation, and computed values by both the scientific and user communities.

2) The USLE is valid (i.e., serves its intended purpose) for conservation and soil erosion control planning.

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

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.

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 contain much unexplained variability that can not be resolved.

6) Equations will be chosen to best represent established 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, fundamental erosion science, practical experience, professional judgment, and overall good judgment (common sense).

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

8) Start from a mean, typical, or accepted value consistent with the USLE unit-plot concept 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.

9) Minimize use of geographic zones and variable classes to avoid step changes (discontinuities) between zones and classes.

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.

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 planning 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·year) for the slope length λ, R = erosivity factor (erosivity unit/area·year), K = soil erodibility factor (mass/ erosivity unit), L = slope length factor (dimensionless), S = slope steepness factor (dimensionless), C = cover-management factor (dimensionless), and P = support practice factor (dimensionless).[2] 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:

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[1] Refer to the RUSLE2 User's Reference Guide for detailed explanations of RUSLE2 terms. Also, see **Glossary of Terms** section in this document.

[2] See List of symbols at end of this chapter.

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

where: A_u = average annual erosion (mass/area·year) for the unit plot (mass/area·year).[3] The terms LSCP are normalized with respect to the unit plot and, therefore, have a value of 1 for unit plot conditions.[4] 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:

$$a_{us} = (EI_{30})K \qquad [2.3]$$

where: a_{us} = the unit-plot erosion (mass/area) from the storm that has the rainfall erosivity EI_{30} (force·length/area)(length/time), E = rain storm energy (force·length/area), and I_{30} = average intensity (length/time) over the continuous 30 minutes with the most rainfall in the storm. The linear relationship between unit plot erosion and storm erosivity EI_{30} means that the erosivity factor R can be computed for a locations as:

$$R = \sum_{j=1}^{M_r} \sum_{m=1}^{M_{s(j)}} (EI_{30})_m \Big/ M_r \qquad [2.4]$$

where: EI_{30} = storm erosivity for storm events greater than 0.5 inches (12 mm), $M_{s(j)}$ = the number of storms in the *jth* year, M_r = number of years in the record being used to compute erosivity.[5]

The linear relationship between erosion on the unit plot and erosivity mathematically means that average daily erosion can be computed as:[6]

$$a_u = rK \qquad [2.5]$$

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[3] The unit plot is 72.6 ft (22.1 m) long on a 9 percent slope, maintained in continuous fallow, tilled up and down hill to a seedbed condition periodically to control weeds and break crusts that form on the soil surface.

[4] 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.

[5] See RUSLE2 User's Reference Guide for a detailed description of the computation of RUSLE2 erosivity values.

[6] Daily erosion computed by RUSLE2 is a long-term average erosion for that day.

where: a_u = daily erosion from the unit plot on the *ith* day and r = the average daily erosivity on the *ith* day. Average daily erosivity values are determined by the disaggregation of average monthly erosivity input values into daily values (see **Section 3.1**).

Although the terms LSCP vary with time as field conditions change, the cover-management factor C is the only one of these USLE terms that is mathematically integrated with time. 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:

$$a_k = KLS\,\mathrm{P} r_k\, c_k \qquad [2.6]$$

where: a, r, and c = the erosion, erosivity, and cover-management (soil loss ratio) factors, respectively, for the *kth* crop stage.[7] 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.[8] Therefore, the average annual cover management C factor in the USLE is computed as:

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

where: M_k = the number of crop stages over the period of N_c years involved in the computation, 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 as:

$$a = rklScp_p p_c p_d \qquad [2.9]$$

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[7] 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.

[8] Erosivity varies during the year. The empirical curve that describes this temporal distribution is referred to as the EI distribution.

where: r = daily erosivity (erosivity unit/area·day), k = daily soil erodibility factor (mass/erosivity unit), l = daily slope length factor dimensionless, c= daily cover-management (soil loss ratio) factor (dimensionless), p_p = daily ponding subfactor (dimensionless), p_c = daily contouring subfactor (dimensionless), and p_d = daily subsurface drainage subfactor (dimensionless).[9] 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.[10]

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, 1974):

$$D = (m+1) rk (x/\lambda_u)^m S c p_p p_c p_d \qquad [2.10]$$

where: D = average daily net detachment by both rill and interrill erosion (mass/area) 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 = daily 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:

$$D_i = 0.5 rk S_i c p_r p_c p_d \qquad [2.11]$$

where: D_i = daily interrill erosion (mass/area·day), 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 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

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[9] 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.

[10] 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.

raindrops and waterdrops falling from vegetation. Detachment on interrill areas is assumed to be uniform 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 slope steepness factor for interrill erosion differs from the slope steepness for rill erosion because 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 in equation 2.11 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:[11]

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[11] Equations 2.11 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 for unit plot conditions. 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.

$$\beta = \left(\frac{K_r}{K_i}\right)\left(\frac{c_{pr}}{c_{pi}}\right)\left(\frac{\exp(-b_r f_g)}{\exp(-0.025 f_g)}\right)\left(\frac{s/0.0896}{3s^{0.8}+0.56}\right) \qquad [2.13]$$

The ratio K_r/K_i = the inherent rill to interrill soil erodibility ratio (see **Section 4.3**), which is computed as a function of soil texture to reflect that 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 erosion ratio for prior land use soil erodibility (see **Section 6.2.2**), which reflects how soil consolidation and soil biomass affect rill erosion differently from how it affects interrill erosion. The ratio $\exp(-b_r f_g)/\exp(-0.025 f_g)$ reflects how ground cover affects rill erosion more than it affects interrill erosion, where b_r and 0.025 = coefficients (percent^{-1}) that express the relative effectiveness of ground cover for reducing rill erosion and interrill erosion, respectively (see **Section 6.2**), and f_g = ground cover expressed as a percent (see **Section 6.2.2**).

The term $(s/0.0896)/(3s^{0.8}+0.56)$ [where s = steepness of overland flow path (sine of slope angle)] reflects how steepness affects rill erosion differently than it does interrill erosion (Foster, 1982). This term assumes that rill erosion varies linearly with steepness.

The assumption in equation 2.12 that rill erosion varies with a slope length exponent of 1 (McCool et al., 1989) is consistent with the maximum slope length exponent of 1 observed in the experimental plot data used to derive the USLE [AH537 (Wischmeier and Smith, 1978)]. The maximum exponent of 1 is also consistent with the 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 (Govers, 1991; McCool et al., 1989) where rill erosion is the dominant erosion process.

The slope length exponent base value is 0.5. Equation 2.12 increases or decreases 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.

Given that rill erosion varies with a slope length exponent of 1, the rill erosion term in equation 2.13 should have included a slope length term. The reason that a slope length term is not in equation 2.13 is because of mathematical limitations in devolving the USLE equation structure into rill and interrill erosion terms. If a slope length term had been included in equation 2.13, RUSLE2 could not have met the requirement that erosion computed for the entire overland flow path length be independent of how many overland flow path segments are used in the computations when other conditions are uniform along the overland flow path (see **Section 5.Appendix 1**).

2.2. Spatial and Temporal Integration

RUSLE2 requires both a spatial and temporal integration. The spatial integration is made by solving the governing equations along the overland flow path each day. Temporal integration is made by summing daily values to obtain totals for the computation duration.[12] 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.[13] 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.

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/unit overland flow width·time), x = distance along the overland flow path from its origin, and D_{rorp} = either rill erosion rate (D_r) (mass/area·time) or deposition (D_p) (mass/area· 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:

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

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[12] Computation duration is the rotation duration (cycle length) for a **rotation** type cover-management description. The computation duration is the length of time specified for the duration of a no-rotation type cover-management description.

[13] 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, 1974).

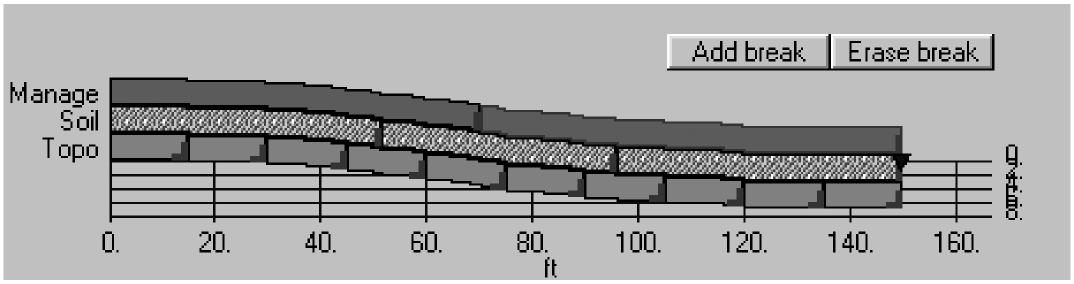

Figure 2.1. Schematic of the three layers that represent an overland flow path (a RUSLE2 hillslope(overland flow path) profile).

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 starting at x = 0, which is the origin of the overland flow path. The incoming sediment load $g_{(i-1)}$ to the first segment at x = 0 is zero because no runoff enters at the origin 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. The sediment load g_i is the sediment load leaving the *ith* segment.

Rill and interrill 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 by assuming that soil, steepness, and cover-management are uniform over the segment. If deposition occurs, interrill erosion D_i is computed with equation 2.11 and the integral for deposition D_p is solved numerically (see **Section 2.3.6**).

The RUSLE2 assumption of uniformity within a segment causes 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 changes between segments. However, runoff rate and sediment load are continuous at adjoining segment points. These step changes require sufficiently short segments to represent variables that vary continuously along the overland flow path. An example is a concave overland flow path (profile) where steepness continuously decreases from its upper end to lower end. A preliminary sensitivity analysis can be conducted to determine appropriate segment lengths for developing an erosion control plan for a specific site.

RUSLE2 could have been constructed to accommodate both step and continuous changes with distance. However, the benefits of representing both continuous and step changes were judged insufficient to merit the increased complexity in the equations, inputs, and programming for most RUSLE2 applications in erosion control planning. Step changes seem to occur more frequently than continuous changes in variables along an overland flow path in most field situations. RUSLE2 represents these step changes, such as those associated with buffer strips and intersection of land slopes on construction sites.

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., 1981a). 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.[14]

A very important RUSLE2 assumption is that detachment and deposition by flow in rill areas at a location 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., 1985b). 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 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.[15]

Another important RUSLE2 assumption is that interrill erosion and deposition in rill areas occur simultaneously. 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 rates 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 local areas that are not

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[14] 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.

[15] 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**).

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 and deposition by rill flow occurs simultaneously has the important benefit of allowing RUSLE2 to compute local deposition in soil surface roughness, furrows between ridges, and similar local roughness features.[16]

2.3.3. Basic deposition equation

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

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

where: D_p = deposition rate (mass/area·time), α_d = a deposition coefficient determined by calibration, V_f = fall velocity of the sediment in still water (length/time), q = overland flow (runoff) rate (volume/overland flow width·time) where flow depth is assumed to be uniform across the slope, T_c = transport capacity (mass/overland flow 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 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., 1989):

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

where: the coefficient K_T coefficient for sediment transportability (mass/volume) and the ζ = coefficient for effect of hydraulic resistance on sediment transport capacity (dimensionless).

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[16] 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.

A RUSLE2 assumption is that all sediment regardless of its composition is equally transportable, and therefore, a single value for sediment transportability is used in RUSLE2 (see **Section 4.7**). 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). For example, slight changes in fine sediment properties significantly affect overland flow's sediment transport capacity computed with sediment transport equations. Slight spatial variations in overland flow hydraulics that can not be described in RUSLE2 also dramatically affect overland flow's sediment transport capacity. Using a complex sediment transport equation is not warranted when RUSLE2 does not capture important details in describing flow hydraulics. Furthermore, the effect of sediment transportability is partially captured by RUSLE2's soil erodibility factor (see **Section 4.1**).[17]

A value for the transportability coefficient K_T was obtained by fitting RUSLE2 to experimental data where deposition occurred on a concave profile overland flow path (Foster et al., 1980c). 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 along on the same overland flow path used to determine the K_T value the point where deposition started. The K_T value was also validated by computing deposition for other laboratory and field experimental data (Foster et al., 1980; Neibling and Foster, 1982; Lu et al., 1988). Deposition was computed with RUSLE2 for a wide range of field conditions and those values were inspected for reasonableness and consistency with field observations (see the **RUSLE2 User's Reference Guide**).

The RUSLE2 calibrated value for K_T is 250,000 (lbs_m/ft^3). This value is based on the following set of units. T_c: lbs_m/(sec·ft width), ζ: dimensionless, q: ft^3/(sec·ft width), s: dimensionless.

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

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[17] 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.

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., 1981a; 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 with:

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

where: q = discharge rate 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 = excess rainfall rate (rainfall rate minus 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**). The RUSLE2 assumption is that excess rainfall rate equals runoff depth divided by one hour. The difference between the two is accounted for in calibration coefficients including the K_T value for sediment transport capacity in equation 2.17. The RUSLE2 principle is to capture runoff's main effects sufficiently well for erosion control planning. RUSLE2 computes excess rainfall rate as a function of hydrologic soil group, surface roughness, ground cover, soil biomass, and soil consolidation to represent cover-management's effect on 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

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 not found. Equations 2.15 and 2.16 along with an equation for transport capacity were written in discrete form for each sediment class as:

$$\frac{D_{pk(1)} + D_{pk(2)}}{2} = \frac{\alpha_d V_{fk}}{[(q_{(1)} + q_{(2)})/2]}\left(\frac{T_{ck(1)} + T_{ck(2)}}{2} - \frac{g_{k(1)} + g_{k(2)}}{2}\right) \qquad [2.19]$$

$$g_{k(2)} = g_{k(1)} + D_{ik}\Delta x + \left(\frac{D_{pk(1)} + D_{pk(2)}}{2}\right)\Delta x \qquad [2.20]$$

and

$$T_{ck} = (g_k / g)T_c \qquad [2.21]$$

where: D_{ik} = interrill erosion for the *kth* sediment class, D_{pk} = deposition rate of the *kth* sediment class, α_d = a deposition coefficient, V_{fk} = fall velocity for the *kth* sediment class, T_{ck} = transport capacity for the *kth* sediment class, T_c = the total sediment transport capacity for all sediment classes, g_k = sediment load for the *kth* sediment class, g = total sediment load, and Δx = the length of the distance step used in the numerical integration. The subscript (1) refers to the upstream end of the distance step and the subscript (2) refers to the downstream 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. The total sediment load can not be computed until sediment load is 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:

$$g_{k(2)} = D_{ik}\Delta x + \left(\frac{D_{pk(1)} + D_{pk(2)}}{2}\right)\Delta x + g_{k(1)} \qquad [2.22]$$

Substitution for D_2 using equation 2.14 in equation 2.22 gives:

$$g_{k(2)} = D_{ik}\Delta x + \left(\frac{D_{pk(1)} + (\alpha_d V_{fk} / q_2)(T_{ck(2)} - g_{k(2)})}{2}\right)\Delta x + g_{k(1)} \qquad [2.23]$$

Equation 2.23 is solved for the sediment load $g_{k(2)}$, 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 transport capacity for a single sediment class computed with equation 2.21 depends on the total sediment load.

Regardless of the numerical procedure, the boundary condition must the determined for each segment (see **Section 2.3.8.2)**. This boundary condition is the deposition rate of each sediment class determined at the upper end of the *ith* segment to start the step by step solution of the equations. The deposition rate at the lower end of the *(i-1)th* segment can not be used as the boundary condition for the upper end of the *ith* segment because deposition values are not continuous at common points of segments. Deposition rates change stepwise at these points even though discharge rate and sediment load are continuous at these points. Steepness makes a step change at common segment points.

The deposition rate at the upstream end of the *ith* segment is computed from:

$$D_{puk(i)} = \left(\alpha_d V_{fk} / q_{(i-1)}\right)\left(T_{cuk(i)} - g_{k(i-1)}\right) \qquad [2.24]$$

where: equation 2.24 is solved for each sediment class using sediment transport capacity computed for each class using equation 2.21. The sediment load $g_{k(i-1)}$ 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 because sediment load is continuous along the overland flow path.

A value of 3 was determined by calibration for the deposition coefficient. Values for α_d were adjusted until the computed sediment distribution matched observed distributions for situations where deposition occurred (Foster et al., 1980c). 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 used to compute deposition must be carefully chosen so that computed values are not affected by arbitrary division of a segment. Segments by definition are uniform in soil, steepness, and cover-management. Dividing a portion of the overland flow path where conditions do not change into segments as illustrated in Figure 2.2 should not affect the detachment and erosion computations. Also, the computations for a segment must not be affected by downslope conditions, including overland flow path length beyond the segment.

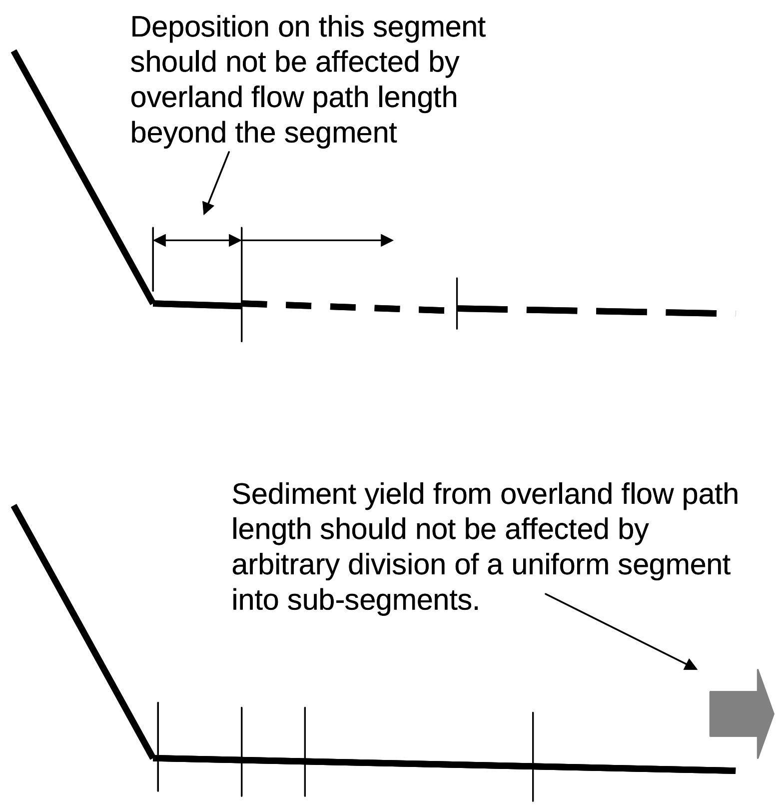

Figure 2.2. Situations where overland flow path lengths and segment divisions should have no effect on computed deposition.

The RUSLE2 procedure avoids these problems by dividing the entire overland flow path 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:

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

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:

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

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 gives acceptable accuracy while minimizing computer run time.

2.3.7. Concept of a representative storm

Runoff is a key RUSLE2 variable used to compute erosion reduction by support practices including contouring, porous barriers, and flow interceptors and deposition on concave overland flow paths. The intent for using RUSLE2 as a guide to erosion control planning is that RUSLE2 compute the relative erosion control effectiveness of support practices by location. For example, 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 is calibrated to compute the effectiveness of support practices at the base Columbia, Missouri location. RUSLE2 compute the deviation in support practice effectiveness by the degree that climatic conditions at a specific location vary from those at the base Columbia, Missouri location. This approach gives RUSLE2 increased robustness.

RUSLE2 uses the 10 year (return period-frequency), 24 hour (storm duration) P_{10y24h} precipitation amount to capture the climatic variation by location to compute erosion control by support practices.[18] This precipitation variable is used as an index of storm severity. A more erosive storm than an average annual storm is used as a storm severity index because support practice effectiveness, especially for contouring, depends on storm severity (Foster et al., 1997). For example, contouring can greatly reduce erosion for small storms but fail completely for large storms.

The effect of support practices and concave overland flow path profile shape on erosion and deposition depends much more on runoff than the combination of raindrop impact and runoff. RUSLE2 uses a representative storm in process-based equations to compute runoff that in turn is used to compute deposition. The daily erosion and deposition values computed with this representative storm are scaled to match the daily detachment values computed with equation 2.10 (**see Section 2.3.9**). The same representative storm is used in the process-based equations for each day, but the computed daily runoff values vary as cover-management conditions change daily. The representative storm is used as an index for storm severity at a location. The intent is not to compute actual runoff on each day but to compute runoff values that show the how relative effectiveness of support practices and concave overland flow path profiles changes daily for the index storm. The index storm captures main-effect differences between locations. RUSLE2 computes comparable P-factor type effects for each day rather than using a single temporally constant P factor value like the USLE and RUSLE1.

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

RUSLE2 also computes an erosivity value for the P_{10y24h} index storm in addition to runoff. The storm erosivity r_{10y24h} for the 10 year-24 precipitation amount P_{10y24h} is computed from:

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

where: γ_m = 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 an index storm. Although the same storm is used each day, computed sediment load changes daily as cover-management conditions temporally change. Daily sediment load values computed using the representative index 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

Inconsistencies occur between the empirical detachment equation (equation 2.10) and the process-based sediment transport capacity equation (equation 2.17) because of differences in the steepness terms in the equations. The steepness effect in equation 2.10 for detachment is a two piece linear equation (see **Section 5.6**), whereas the steepness effect in equation 2.17 for sediment transport capacity is a single linear term. Equations 2.10 and 2.17 are calibrated to be close at the unit-plot nine percent steepness. However, the steepness effect in equation 2.10 can exceed the steepness effect in equation 2.17 at both flat and steep slopes depending on values for the other terms in the equations. Although equation 2.10 is generally assumed to represent detachment limiting conditions in RUSLE2, this empirical equation reflects a mixture of both detachment and transport capacity limiting at low steepness. The assumption used to deal with this and other similar inconsistencies that occur between the empirical USLE formulation and the process-based equations is that RUSLE2 gives the empirical USLE erosion estimate for uniform overland flow paths.[19]

The inconsistencies between these two steepness 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.

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[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 (see **Section 1.2 and 1.3**).

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 USLE uniform slope assumptions.

Many RUSLE2 conservation and erosion control planning applications 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 to determine if 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:

$$dT_c / dx = K_T \zeta \sigma s \qquad [2.28]$$

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 equation 2.11 using the representative (index) storm erosivity r_{10y24h} (see **Section 3.2.4**).

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. No local deposition occurs 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]

$$g = r_{10y24h} kScp_p p_c p_d x_{(1)}^{m_i+1} / \lambda_u^{m_i} \qquad [2.29]$$

where: g = the total sediment load for all sediment classes and $x_{(1)}$ = distance to downstream of the first segment.[21] The sediment load g_k of each sediment class at the end of the first segment is given by:

$$g_k = \psi_k g \qquad [2.30]$$

where: ψ_k = sediment mass in the *kth* sediment class (fraction). This special case is detachment limiting. Therefore, the distribution of sediment classes in the sediment load at the end of segment 1 for Case 1 where $dT_c/dx > D_i$ equals the distribution of the sediment classes at the point of detachment (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 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 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:

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[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.

$$D_{qk} = [(a_d V_{fk} / \sigma)/(1 + a_d V_{fk} / \sigma)][(dT_c / dx - D_i)\psi_k] \quad [2.31]$$

$$g_{qk} = \psi_k T_c - qD_{qk} / (a_d V_{fk}) \quad [2.32]$$

$$q = \sigma x_{(1)} \quad [2.33]$$

$$T_c = K_T \zeta q s \quad [2.34]$$

where: D_{qk} and g_{qk} 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 $x_{(1)}$ = the distance to the end of the first segment. The subscript k refers to sediment class. 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:

$$\omega_k = g_{qk} / \sum_{k=1}^{5} g_{pk} \quad [2.35]$$

where: ω_k = the portion of the total sediment load leaving the first segment that is composed of sediment in the *kth* sediment class and 5 is the number of sediment classes used in RUSLE2. The sediment load in each sediment class at the end of the first segment is computed as:

$$g_k = \omega_k g \quad [2.36]$$

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 on 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 upstream end of the *ith* segment. This transport capacity is computed using the runoff discharge rate q_{i-1}, the slope steepness s_i, and sediment transport capacity coefficient ζ_i for the ith segment. Therefore, transport capacity at the upstream end of the *ith* segment $T_{cu(i)}$ does not equal the transport capacity $T_{cl(i-1)}$ at the downstream 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 segment 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:

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

where: g_p = potential sediment load. The boundary condition is that this potential sediment load be less than transport capacity at the downstream 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:

$$g_{p(i)} = g_{(i-1)} + r_{10y24h} k_{(i)} S_{(i)} c_{(i)} p_{p(i)} p_{c(i)} p_{d(i)} \left(x_{(i)}^{m_i+1} - x_{(i-1)}^{m_i+1}\right) / \lambda_u^{m_i} \quad [2.38]$$

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:

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

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 downstream 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:

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

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.

[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.

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 the 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.

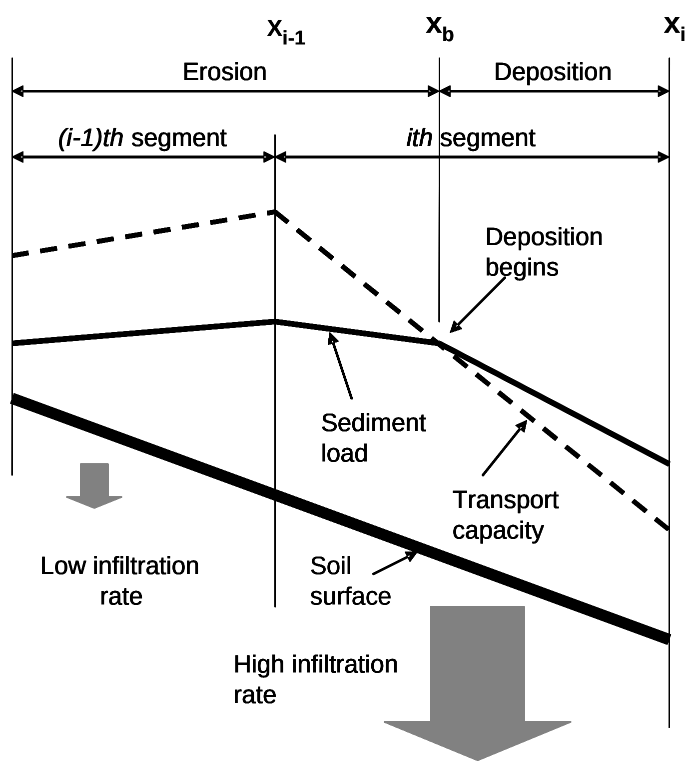

Figure 2.3. Illustration where detachment ends and deposition begins within the ith segment

Two conditions must be met for this case. The first condition is that the incoming sediment load is less than sediment transport capacity at the upstream 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 downstream 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:

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

where: g_b = sediment load at the location x_b = where deposition begins. The sediment transport capacity T_{cb} where deposition begins is given:

$$T_{cb} = K_T \zeta_{(i)} s_{(i)} \left[q_{(i-1)} + \sigma_i \left(x_b - x_{(i-1)} \right) \right] \qquad [2.42]$$

where: σ = the excess rainfall rate (rainfall rate minus 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:

$$g_{bk} = g_{k(i-1)} + \psi_k \left(g_b - g_{(i-1)} \right) \qquad [2.43]$$

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.

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[23] Excess rainfall rate is negative for situations where RUSLE2 computes a decreasing runoff rate within a segment (see **Section 3.3.1.1**).

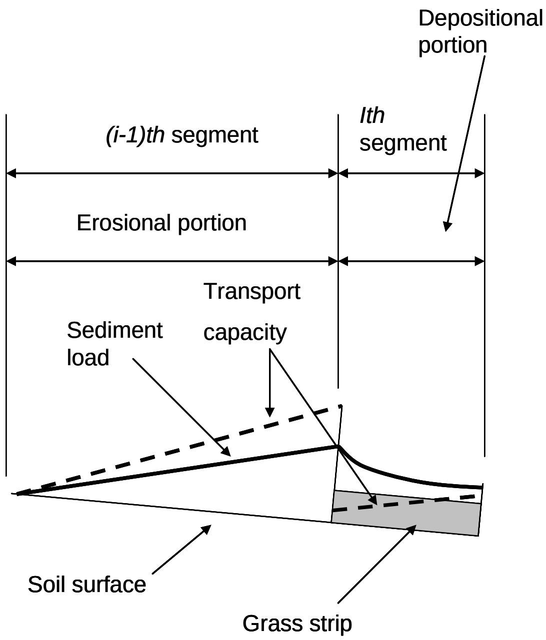

Figure 2.4. Narrow grass where deposition occurs over entire segment

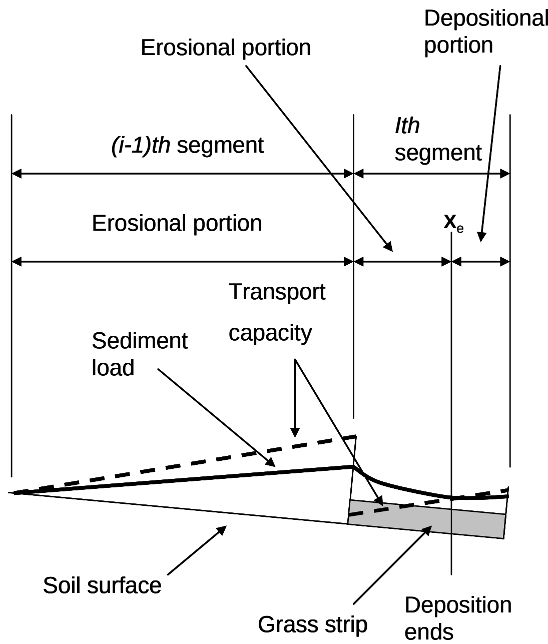

Figure 2.5. Grass strip sufficiently wide that deposition ends within segment and erosion occurs on lower portion of segment

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.

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. This boundary condition 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:

$$g_{p(i)} = g_e + r_{10y24h} k_{(i)} S_{(i)} c_{(i)} p_{p(i)} p_{c(i)} p_{d(i)} \left(x_i^{m_i+1} - x_e^{m_i+1} \right) / \lambda_u^{m_i} \qquad [2.44]$$

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:

$$g_{k(i)} = g_{ek} + \psi_k \left(g_{(i)} - g_e \right) \qquad [2.45]$$

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 with 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 for the representative storm. That sediment load g_{detcap} is computed as:

$$g_{\det cap(i)} = r_{10y24h} k_{(i)} S_{(i)} c_{(i)} p_{p(i)} p_{c(i)} p_{d(i)} \left(x_{(i)}^{m_i+1} - x_{(i-1)}^{m_i+1} \right) / \lambda_u^{m_i} \qquad [2.46]$$

The scaling factor δ_i for each *ith* segment is computed as:

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

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

$$g_{daily \det cap(i)} = r k_{(i)} S_{(i)} c_{(i)} p_{p(i)} p_{c(i)} p_{d(i)} \left(x_{(i)}^{m_i+1} - x_{(i-1)}^{m_i+1} \right) / \lambda_u^{m_i} \qquad [2.48]$$

where: $g_{dailydetcap(i)}$ = 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:

$$g_{daily(i)} = \delta_{(i)} g_{daily\,\det cap(i)} \quad [2.49]$$

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:

$$D_{daily(i)} = \left(g_{daily(i)} - g_{daily(i-1)}\right) / \left(x_{(i)} - x_{(i-1)}\right) \quad [2.50]$$

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: (1) average annual erosion rate for the entire overland flow path (sediment yield from the overland flow path), (2) average annual detachment rate for the entire overland flow path, (3) average annual erosion rate for the eroding portion of the overland flow path, and (4) 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:

$$G_{\lambda} = \left(\sum_{j=1}^{J_d} g_{daily\lambda(j)} \right) \Bigg/ M_d \quad [2.51]$$

where: G_{λ} = the average annual sediment load (i.e., sediment yield, sediment delivery) at the end of the overland flow path, gdaily$\lambda_{(j)}$ = the daily sediment load at the end of the overland flow path on the *jth* day, M_d = the number of years in the computation period

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[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.

(duration entered in cover-management description, see **Section 2.2**), and J_d = the total number of days in the computation period (i.e., $J_d = 365 \cdot M_d$). 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:

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

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 given by:

$$g_{\det(i)} = g_{\det(i-1)} + D_{i(i)}\left(x_{(i)} - x_{(i-1)}\right) + \Delta g_{r(i)} \qquad [2.53]$$

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**.

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

$$G_{\det\lambda} = \left(\sum_{j=1}^{J} g_{\det\lambda(j)}\right) \Big/ M_d \qquad [2.54]$$

where: $G_{det\lambda}$ = 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:

$$A_{\det} = G_{\det\lambda} / \lambda_o \qquad [2.55]$$

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:

$$G_{(i)} = \left(\sum_{j=1}^{J_d} g_{daily(i,j)} \right) \Big/ M_d \qquad [2.56]$$

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

$$D_{aseg(i)} = \left(G_{(i)} - G_{(i-1)}\right) / (x_{(i)} - x_{(i-1)}) / \left(x_{(i)} - x_{(i-1)}\right) \qquad [2.57]$$

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

$$A_{erod} = \left[\left(G_{(l1)} - G_{(u1)}\right) + \left(G_{(l2)} - G_{(u2)}\right) + \left(G_{(l3)} - G_{(u3)}\right) + \ldots\right] / \left[\left(x_{(l1)} - x_{(u1)}\right) + \left(x_{(l2)} - x_{(u2)}\right) + \left(x_{(l3)} - x_{(u3)}\right) + \ldots\right] \qquad [2.58]$$

where: A_{erod} = average annual erosion rate for the eroding portions of the overland flow path, the subscript l refers to the downstream end of an eroding portion of the overland flow path, the subscript u refers to the upstream 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 along an overland flow path as soil saved is computed as (Foster et al., 1997):[25]

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

where: $b_{d(i)}$ = the fraction of the deposition in the *ith* segment that is credited as soil saved (i.e., deposition benefit) and $x_{du(i)}$ = the location of the upper edge of deposition in the

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[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.

segment in which the deposition occurs. A significantly reduced benefit is computed when the deposition occurs close to the overland flow path end, which is the location x = λ. The credited deposition in a segment is computed as:[26]

$$\Delta g_{pb(i)} = \Delta gp_{a(i)} b_{d(i)} \quad [2.60]$$

where: $\Delta g_{pb(i)}$ = daily deposited sediment credited as soil saved (mass/width) and $\Delta g_{pa(i)}$ = the daily computed total deposition for the segment before any credit is taken (mass/width). The daily conservation planning sediment load along the overland flow path is computed as:

$$g_{cp(i)} = g_{cp(i-1)} + \Delta g_{pb(i)} + \Delta g_{i(i)} + \Delta g_{r(i)} \quad [2.61]$$

where: g_{cp} = daily conservation planning sediment load along the overland flow path, $\Delta g_{i(i)}$ = total interrill detachment within the segment (mass/width) and $\Delta g_{r(i)}$ = total rill detachment within the segment (mass/width). 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**.

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

$$G_{cp\lambda} = \left(\sum_{j=1}^{J_d} g_{cp\lambda(j)} \right) \Big/ M_d \quad [2.62]$$

where: $G_{cp\lambda}$ = the average annual sediment load for conservation planning.

The conservation planning soil loss is given by:

$$A_{cp} = G_{cp\lambda} / \lambda_o \quad [2.63]$$

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

Deposition occurs in terrace channels that are on a sufficiently low grade. The credit for soil saved computed for this deposition is computed with (Foster and Highfill, 1983; Foster et al., 1997):

$$a_{cpt} = a_{ty} \exp[-0.011(\lambda_t - 100)] \quad \lambda_t > 100 \quad [2.64]$$

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

$$a_{cpt} = 0.45 a_{ty} \quad \lambda_t \leq 100 \qquad [2.65]$$

where: a_{cpt} = the daily conservation planning sediment yield [average erosion for area (mass/area)] when deposition occurs in terrace channels, a_{yt} = daily sediment yield [average erosion for area (mass/area)] from terrace channels, and λ_t = terrace spacing (feet). The average annual conservation planning soil loss for conservation planning is:

$$A_{cp} = \left(\sum_{j=1}^{J_d} a_{cp(j)} \right) \bigg/ M_d \qquad [2.66]$$

2.3.10.5. Comments on conservation and erosion control planning variables

The values for all four of these conservation and erosion control planning variables 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 of the four will be the average erosion rate for the eroding portion of the overland flow path. In this example, this part of the overland flow path is from its origin to the location where deposition begins at the upper edge of the backwater created by the vegetation strip. 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 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. 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).

2.4. List of symbols

a = daily erosion (mass/area·day)

a_{cpt} = daily conservation planning soil loss for terraces (mass/area·day)

a_{yt} = daily average sediment yield expressed for terrace interval expressed as average erosion for area (mass/area·day)

a_k = erosion in *kth* crop stage (mass/area)

a_u = unit plot daily erosion (mass/area·day)

a_{us} = unit plot erosion for a single storm (mass/area)

A = average annual erosion (mass/area·year)

A_{cp} = average annual conservation planning soil loss (mass/area·year)

A_{det} = average annual detachment rate for the entire overland flow path (mass/time·year)

A_{erod} = average annual erosion for the eroding portions of the overland flow path (mass/area·year)

A_{sedyld} = average annual erosion rate for the overland flow path length (mass/area·year)

A_u = unit plot average annual erosion (mass/area·year)

b_d = deposition in a segment credited as soil saved (i.e., deposition benefit) (fraction)

b_r = **b** value, coefficient for ground surface) cover effectiveness for rill erosion ($percent^{-1}$)

c = daily cover-management factor (soil loss ratio) (dimensionless)

c_k = cover-management factor (soil loss ratio) for *kth* crop stage (dimensionless)

c_{pr}/c_{pi} = rill to interrill prior land use soil erodibility ratio

C = average annual cover-management factor (dimensionless)

D = daily detachment by rill and interrill erosion combined (mass/area·day)

D_{aseg} = average annual erosion for a segment (mass/area·day)

D_i = daily detachment by interrill erosion (mass/area·day)

D_i = interrill erosion rate (mass/area·time)

$D_{daily\,=}$ average daily net erosion for a segment (mass/area·day]

D_p = deposition rate in rill areas (mass/area· time)

D_{pk} = deposition rate for the *kth* sediment class (mass/area·time)

D_{puk} = deposition rate at the upstream end of a segment for the *kth* sediment class (mass/area·day)

D_{qk} = quasi-deposition rate in first segment for *kth* sediment (mass/area· time)

D_r = rill erosion rate(mass/unit area· time)

D_{rorp} = either rill erosion (D_r) or deposition (D_p) in rill areas (mass/area·time)

$\exp(-b_r f_g)/\exp(-0.025 f_g)$ = rill erosion surface cover effect to interrill erosion surface cover effect ratio

E = rain storm energy (force·length/area)

EI_{30} = rain storm erosivity (force·length/area)·(length/time)

f_g = ground (surface) cover (percent)

f_k = portion of average annual erosivity that occurs during *kth* crop stage (fraction)

g = sediment load (mass/unit overland flow width· time)

g_b = sediment load at the location where deposition begins within segment (mass/width· time)

g_{bk} = sediment load for the *kth* sediment class at the location where deposition begins within segment (mass/width· time)

g_{cp} = daily conservation planning sediment load (mass/width·day)

$g_{cp\lambda}$ = daily conservation planning sediment load at end of overland flow path (mass/width·day)

g_{daily} = daily sediment load (mass/width· day)

$g_{daily\lambda}$ = daily sediment load at end of overland flow path (mass/width· day)

$g_{dailydetcap}$ = daily sediment load that would be produced if detachment occurred at detachment capacity (mass/width· day)

g_{det} = daily sediment load produced by detachment (mass/width· day)

g_{detcap} = daily sediment load that would result from detachment at capacity rate (mass/width· day)

g_{ek} = sediment load where deposition ends for *kth* sediment class (mass/width· time)

g_k = sediment load for *kth* sediment class (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_{qk} = quasi-sediment load for *kth* sediment class rate for first segment (mass/width·time)

$G_{cp\lambda}$ = average annual conservation planning sediment load at end of overland flow path (mass/width·year)

$G_{det\lambda}$= average annual sediment load produced by detachment at end of overland flow path (mass/width·year)

G_{λ} = average annual sediment load (i.e., sediment yield, sediment delivery) at end of overland flow path (mass/width·year)

I_{30} = average intensity over the continuous 30 minutes with most rainfall in storm (distance/time)

J_d = number of days in computation period (J_d =365M_d)

k = daily soil erodibility factor (mass/erosivity unit)

K = average annual soil erodibility factor (mass/erosivity unit)

K_r/K_i = inherent rill to interrill soil erodibility ratio

K_T = sediment transportability coefficient (mass/volume)

l = daily slope length factor (dimensionless)

L = average annual slope length factor (dimensionless)

m = daily slope length exponent (dimensionless)

M_c = number of year in computation for cover-management computation

M_d = number of years in the computation period

M_k = number of crop stages in computation period

M_r = number of years in the record being used to compute erosivity

$M_{s(j)}$ = the number of storms in the *jth* year

n_i = number of sub-segments within the *ith* segment (integer)

n_o = 200, number of sub-segments for the entire overland flow path length, used to solve numerical deposition equation

p_c = daily contouring subfactor dimensionless)

p_d = daily subsurface drainage subfactor (dimensionless)

p_p = daily ponding subfactor (dimensionless)

P = average annual support practice factor (dimensionless)

P_{10y24h} = 10 year(return period)-24 hour (storm duration) precipitation amount (length)

q = overland flow (runoff) rate (volume/width·time)

q_0 = 0, discharge rate at x = 0 (mass/width·time)

r = daily erosivity (erosivity unit/area·day)

r_k = erosivity during *kth* crop stage (erosivity unit/area)

r_{10y24h} = storm erosivity associated with 10 year-24 hour precipitation amount P_{10y24h} (erosivity unit)

R = average annual erosivity factor (erosivity unit/area·year)

$(s/0.0896)/(3s^{0.8}+0.56)$ = steepness effect for rill erosion to interrill erosion ratio

s = overland flow path steepness (sine of slope angle)

S = average annual slope steepness factor (dimensionless)

S_i = slope steepness factor for interrill erosion

T_c = sediment transport capacity in rill areas (mass/overland flow width·time)

T_{ck} = transport capacity for *kth* sediment class (mass/width·time)

T_{clk} = sediment transport capacity at the downstream (lower) end of segment (mass/width·time)

T_{cuk} = sediment transport capacity at the upstream (upper) end segment (mass/width·time)

T_{cb} = sediment load where deposition begins (mass/width·time)

V_f = sediment fall velocity (length/time)

V_{fk} = sediment fall velocity for *kth* sediment class (length/time)

x = distance from origin of overland flow path (length)

x_b = location where deposition begins (length)

x_e = location where deposition ends (length)

x_{ud} = location of upper edge of deposition in a segment in which deposition occurs (length)

α_d = deposition coefficient (dimensionless)

β = daily ratio of rill to interrill erosion for unit plot length

δ = scaling factor used to compute daily sediment load

Δg_i = daily sediment load produced by interrill erosion in a segment (mass/width·day)

Δg_{pa} = daily sediment load deposited in a segment before any credit is taken for deposition benefit (mass/width·day)

Δg_{pb} = daily sediment load deposited in a segment credited as soil saved (mass/width·day)

Δg_r = daily sediment load produced by rill erosion in a segment (mass/width·day)

Δx = length of the distance step used in the numerical integration to compute deposition (length)

γ_m = the maximum monthly erosivity density at the location (erosivity unit/length)

ζ = coefficient for effect of hydraulic resistance on sediment transport capacity

K = the number of crop stages

λ = slope length (length)

λ_o = overland flow path length (length)

λ_u = unit plot length (length)

σ = excess rainfall length rate (rainfall rate - infiltration rate) (length/time)

ψ_k = sediment mass in *kth* sediment class (fraction)

indices

i = segment along overland flow path

j = year

k = crop stage

k = sediment class

m = storm

1 and 2 = subscript 1 for upstream (upper) end of distance step and subscript 2 for downstream (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 (return period)-24 hour (storm duration) 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, deposition in terrace channels, and the effectiveness of contouring (e.g., see **Section 7.1**). 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, and temperature into daily values.

3.1.1. Basic disaggregation procedure

The same basic disaggregation procedure is used for monthly temperature, 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 month and the daily value at the end of the month equals the mean of the monthly values for the current and next month 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 average monthly value of the variable being disaggregated, 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 minimums 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 average monthly value M_j. The value for t_c is determined so that the total area under the two linear lines equals the average monthly value M_j. The area under the two lines is given by:

$$M_{(j)} = t_c(Y_b + M_{(j)})/2 + (1 - t_c)(M_{(j)} + Y_e)/2 \qquad [3.3]$$

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

$$t_c = [M_{(j)} - (Y_e + M_{(j)})/2]/[(Y_b + M_{(j)})/2 - (Y_e + M_{(j)})/2] \qquad [3.4]$$

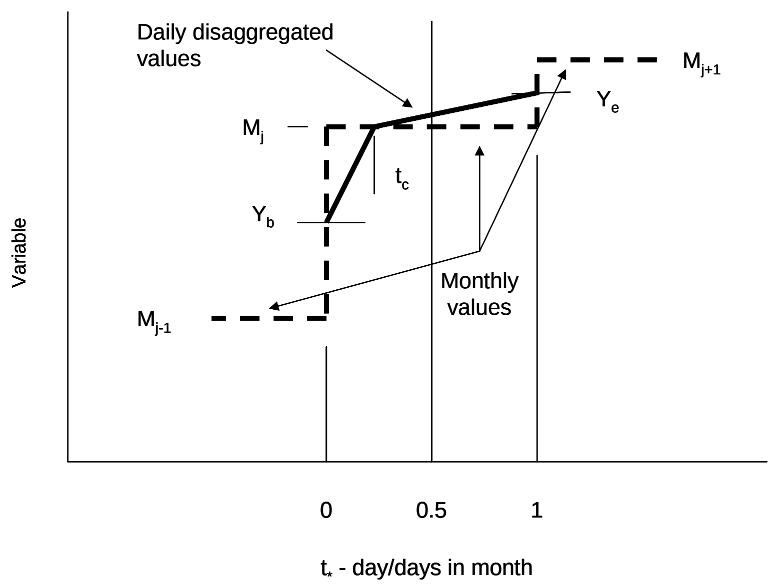

Figure 3.1. Illustration of two linear equations used to disaggregate monthly values into daily values for increasing or decreasing monthly values.

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

$$y_d = (d / D_{(j)})[(M_{(j)} - Y_b)/t_c] + Y_b \qquad [3.5]$$

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

$$y_d = (1 - d / D_{(j)})[(M_{(j)} - Y_e)/(1 - t_c)] + Y_e \qquad [3.6]$$

3.1.1.2. Local maxima and minima

Figure 3.2 illustrates a local maximum. The equations apply both to local maximums and minimums.

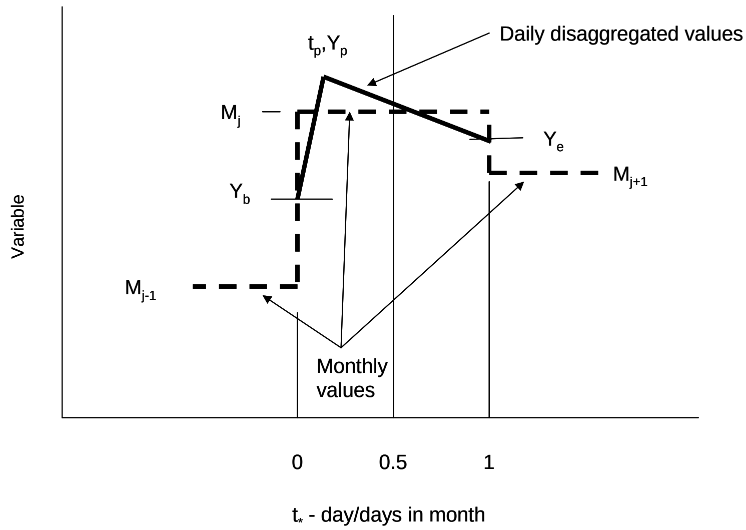

Figure 3.2. Illustration of two linear equations used to disaggregate monthly values for a local maxima or minima.

The daily value at the beginning and end of the month are computed using equations 3.1 and 3.2. The total area under the two lines must equal the average monthly value as:

$$M_{(j)} = (Y_b + Y_p)t_p / 2 + (Y_p + Y_e)(1 - t_p) / 2 \qquad [3.7]$$

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:

$$Y_p = 2M_{(j)} + t_p(Y_e - Y_b) - Y_e \qquad [3.8]$$

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

$$t_p = 1 - (M_{(j)} - Y_b)/(2M_{(j)} - Y_b - Y_e) \qquad [3.9]$$

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

$$y_d = (d / D_{(j)})(Y_p - Y_b) / t_p + Y_b \qquad [3.10]$$

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

$$y_d = [(Y_p - Y_e)/(1 - t_p)](1 - d / D_{(j)}) + Y_e \qquad [3.11]$$

3.1.2. Disaggregation procedure for temperature and erodibility

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

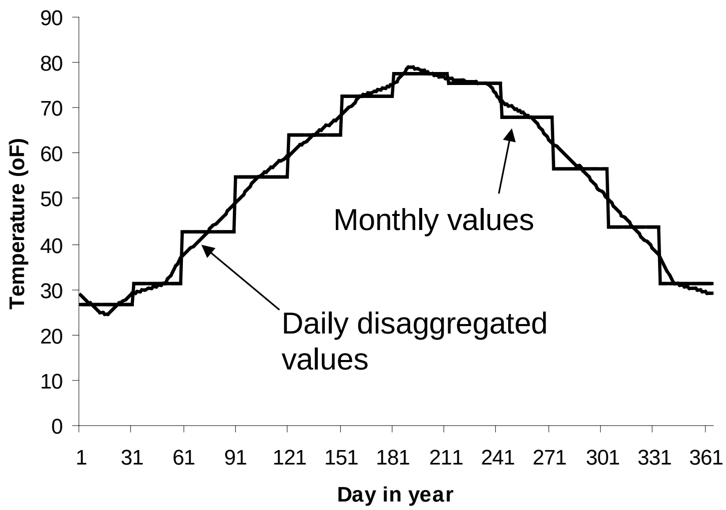

Figure 3.3. Daily temperature values obtained by disaggregating monthly temperature values at Columbia, Missouri.

3.1.3. Disaggregation procedure for precipitation and erosivity

When the disaggregation procedure is applied to monthly precipitation and erosivity, the average monthly value is divided by number of days in the month to obtain a mean daily value for the month. The disaggregation procedure is applied to the mean daily value in each month. Daily precipitation and erosivity values must be checked for negative values in very low rainfall areas like Yuma, Arizona. 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, Missouri.

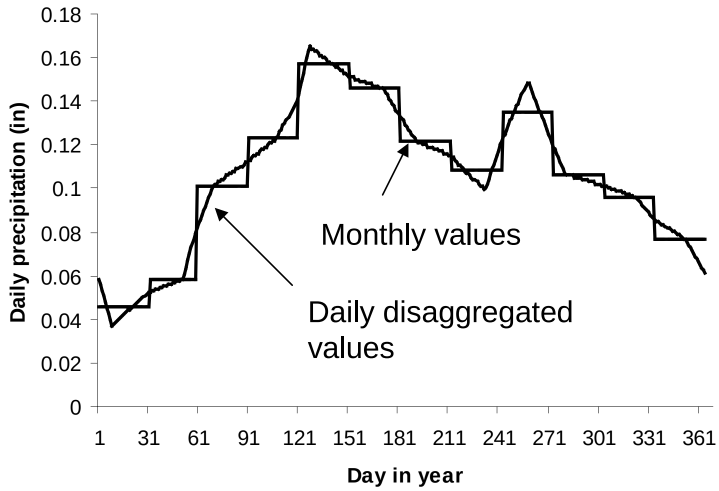

Figure 3.4. Daily precipitation values obtained from disaggregating monthly precipitation values at Columbia, Missouri.

3.2. Climate (weather) variables

The four basic RUSLE2 weather variables 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 daily erosivity values used to compute daily erosion (see **Section 3.1**). Monthly erosivity values can be input directly 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 values is to compute erosivity values for individual storms using measured weather data.

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[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, or (3) determined from input values for annual erosivity and the biweekly temporal distribution of erosivity.

3.2.1.1. Storm erosivity

Erosivity, the product of a 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 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 = unit energy (energy content per unit area per unit rainfall depth) in the *kth* period, and ΔV = the amount (depth) of rainfall in the *kth* period, k = 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., 1995; 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 RUSLE2computation of storm erosivity.

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 3700 15-minute precipitation gage locations across the Continental US (Hollinger et al., 2002). 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.

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[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.

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 application as a guide for conservation planning. 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 sometimes 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) between locations within geographic regions and between regions is just as important as the absolute erosion estimates computed with RUSLE2. Land users impacted by erosion prediction 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 at 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 land users 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 on-site soil resource from excessive degradation by erosion. 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 density 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 measured 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:

$$R_{m(j)} = \alpha_{(j)} P_{md(j)} \quad [3.15]$$

where: R_m = average monthly erosivity, α = average monthly erosivity density, and P_{md} = average monthly precipitation determined from daily precipitation gage data, all for the *jth* month. Erosivity density refers to the erosivity content per unit precipitation. Erosivity density for a month is computed from measured 15-minute precipitation data as:

$$\alpha = \frac{\sum_{i=1}^{n} E_{(i)} I_{30(i)}}{\sum P_{15}} \quad [3.16]$$

where: all values were determined from 15-minute precipitation gage data including precipitation amount P_{15} from all storms and storm energy E is computed using equations 3.13 and 3.14, i = the index for storm in a month and n = total number of storms greater than 12 mm but smaller than a 50-yr event in a given month. Unit energy e_k for each *kth* period is computed from the average intensity for each 15-minute period in the storm (i.e., $i_k = \Delta V_k/15$ minutes and V_k = the rainfall amount in the *kth* 15-minute period). The I_{30} values used in equation 3.16 using 15-minute precipitation data were multiplied by a 1.04 factor to account for the fact that maximum intensity values from the 15-minute precipitation data are slightly lower than those computed with breakpoint rainfall (Hollinger et al., 2002). Breakpoint rainfall data are data divided into non-uniform periods where constant rainfall intensity can be assumed for each period. Breakpoint data are preferred 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 $\hat{e}P_{15}$ where $\hat{e}$ = effective unit energy for a month (Foster et al., 1982d). By assuming a representative $\bar{I}_{30}$ for the month, erosivity density is approximated by:

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[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 Tennessee.

$$\alpha \approx \frac{\bar{I}_{30}\hat{e}\sum_{i=1}^{n} P_{15(i)}}{\sum_{i=1}^{n} P_{15(i)}} \qquad [3.17]$$

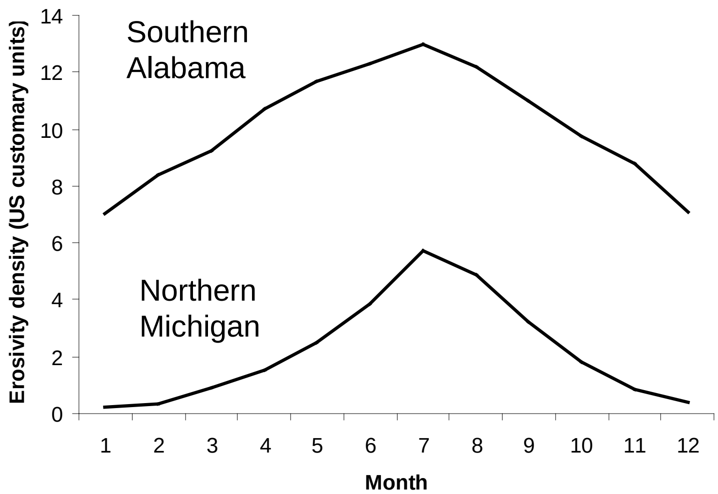

Figure 3.5. Erosivity density values for two locations.

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

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

Equation 3.18 shows that erosivity density varies directly with 30-minute rainfall intensity.

Erosivity density varies by location as illustrated in Figure 3.5 that shows that erosivity is 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 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]

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[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

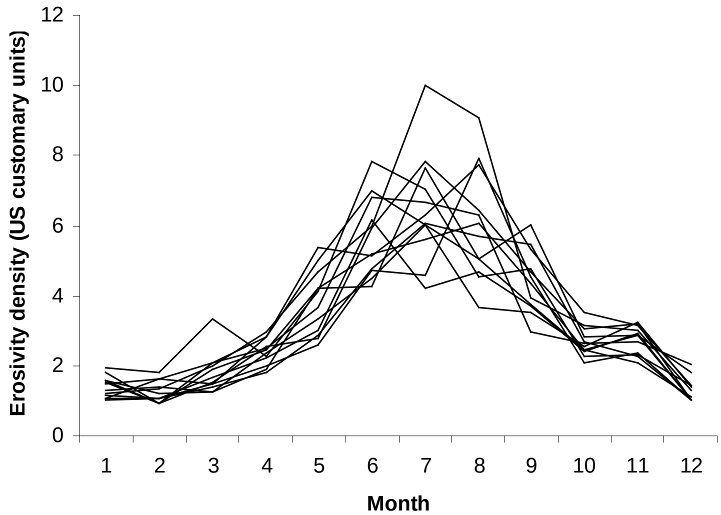

Figure 3.6. Spatial and temporal variability in erosivity density for locations in Southwestern Indiana.

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 data set), the outlier data point was adjusted to be consistent with other

values are computed from measured weather data collected by the National Weather Service. 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.

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.

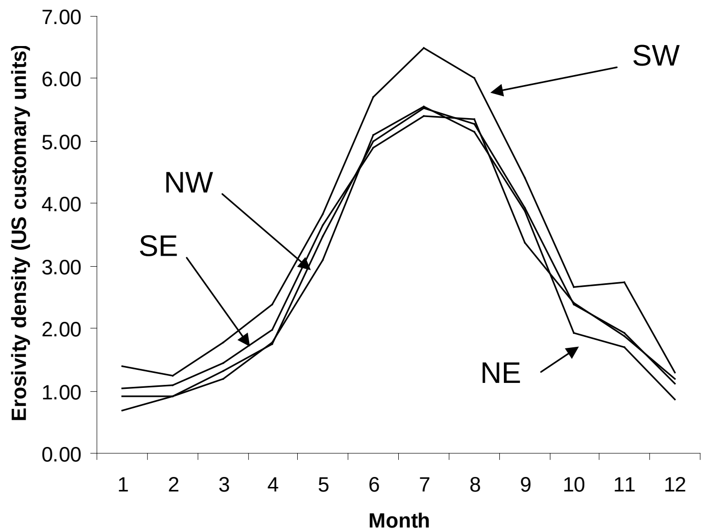

Figure 3.7. Erosivity density values spatially averaged for the four quadrants in Indiana.

A compromise was made in the number of nearest neighbors used in the kriging 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 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 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 result 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.

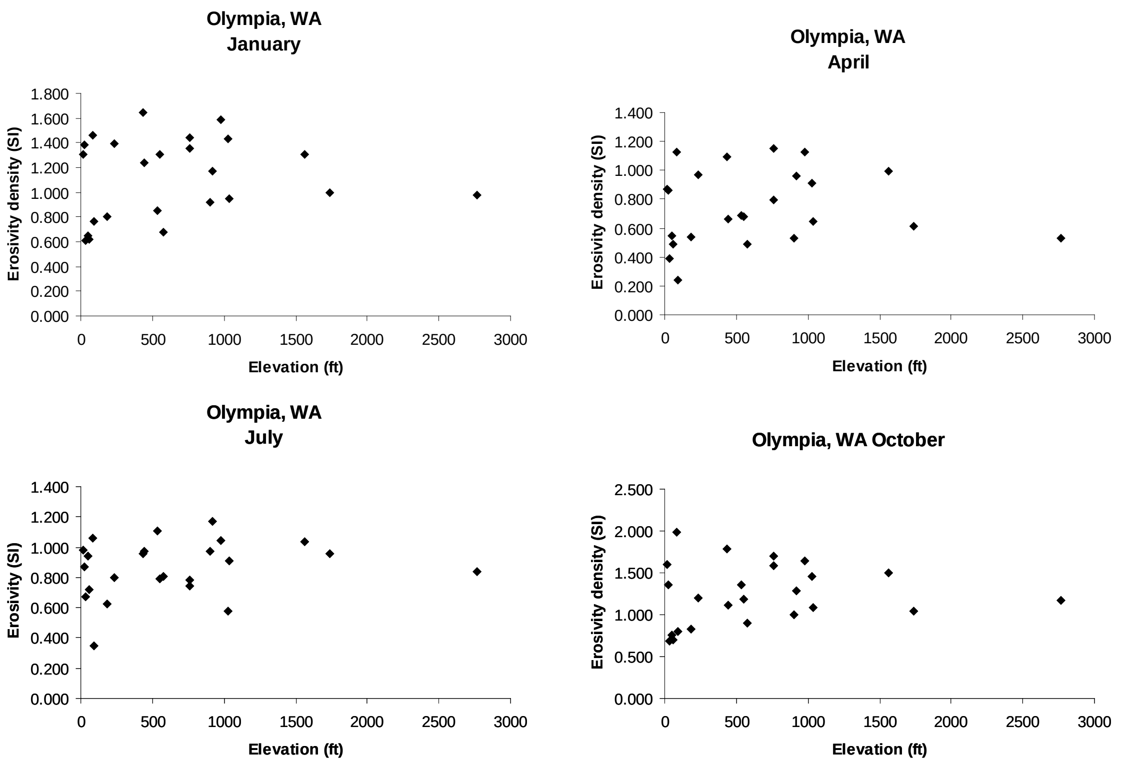

Figure 3.8. Variation of erosivity density with elevation in the Olympia, Washington region.

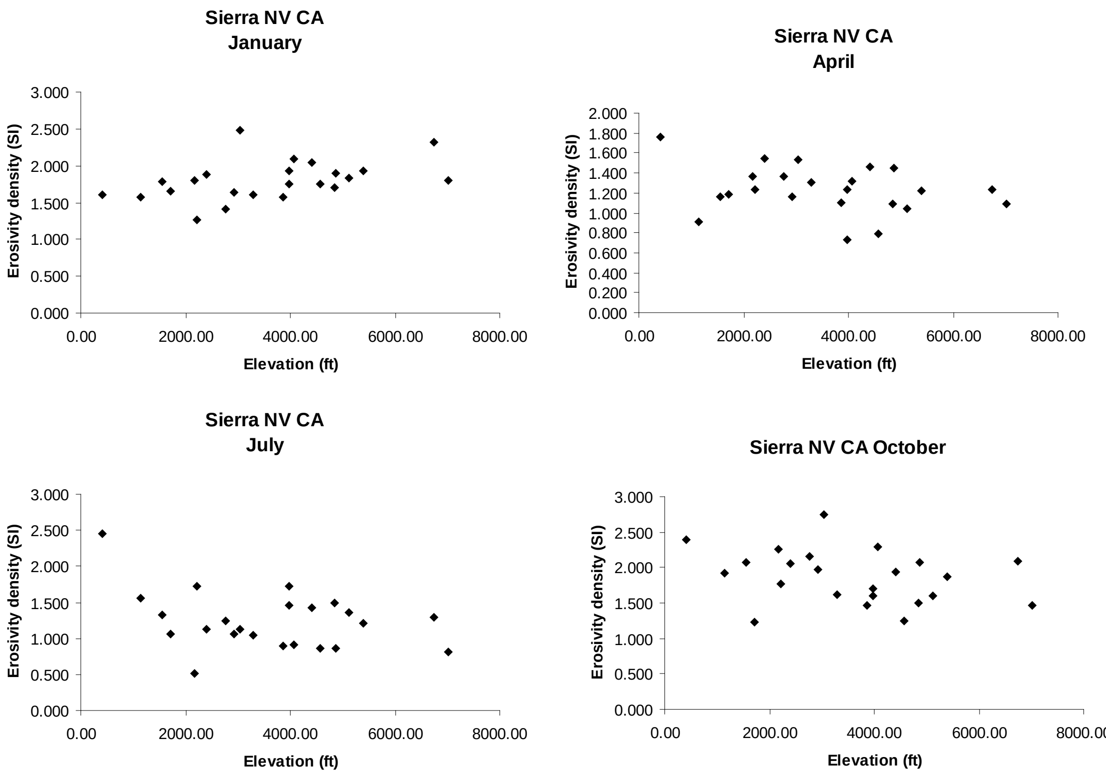

Figure 3.9. Variation of erosivity density with elevation in Sierra NV-CA region.

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

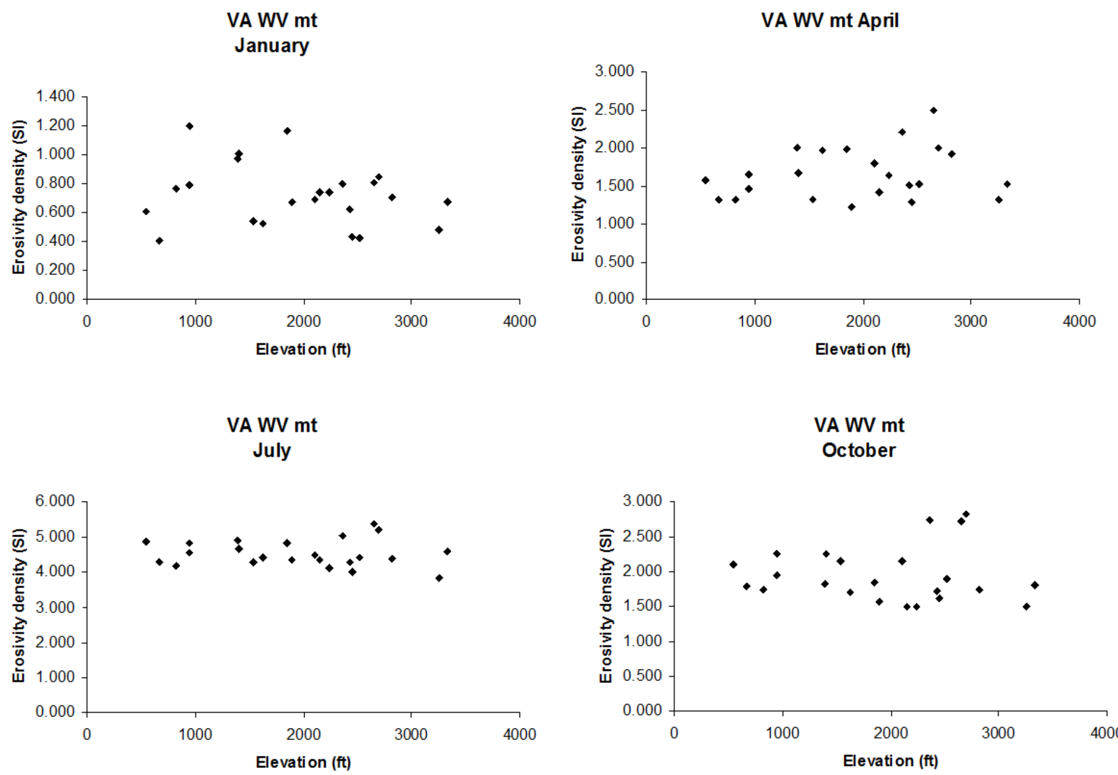

Figure 3.10. Variation of erosivity density with elevation in the West Virginia and Virginia mountainous region.

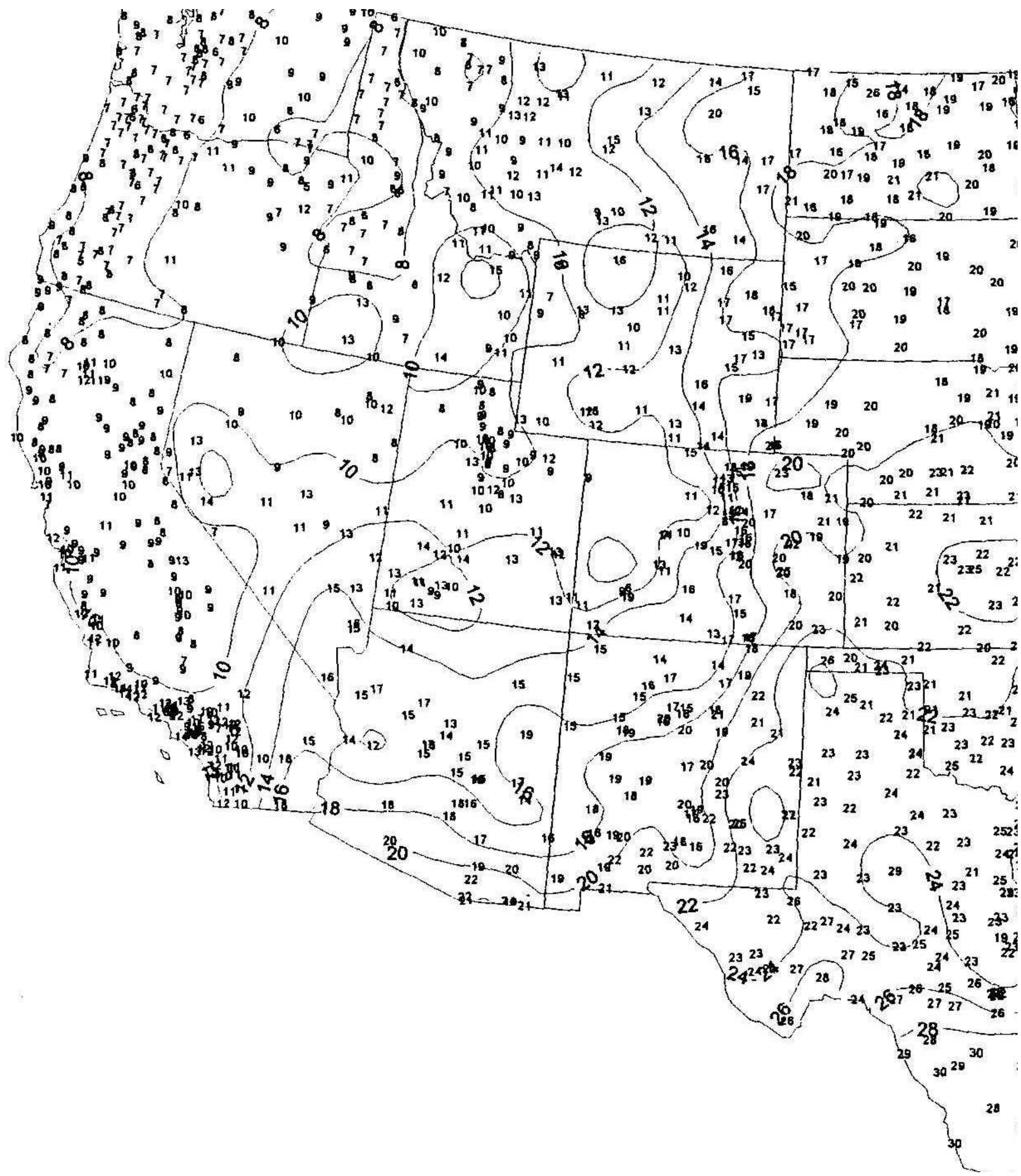

Figure 3.11. Average maximum 30 minute intensity computed for all storms. Source: Illinois State Water Survey (Hollinger et al., 2002).

3.2.1.4.2. Advantages of erosivity density approach

The erosivity density approach has major advantages. It produces 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.

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 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 standard 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.

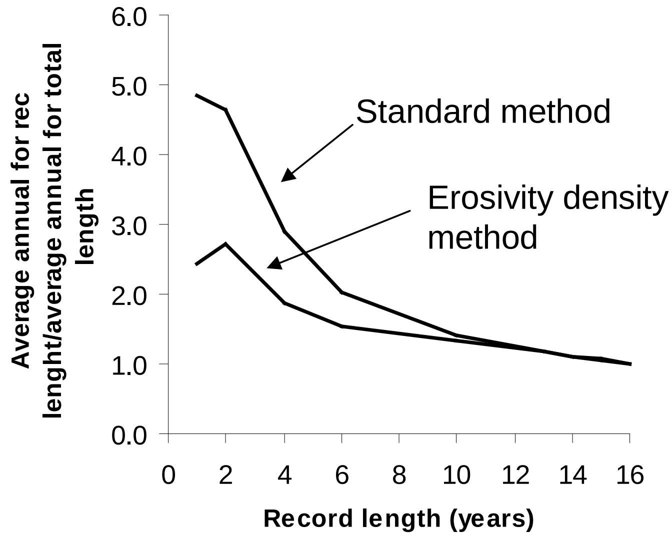

Figure 3.12. Effect of record length on variation of average annual values for erosivity and erosivity density for Beaver County, Utah.

Data for a gage location were not automatically discarded because of a short record length in the Western US in order to include as many 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 in 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):

$$r_s = a_p P_s^b \qquad [3.19]$$

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_p 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_p 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_p 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):

$$F = \frac{\sum_{j=1}^{12} P_{m(j)}^2}{\sum_{j=1}^{12} P_{m(j)}} \qquad [3.20]$$

where: F = the modified Fournier index, P_m = average monthly precipitation, and j = 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 3.2. Average annual erosivity values at these locations are plotted as a function of the modified Fournier index in Figure 3.13.

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

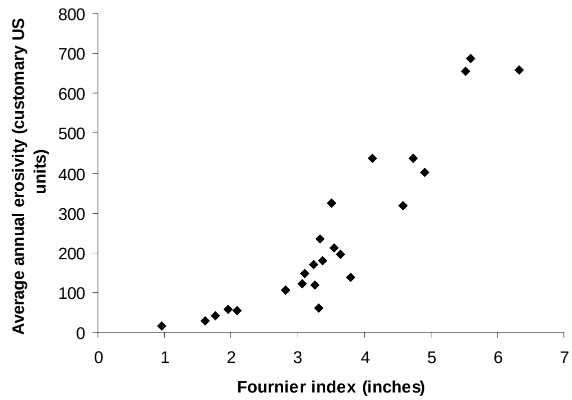

Figure 3.13. Relation of average erosivity to modified Fournier index for several US locations.

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:

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

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:

$$F_r = \frac{\sum_{j=1}^{12} P_{m(j)}^{z}}{\sum_{j=1}^{12} P_{m(j)}} \qquad [3.22]$$

$$R = a_r F_r \quad [3.23]$$

where: F_r = the modified Fournier index where a value for the exponent z 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.

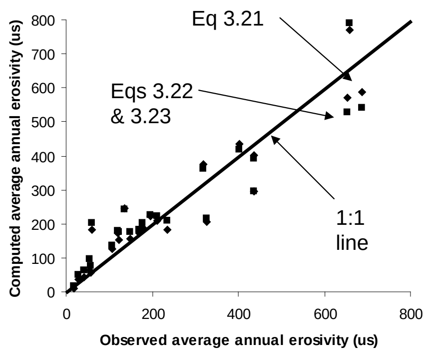

Figure 3.14 Comparison of alternate ways of using a modified Fournier index to estimate average annual erosivity.

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

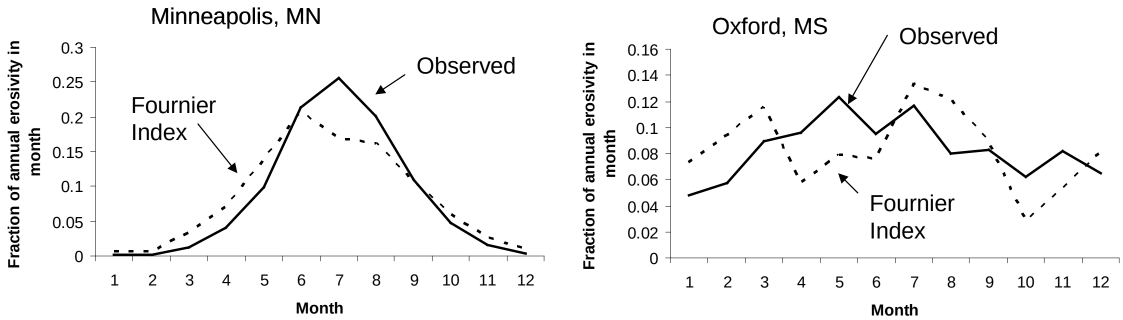

Figure 3.15. Comparison of monthly erosivity distributions computed with the modified Fournier index with observed monthly erosivity distributions.

conservation and erosion control planning. The data should be divided into subsets according to the relation of intensity to precipitation amount.

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, 1965, 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. The National Weather Service 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, National Weather Service, 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 variables that spatially affect precipitation. RUSLE2 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 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 when using RUSLE2 for conservation and erosion control planning.

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 observed temperature data do not seem be as 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 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 captured 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 computed a precipitation amount for the 10 year-EI storm using an empirical equation. This equations was derived by fitting storm erosivity values as a function of storm 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) that includes the eastern portions of Washington and Oregon and northern portion of Idaho. 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. 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).

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 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 highly saturated thawing soil produces a highly erodible soil 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.

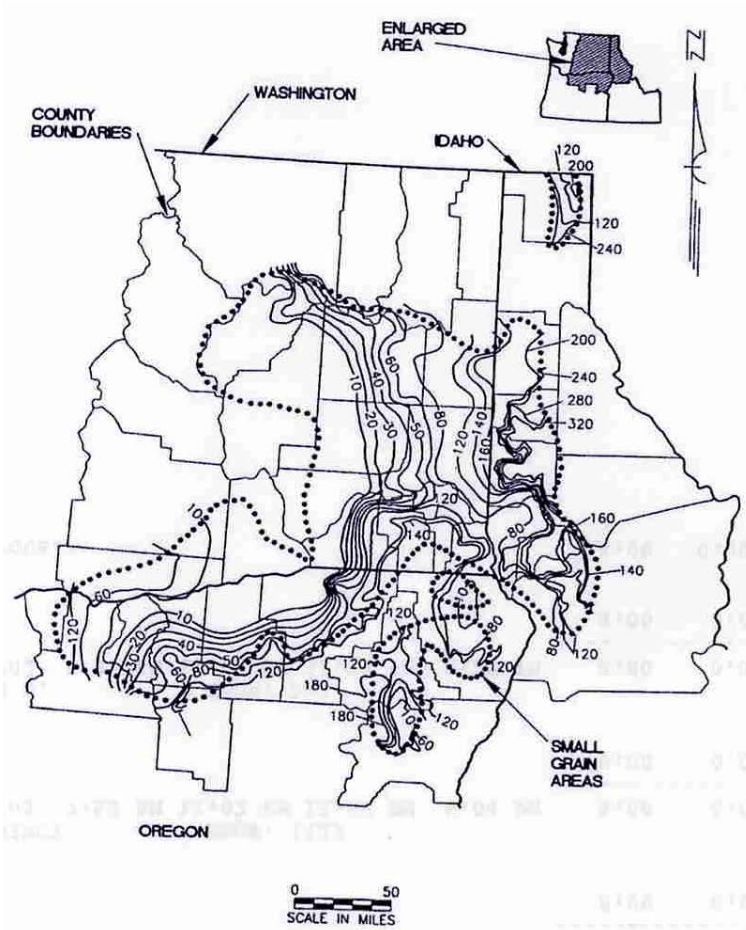

Figure 3.16. Area in Oregon, Washington, and Oregon where RUSLE2 Req procedure works best. Ignore contour lines.

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 3**) 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 northern 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 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 erosion, which is represented by a decreased soil erodibility value during that period. 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 index (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, 7 and 3.4.5**). This procedure captures runoff's main effects but not every detail. 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 divided by one hour. Rainfall depth 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) needed to produce runoff.

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 if P < 0.2S (see **Section 2.3.5**). The negative excess rainfall rate causes RUSLE2 to compute a decreasing discharge rate along the overland flow path.

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 including ground cover, soil surface roughness, soil biomass, and soil consolidation, change daily (see **Section 6**).

Equations were derived for RUSLE2 that compute curve number values as a function of cover-management variables and hydrologic soil group. First, curve number values was assigned to each hydrologic soil group for a wide range of cover-management conditions based on standard NRCS procedures for non-Req conditions and measured runoff from USDA-ARS research plots at Pullman, Washington for Req conditions. These curve number values are comparable to those used in RUSLE1. The equations used to compute RUSLE2 curve numbers were empirically derived using equation forms chosen to represent the trend of curve number values as a function of key cover-management variables. Coefficient values for these equations were obtained by fitting the equations to the assigned curve number values.

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 and the inherent potential of the soil for producing runoff. Hydrologic soil group is the variable used in RUSLE2 to represent the inherent runoff potential of the soil. 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, 3.26, 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 s_c 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. This curve number is decreased for increases in both 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 3**). 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:

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

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

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

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_{cl}, a_{clu}, a_{rl}, and a_{ru}, which vary with hydrologic soil group, are given in Table 3.3.

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:

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

where: N_{u45} = the curve number for a fully consolidated soil with no ground (surface) cover or soil biomass and soil surface roughness = 0.24 inches, 0.55 = the range in the soil consolidation subfactor s_c 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 and soil biomass.

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

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

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 runoff potential, i.e., hydrologic soil group A, than soils having high runoff 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:

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

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:

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

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

$$N_l = N_{u100} - s_l(1 - s_c) \quad [3.35]$$

where: s_l is computed from:

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

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

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

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 index curve number N_{lb45} used to calculate curve numbers for fully consolidated soil at high soil biomass with no ground cover are also given in Table 3.3.

Table 3.4. RUSLE2 (R2) curve numbers computed for Columbia, Missouri compared with curve numbers used in RUSLE1 (R1) for A, B, C, and D hydrologic soil groups

Cover-management condition		A		B		C		D	
R1 class	Description	R1	R2	R1	R2	R1	R2	R1	R2
C1	Established meadow, very dense cover with high soil biomass	30	45	58	64	71	71	78	78
C2	Mixed grass-legume hay, moderate cover, and moderate to high soil biomass	46	61	66	75	78	80	83	85
C3	Heavy cover (75-95%) or very rough with moderate biomass	54	46	69	62	79	70	84	77
C4	Moderate cover (40-65%) or rough with moderate soil biomass	55	54	72	66	81	75	85	81
C5	Light cover (10-30%), moderate roughness, and low to moderate soil biomass	56	61	75	70	83	76	87	82
C6	Essentilly no cover (5%), minimal roughness and low to moderate soil biomass	64	67	78	78	85	82	89	84
C7	Very little soil biomass and smooth	77	84	86	90	91	91	94	93
	Cut soil, no soil biomass without mulch		94		98		99		99
	Cut soil, no soil biomass with 4000 lbs/ac straw mulch		94 - 63		98 - 77		98 - 82		99 - 87
	Fill soil, graded smooth with no mulch		87 - 88		92 - 93		93 - 94		94 - 95
	Fill soil, graded smooth with 4000 lbs/ac straw mulch		81 - 85		86 - 90		89 - 92		91 - 94

Notes:

The curve numbers from RUSLE2 were taken at planting time because theRUSLE1 curve numbers are most applicable for that period.

The range in RUSLE2 curve numbers for the construction site conditions are for the 12 month period

A-hydrologic soil group (lowest runott potential) to D-hydrologic soil group (highest runoff potential)

RUSLE2 computed curve number values as shown in Table 3.4 along with the curve number values used in RUSLE1. RUSLE2 adequately captures the trends in curve numbers for land use that varies from construction sites to dense grass. RUSLE2 computes higher curve number values for the A-hydrologic soil group soils (low runoff potential) than those used in RUSLE1. However, the higher curve numbers are considered more appropriate for RUSLE2 applications. RUSLE2 also computes curve number values that are consistent with those reported for a wide range of land uses (Haan et al. 1994).

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 3.5 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 3.5. 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_{lb45}	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. A RUSLE2 input value used to describe non-erodible cover 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:

$$N = N_b(1 - f_\mu) + f_\mu[N_b f_\rho + 100(1 - f_\rho)] \qquad [3.38]$$

where: N = overall, effective curve number used in equation 3.25 or 3.27 to compute runoff, f_μ = fraction of the soil surface covered by non-erodible cover, f_ρ = 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 the 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.

A RUSLE2 input for subsurface drainage is the portion of the area represented by the overland flow path that is subsurface drained. RUSLE2 uses this input to compute an effective curve number value 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 increased soil moisture increases soil erodibility and residue decomposition and decreases soil surface roughness. 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 (force/unit area), γ = weight density of water (force/volume), y = flow depth (length), and s = overland flow path steepness (sine of slope angle). Flow depth is computed with the Manning equation as (Chow, 1959):

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

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 [q - ft3/(sec·ft width), y – ft] 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 form 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., 1982b).

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: T_c = sediment transport capacity (mass/width·time), and τ_g = grain roughness shear stress(force/aea). 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., 1982b):

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

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. Form roughness shear stress for computing contouring failure

3.4.3.1. Main equations

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

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

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[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).

where: τ_f = 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 form 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 value 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. Form roughness shear stress for contouring failure is computed with:

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

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 (feet) along overland flow path.[33]

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 include a moldboard plow in the spring for primary tillage, two secondary tillage operations to prepare the seedbed, row planter to seed the crop, row cultivator to control weeds, and harvest. Table 3.6 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 computed values are much longer than those given in AH537. The values computed by RUSLE2 are considered acceptable.

Table 3.6. Critical slope lengths

	Critical slope length (ft)	
Slope steepness (%)	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 form 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

[33] Mixed units are given in these equations for consistency with the equations used in the RUSLE2 computer program to facilitate a comparison of computer code with this documentation.

where runoff shear stress acting on form 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. 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 leave increased surface soil roughness and surface crop residue cover also increase RUSLE2 computed critical slope length as illustrated in Table 3.7.

Table 3.7. RUSLE2 computed critical slope lengths for three tillage systems for continuous 50 bu/ac corn.

	RUSLE2 computed critical slope length (ft)		
Slope steepness (%)	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 the soil's 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 conservation planning, and in that context, RUSLE2 is a major improvement over the USLE and RUSLE1.

3.4.3.2. Form roughness shear stress below segment having a high hydraulic roughness

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 form 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. Form 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 form 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 total Manning's n_t in the transitional region is:

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

where: n_{et} = Manning's n_t in the transitional zone, n_{tl} = the total Manning's n_t in the lower segment, Manning's n_{tu} = 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, erosion from other strip cropping systems was also studied at other locations (Borst et al., 1945; Hill et al.,. 1944; Hood and Bartholomew, 1956; Smith et al. 1945). RUSLE2 gives similar results for these systems discussed in AH703 (Renard et al., 1997; Foster et al., 1997).

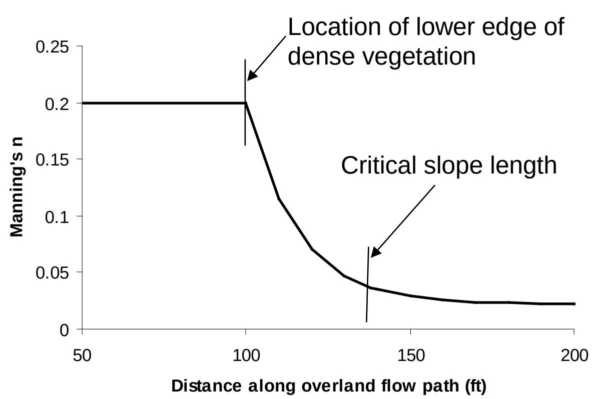

Figure 3.17. Decrease in Manning's n_t along overland flow path below a segment having a high Manning's n_t.

The reduction in form roughness shear stress by runoff spreading reduces the portion of an overland flow path where form 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., $P_{10y-24h}$ 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 form 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 form 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 form 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 form 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 form 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 form 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 form roughness shear stress at the upper end of the segment is less than the critical shear stress for contouring failure, and form 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 form 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 form 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 form 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 form roughness shear stress equals the critical shear stress for contouring failure. This location is computed with equations 2.18 and 3.46.

If form 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 form 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 form roughness shear stress within the segment is less than the critical shear stress for contouring failure, then form 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 form 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 form 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 form 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 form 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:

$$P_{cf} = (f_{Rd} / f_{Rmx}) P_{10y24h} \qquad [3.48]$$

where: P_{cf} = the daily precipitation amount used to compute contouring failure, f_{Rdj} = the fraction of the annual erosivity that occurs on the *jth* day, and f_{Rmx} = the fraction of the annual erosivity that occurs on the day when maximum daily erosivity occurs.[34] **The time varying precipitation computed with equation 3.48 is only used to compute contouring failure. It is not used anywhere else in RUSLE2.**

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., 1980a; Hayes et al., 1984; McGregor 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:

$$\Delta x_b = 3.44[n_t q_u / (1.49 s_{lh}^{0.5})]^{0.6} / s_{uh} \qquad [3.49]$$

where: Δx_b = the backwater length (ft), q_u = discharge rate (ft^2/s) at the upper edge of the segment having the high total Manning's n_t, s_{lh} = the steepness of the segment having the high Manning's n (**sine** of the slope angle), and s_{uh} = steepness of the immediately upslope segment (the **tangent** of the slope angle). 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 et al., 1999). The RUSLE2 computed backwater length was compared to

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[34] In an early version of RUSLE2, contouring failure was computed with the single precipitation P10y,24h precipitation amount. Runoff rate varies temporally only as cover-management variables varied temporally. Although RUSLE2 was calibrated to give the correct critical slope length, the timing of contouring failure was out of phase with precipitation during the year. Use of Equation 3.48 gave the correct timing for contouring failure.

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 lower edge of the segment having the high total Manning's n_t and decreases the length of the immediate downslope segment by the same amount except for the segment at the end of the overland-flow path.

3.4.5. Ponding

Water deeper than about 3 mm reduces raindrop impact erosivity (Mutchler, 1970; Mutchler and Murphree, 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 high 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 (inches), computed with P10y24h precipitation amount, 3.03 = a reference runoff depth (inches) selected to represent runoff and 0.01 = a reference overland flow path steepness to represent slopes typical of cotton production in the Mississippi Delta where the water depth effect is most highly important. This ponding effect has been studied by Mutchler et al. (1982), Mutchler and McGregor (1983), Mutchler and Murphree (1985), and McCool et al. (1987). This normalized flow depth is then used to compute a ponding subfactor value using:

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

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 3.8 where daily ponding values have been weighted by the temporal erosivity distribution (see **Sections 3.1** and **3.2.1**).

Table 3.8. 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:

$$n_t = 0.11[1 - \exp(-0.6 r_n)] + [0.075(f_g/100)/\exp(0.35 r_n)] + n_v + n_s \text{ if } n_t < 0.01, n_t = 0.01 \quad [3.52]$$

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

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 (surface) cover (percent) (see **Section 6.2**), n_v = Manning's n contributed by live vegetation (see **Section 9.2.6**), 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., 1980b; Foster, 1982; Foster et al., 1982a; Foster et al., 1997; Gilley and Finkner, 1991; Gilley and Kottwitz, 1994; Gilley and Kottwitz, 1995).

Equation 3.52 represents form and form 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_g of 0.01.

The ground (surface) 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.

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

$$n_{vmxc} = 0.017154 R_v + 3.82 \times 10^{-5} R_v^5 \quad [3.54]$$

where: n_{mvxc} = the Manning's n for live vegetation in rows on the contour at maximum canopy cover and R_v = 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.[35] Using these input retardance values listed in Table 3.9, 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.

Table 3.9. 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

Table 3.10. 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

The hydraulic roughness for vegetation 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_{vmxc}

[35] Assignment of retardance values considers the geometrical arrangement of the vegetation rows. For example, retardance for small grain represents the net retardance for multiple grain rows whereas the retardance for a narrow 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.

by a factor based on the user entered row width. Values for this factor are given in Table 3.10. 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:

$$n_{vrg} = n_{vud} + (n_{vc} - n_{vud})[1 - (s_r / s_{ud})^{1/2}] \quad [3.55]$$

where: n_{vrg} = vegetation Manning's n for the row grade s_r, n_{vc} = vegetation Manning's n for rows on the contour (perpendicular to the overland flow path), n_{vud} = vegetation Manning's n for rows parallel to overland flow path (i.e., up and down slope), s_r = row grade (tangent of slope angle), and s_{ud} = overland flow path steepness (tangent of slope angle).

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:

$$n_v = n_{vmx}(h_f / h_{fmx})^{0.3} \quad [3.56]$$

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

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:

$$n_s = n_{sk}(B_{td} / B_{tk}) \quad [3.57]$$

where: n_s = Manning's n for standing residue on day d, n_{sk} = Manning's n for the standing residue on the day that the live vegetation is killed, B_{td} = standing residue biomass (dry matter basis) on day d, and B_{tk} = the live vegetation biomass (dry matter basis) on the day that the vegetation is killed (see **Section 9.2.5**).

3.5. List of symbols

a_{cl} = a coefficient used to compute curve number values as a function of ground (surface) cover when surface roughness is less than 0.24 inches

a_{cu} = a coefficient used to compute curve number values as a function of ground (surface) cover when surface roughness is greater than 0.24 inches

a_f = coefficient used to compute form roughness shear stress

a_F = coefficient used to compute average annual erosivity from Fournier index

a_p = coefficient in equation that computes storm or daily erosivity from storm or daily precipitation

a_r = coefficient used to average annual erosivity from RUSLE2 modified Fournier index

a_{rl} = a coefficient used to compute curve number values as a function of soil surface roughness when soil surface roughness is less than 0.24 inches

a_{ru} = a coefficient used to compute curve number values as a function of soil surface roughness when soil surface roughness is greater than 0.24 inches

a_{45} = coefficient used to compute curve number values for fully consolidated soils as a function of ground (surface) cover

b= exponent in equation that computes storm or daily erosivity from storm or daily precipitation

b_B = a decay coefficient used how the curve number values decreases exponentially as a function of soil biomass

b_D = a decay coefficient used to compute how curve number values are affected by the interaction of the soil consolidation factor and soil biomass

B_s = soil biomass per unit depth (dry mass/area·soil depth)

B_{tk} = live above ground biomass on day that vegetation is killed (mass/area)

B_{td} = live above ground biomass on day d (mass/area)

D = number of days in the month

e = unit storm energy (energy content per unit area per unit rainfall depth) [force-distance/(area·length)]

$\hat{e}$ = effective unit storm energy directly (force-length)/(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 that represents the main effect of soil biomass on curve number values

f_d = fraction of area represented by an overland flow path that is subsurface drained

f_g = net ground (surface) cover (percent)

f_{Rd} = fraction of the annual erosivity that occurs on *jth* day

f_{Rmx} = fraction of the annual erosivity that occurs on day when maximum daily erosivity occurs

f_μ = portion of the soil surface covered by non-erodible cover (fraction)

f_ρ = portion of the non-erodible cover that is permeable (fraction)

F = the modified Fournier index

F_r = the RUSLE2 modified Fournier index

h_f = daily effective fall height for a particular vegetation description (length)

h_{fmx} = maximum daily effective fall height for the vegetation description (length)

i = rainfall intensity for a period during rainstorm (length/time)

I_{30} = maximum 30-minute intensity for a rain strom (length/time)

$\bar{I}_{30}$ = representative maximum 30 minute intensity for rain storms occurring in amonth (length/time)

m = number of periods in a storm used to compute storm energy

M = monthly value of climate variable being disaggregated

n = number of rainstorms in a month

n_{et} = 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_s = Manning's n contributed by standing residue

n_{sk} = Manning's n contributed by standing residue on the day that live vegetation is killed

n_t = total Manning's n

n_{tl} = total Manning's n_t in segment downslope of high hydraulic resistance segment

n_{tu} = Manning n_t in upslope high hydraulic resistance segment

n_v = Manning's n contributed by live vegetation

n_{vc} = vegetation Manning's n for rows (strips) on the contour (perpendicular to the overland flow path)

n_{vmx} = vegetation Manning's n at maximum growth in the vegetation description

n_{vmxc} = Manning's n for live vegetation in rows (strips) on the contour at maximum canopy cover

n_{vrg} = vegetation Manning's n for row grade s_r

n_{vud} = vegetation for Manning's n for rows up and down slope (parallel to overland flow path)

N = curve number in NRCS curve number method 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 = lower 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} = index 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 and the soil has been recently mechanically disturbed

N_{l45} = N_{lB} curve number adjusted for ground cover

N_{s100} = a starting curve number value for unit plot conditions

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_{u45} = the curve number for a fully consolidated soil with no ground (surface) cover or soil biomass and soil surface roughness = 0.24 inches

N_{u100} = curve number value that represents the effect of ground cover and soil roughness on curve number on a soil recently mechanically disturbed with no soil biomass

p_r = daily ponding subfactor

P = precipitation depth (length)

P_a = additional precipitation required so that zero runoff would be computed when infiltration is greater than precipitation (length)

P_{cf} = daily precipitation amount used to compute contouring failure (length)

P_{md} = 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} = storm precipitation amount determined from 15-minute precipitation gage data (length)

q = discharge rate (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 $q_i = x\sigma_i$ computed using excess rainfall rate in inches/hour rather than ft/sec

q_u = discharge rate at upper edge of segment having high hydraulic resistance (volume/width·time)

Q = runoff depth computed with NRCS curve number method (length)

r_a = adjusted soil surface roughness index (length)

r_n = adjusted soil surface roughness index used to compute Manning n for soil surface roughness (length)

r_s = storm erosivity (erosivity units)

R = average annual erosivity (erosivity units)

R_m = average monthly erosivity (erosivity units)

R_v= 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

s = overland flow path steepness (sine of slope angle)

s_c = soil consolidation subfactor

s_l = change in lower curve numbers per unit change in soil consolidation subfactor

s_{lh} = steepness of segment having high hydraulic resistance (**sine** of slope angle)

s_r = row grade (**tangent** of slope anagle)

s_u = change in upper curve number per unit change in the soil consolidation

s_{ud} = steepness of overland flow path (**tangent** of soil angle)

s_{uh} = steepness of segment immediately upslope of high hydraulic resistance segment (**tangent** of slope angle)

S = a variable in NRCS curve number equation used to compute runoff

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

T_c = sediment transport capacity (mass/width·time)

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 = flow depth (length)

y_d = daily value of climate variable being disaggregated

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

z = exponent in RUSLE2 modified Fournier index

α = average monthly erosivity density (erosivity units/length)

α_m = maximum monthly erosivity density

Δx_b = backwater length upslope of a segment having a high hydualic resistance (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_f = form roughness shear stress (force/area)

τ_g = grain roughness shear stress (force/area)

τ_t = total shear stress (force/area)

ζ = coefficient that has absorbed γ and the Manning's n_g for grain roughness

Indices

i – storm

j - month

k – period during a 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. These nomographs can be used to estimate soil erodibility factor values for most situations (See RUSLE2 User's Reference Guide), especially where the original soil profile has been disturbed.

The RUSLE2 soil erodibility factor is a measure of soil erodibility under unit plot conditions. These conditions empirically measure soil erodibility where cover-management effects 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 RUSLE2 erosivity variable and, therefore, should not be used in other erosion prediction technologies that use a different erosivity factor than the RUSLE2 erosivity factor. Conversely, soil erodibility factor values from other erosion models that use an erosivity factor that differs from the RUSLE2 erosivity factor can not be used in RUSLE2.

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. The RUSLE2 soil erodibility factor is a function of local climate in addition to soil properties 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. However, the RUSLE2 temproal soil erodibility equation described below takes location into account.

4.1.1. Standard soil erodibility nomograph

The standard soil erodibility nomograph (Wischmeier et al., 1971) was derived from erosion 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:[36]

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

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 (Wischmeier et al., 1971):

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

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

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 are:

$$k_{t68} = 2.1[68(100 - P_{cl})]^{1.14}/10000 \quad [4.4]$$

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

where: k_{t68} = base soil texture subfactor in soil erodibility nomograph when $P_{sl} + P_{vfs} > 68\%$.

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

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[36] Units for K and associated variables are US customary units

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**), but organic matter content values were not adjusted to unit plot conditions.

The organic matter relationship in the soil erodibility nomograph ***can 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. The definitions for those classes 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 must 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 consider landscape position.

For example, the permeability rating 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 input permeability rating should consider the presence of rock fragments. ***The permeability rating should not reflect current or past cover-management on runoff; it is a rating for the soil in unit plot condition*** (see **Sections 4.6 and 7.4** and RUSLE2 User's Reference Guide). The RUSLE2 temporal soil erodibility equation described in **Section 4.5** takes into account how the permeability rating varies as climate varies among locations.

The equation for the permeability subfactor is given by:

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

where: P_r = the soil profile permeability class.

4.1.2. RUSLE2 modified soil erodibility nomograph

Soil erodibility factor values computed with the standard soil erodibility nomograph do 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. This problem seemed most associated with the soil structure subfactor. 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 (Wischmeier and Mannering, 1969; Wischmeier et al., 1971). 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:

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

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. 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, the sand, silt, and clay content may be known for a soil, but 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:

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

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.

4.3. 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:

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

$$+ 0.35(P_{cl}/100)[1-\exp(-0.05P_{cl})]$$

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.

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

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., 1991a), 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. Conversely, soils very high in silt are assumed to have increased rill erosion relative to interrill erosion. Increased rill erosion relative to interrill erosion is expected because of reduced clay content that reduces soil cohesiveness, which increases rill erosion more than interrill erosion. In addition, soils high in silt produce increased runoff, which increases rill erosion more than interrill erosion.

Soils high in sand are more susceptible to rill erosion than interrill because of low clay content and reduced cohesiveness. However, offsetting the increase in rill erosion susceptibility is decreased runoff, which would 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 RUSLE1 procedures.

4.4. Geographic soil erodibility variability

Even when soil properties are identical, RUSLE2 soil erodibility factor values should 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 also vary with the temporal distribution of erosive precipitation because of the interaction between the temporal variation of erosive precipitation and the temporal variation of soil erodibility values [(AH703 (Renard et al., 1997)]. The temporal variation of erosive precipitation varies among locations

The RUSLE2 standard and modified soil erodibility nomographs do not take these factors into consideration. The data used to derive the standard 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 a greater 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 much greater effect on rill-interrill erosion than does the soil erodibility factor.

The temporal soil erodibility equation described in **Section 4.5** takes into account soil erodibility factor values vary with location as temperature and precipitation var with location. Also, the effect of rainfall amount, intensity, and temporal climate patterns are considered in RUSLE2 equations for estimating rill-interrill erosion 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 varies temporally (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**).

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).[37]

Although the reasons for soil erodibility varying temporally are partially known, adequate equations for temporal soil erodibility are lacking. The pattern for temporally varying soil erodibility seems well defined for plots at Morris, Minnesota and Holly Springs, Mississippi but not at other locations (Mutchler and Carter, 1983). A complication in making soil erodibility measurements is the coincidence 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.

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[37] 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**).

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 for these conditions are not usable because of very large variability. In many cases, measurements were not made during 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

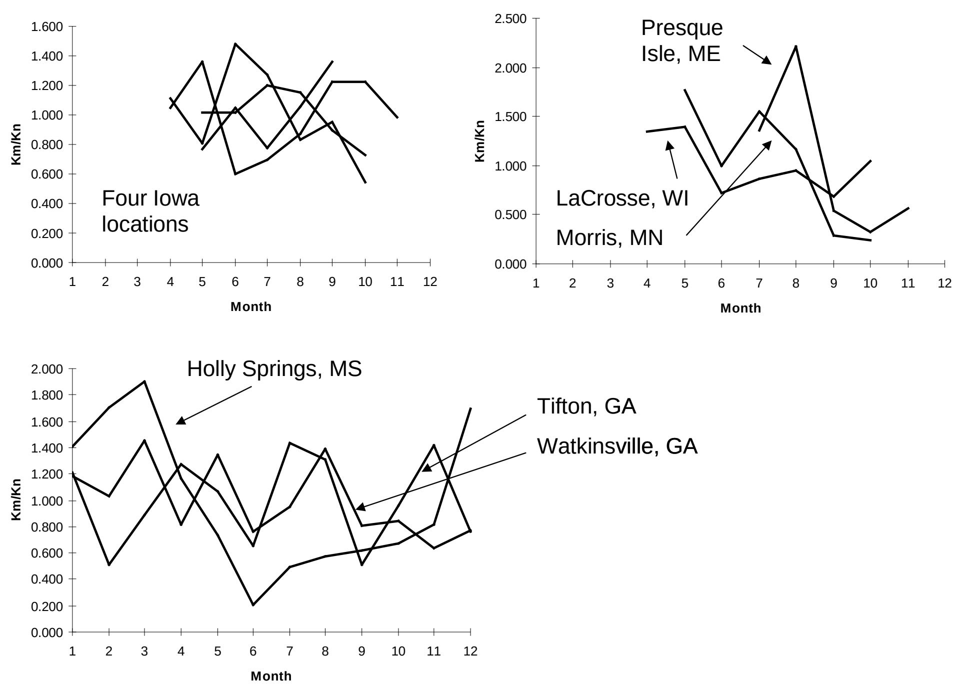

Figure 4.1. Monthly variation in soil erodibility at several locations.

RUSLE2. An equation for RUSLE2was empirically derived from these data.

4.5.1. Basic assumptions

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. The RUSLE2 summer period is defined for temporal soil erodibility purposes as the period 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.

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 referenced to summer conditions at location

Average values for the ratio of monthly soil erodibility to average soil erodibility for the RUSLE2 summer period were computed for the data collected at the locations listed in Table 4.2. Average soil erodibility for the RUSLE2 summer period 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 because the plots were not operated during the winter as can be seen in Figure 4.1. However, the plots were operated throughout the year in the southern US locations and the total data for the year were used to compute an average erodibility value for the southern locations.

The resulting equation from fitting the data is:

$$K_j / K_n = 0.591 + 0.732(P_j / P_s) - 0.324(T_j / T_s) \qquad [4.13]$$

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 4.13 does not describe increased soil erodibility during or immediately after soil thawing.

The fit of equation 4.13 to the observed data at three locations is shown in Figure 4.2, which also represents the fit at the other locations. Equation 4.13 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

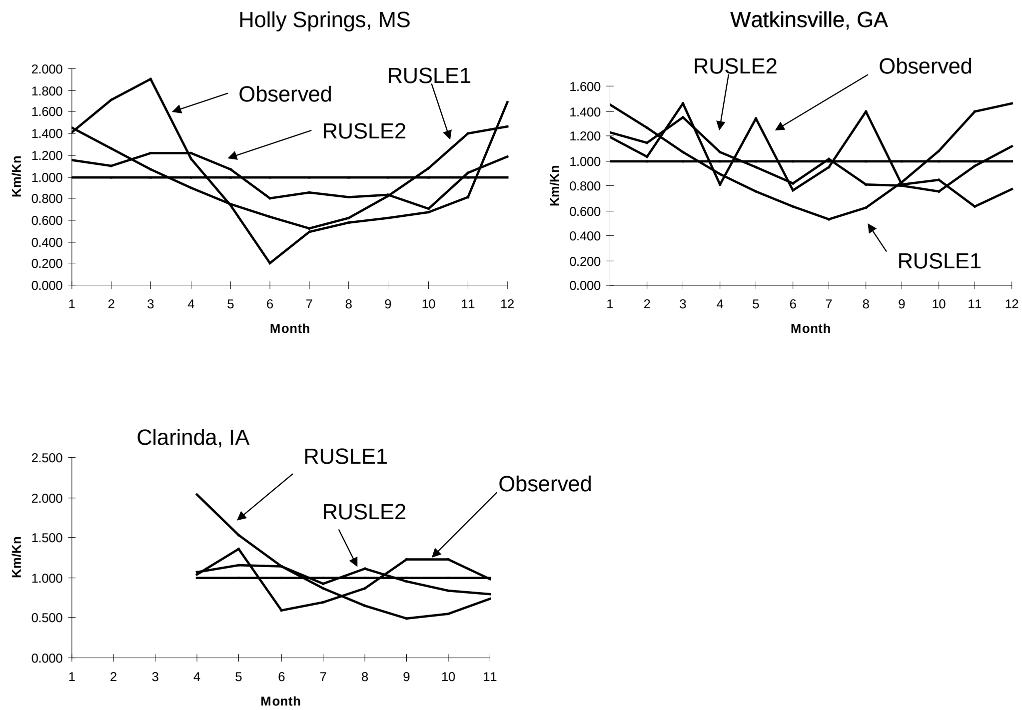

Figure 4.2. Fit of RUSLE2 temporal erodibility equation (equation 4.13), RUSLE1 equation, and constant value to observed data.

equation 4.13 is only slightly better than assuming a time invariant soil erodibility factor value for the summer period.

Computed values from equation 4.13 are shown in Figure 4.3 for Tombstone, Arizona and compared to values computed with the RUSLE1 equations and observed values. Very clearly, equation 4.13 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.[38] The observed values are not

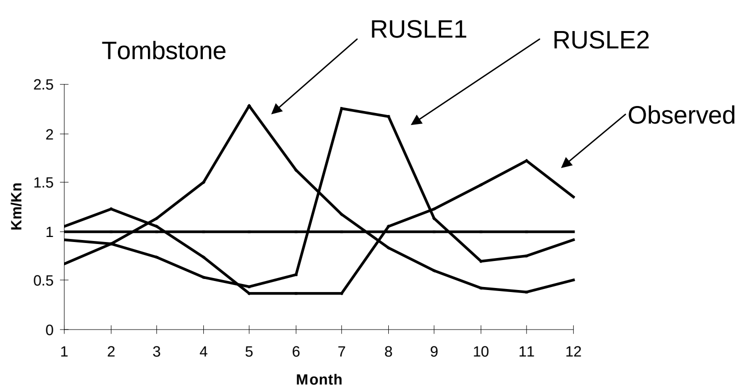

Figure 4.3. Fit of temporal erodibility equations to data from simulated rainfall on rangeland plots at Tombstone, Arizona.

JSDA-Agricultural Research
Service, Tucson, Arizona.

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 4.13 to the observed Tombstone, Arizona data is comparable to the fit of equation 4.13 to soil erodibility values produced by natural rainfall in the eastern US.

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).

4.5.3. Temporal soil erodibility for the summer period referenced to summer conditions at Columbia, Missouri

Equation 4.13 does acceptably well in capturing the relative temporal variations in soil erodibility at a location. Equation 4.13 is an improvement over using a constant soil erodibility factor at a location.

However, equation 4.13 gives exceptionally high soil erodibility values that do not seem reasonable in many western US locations. For example, equation 4.13 computes summer soil erodibility values at Tombstone, Arizona that are twice the average erodibility for summer period (i.e, the period that average daily temperature exceed 100 ^{o}F). The soil erodibility nomograph gives the same average erodibility for both Columbia, Missouri and Tombstone when soil properties are the same at the two locations.. However, the absolute July soil erodibility at Tombstone should not be higher than the absolute July soil erodibility at Columbia.

The root cause of the problem is that the soil erodibility nomograph is not a function of climate at a location. This deficiency does not cause major problems in the Eastern US, but it does cause great problems in the Western US.

To fix this problem, the P_s and T_s variables in equation 4.13 were changed from location values to values at Columbia, MO. The temporal soil erodibility equation referenced to Columbia, Missouri is:

$$K_j / K_n = 0.591 + 0.732(P_j / 0.123) - 0.324(T_j / 62.8) \qquad [4.14]$$

$$If\,(K_j / K_n) > 2.0 \text{ then } (K_j / K_n) = 2.0$$

$$If\,(K_j / K_n) < 0.4 \text{ then } (K_j / K_n) = 0.4$$

where: P_j = daily precipitation (inches), 0.123 (inches) = the daily average reference precipitation at Columbia, Missouri, T_j = the daily temperature (^{o}F), and 62.8 (^{o}F) = the daily average reference temperature at Columbia, Missouri. The j subscript is for the *jth* day. The reference precipitation and temperature value for Columbia, Missouri are for the time period that the average daily temperature is above 40 ^{o}F.

Either the standard or RUSLE2 soil erodibility nomographs can be used to determine a value for the nominal soil erodibility factor K_n, or another soil erodibility value can be used if values computed by the RUSLE2 soil erodibility nomographs are not applicable. The upper limit of 2 and the lower limit of 0.4 for the ratio K_j/K_n provides robustness by preventing extreme precipitation and temperature from excessively affecting daily soil erodibility factor values.

4.5.4. Temporal soil erodibility for the winter period

Equation 4.14 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:

$$K_{(j)} / K_n = (K_{s(j)} / K_n) \exp[-0.2(30 - T_{(j)})] \qquad [4.15]$$

where: $K_{s(j)}$ = the soil erodibility factor value computed with equation 4.14 on the *jth* day, T_j = the average daily temperature on the *jth* day (^oF), and 30 = the average daily temperature below which soil erodibility is reduced because of soil freezing (^oF). The *exp* term in equation 4.15 computes a K_j/Kn value less than 0.05 when average daily temperature is less than 15 ^oF. The exponential decay term in equation 4.15 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 4.15 is air temperature rather than soil temperature.

Equation 4.15 does not compute increased erosion during and immediately after soil thawing.

4.5.5. Temporal soil erodibility for winter and summer periods combined

Figure 4.4 shows temporal soil erodibility factor values computed for the entire year at selected locations. Note the difference in the mean soil erodibility factor value among the locatins for the same base soil erodibility factor value.

4.5.6. 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 4.14 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 4.15 does not apply where Req effects are assumed to occur (see **Section 3.2.5** and RUSLE2 User's Reference Guide).

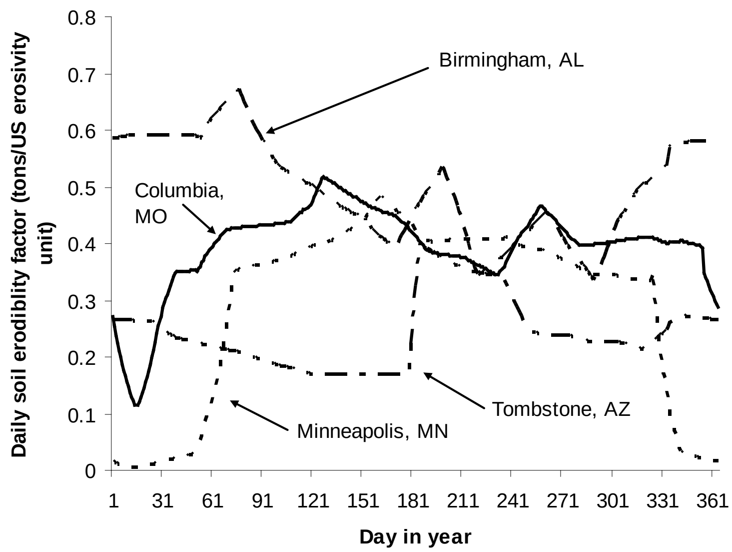

Figure 4.4. RUSLE2 computed temporal soil erodibility factor values for the same base soil erodibility factor value. The temporal soil erodibility factor equations are referenced to Columbia, Missouri.

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 and 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. 20-40=+1; 40-60=+2; 60-80=+3; >80=+4; max permeability is class=6 (very slow).

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 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., 1985b). The RUSLE2 intent in representing sediment characteristics is to capture main effects rather than precisely representing all variables that affect sediment characteristics at the point of detachment. Also, more detail, such as more than the five sediment particle classes used in RUSLE2 equations is desired for computing deposition. However, the desired information is not readily available for most RUSLE2 applications 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., 1985b). 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 assigned to the large aggregate class than to the small aggregate class because density decreases as aggregate size increases (Foster et al., 1985b).

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

4.7.3. Diameters of sediment particle classes

The diameters of the sediment particle classes are 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 where equation applies
Primary clay	d_{cl}	0.002	
Primary silt	d_{sl}	0.010	
Small aggregate	d_{sa}	0.030	$P_{cl} < 25$
	d_{sa}	$0.2(P_{cl}/100 - 0.25) + 0.03$	$25 \leq P_{cl} \leq 60$
	d_{sa}	0.100	$P_{cl} > 60$
Large aggregate	d_{la}	0.300	$P_{cl} \leq 15$
	d_{la}	$2P_{cl}/100$	$P_{cl} > 15$
Primary sand	d_{sd}	0.200	

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 used for 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. Distribution of sediment mass among particle classes at the poi				
Particle class	Fraction			
	Symbol		Condition	Comment
Primary clay	F_{cl}	$0.26P_{cl}/100$		
Primary silt	F_{sl}	$P_{sl}/100 - F_{sa}$		
Small aggregate	F_{sa}	$1.8P_{cl}/100$	$P_{cl} < 25$	
	F_{sa}	$0.45 - 0.6(P_{cl}/100 - 0.25)$	$25 \le P_{cl} \le 50$	If $F_{sl} < 0$, $F_{sl} = 0.0001$ and
	F_{sa}	$0.6P_{cl}/100$	$P_{cl} > 50$	$F_{sa} = P_{sl}/100 - F_{sl}$
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}	$(P_{sd}/100)(1 - P_{cl}/100)^5$		
Note:				
If the clay content of the large aggregate class is less than $0.5P_{cl}$, the value for F_{sa} must be reduced to meet this condition.				

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 as 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.[39] The RUSLE2 assumption is that the ratio of organic matter to clay on a mass basis is the same for all sediment particle classes where clay is present. That ratio is given by:

$$r_{om,cl} = P_{om} / P_{cl} \quad [4.16]$$

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.

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,

$$f_{cl,sa} = P_{cl} / (P_{cl} + P_{sl}) \quad [4.17]$$

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:

$$f_{sl,sa} = P_{sl} / (P_{cl} + P_{sl}) \quad [4.18]$$

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:

$$f_{om,sa} = r_{om,cl} f_{cl,sa} \quad [4.19]$$

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

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[39] The terms clay, silt, and sand sometimes refer to particle sizes. However, as used herein, clay, silt, and sand refer to mineral particles in the clay, silt, and sand sizes. The fractions of the primary particles sum to 1. Organic matter is not considered in determining fraction of the particles classes.

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

$$f_{cl,la} = (P_{cl}/100 - F_{cl} - f_{cl,sa}F_{sa})/F_{la} \quad [4.20]$$

$$f_{sl,la} = (P_{si}/100 - F_{si} - f_{sl,sa}F_{sa})/F_{la} \quad [4.21]$$

$$f_{sd,la} = (P_{sd}/100 - F_{sa})/F_{la} \quad [4.22]$$

Equations 4.20-4.22 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 4.20 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:

$$f_{om,la} = f_{cl,la} r_{om,cl} \quad [4.23]$$

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

Table 4.6. Specific surface area of soil/sediment constituents.

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

Each constituent of clay, silt, sand, and organic matter 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 area 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.1980a, 1980b; Foster et al., 1981a). 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:

$$E_r = S_{sed} / S_{soil} \qquad [4.24]$$

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 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 4.7. 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 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.

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 remains 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:

$$t_c = 20 \quad P_a < 10 \tag{4.25}$$

$$t_c = 26.5 - 0.65P_a + 0.5 \quad 10 \le P_a \le 30 \tag{4.26}$$

$$t_c = 7 \quad 30 < P_a \tag{4.27}$$

where: t_c = the time to soil consolidation (years) and P_a = annual precipitation (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 resistant 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., 1985b). Mechanical compaction of the soil is assumed to have little effect on this increase in erosion resistance in RUSLE2. 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 period 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 amount and reduced number of rainfall events. Equations 4.25 and 4.26 are based on judgment.

4.9. List of symbols

b = coefficient used to compute ground cover subfactor values

d_{cl} = diameter of primary clay sediment class (mm)

d_{la}= diameter of large aggregate sediment class (mm)

d_{sa}= diameter of small aggregate sediment class (mm)

d_{sd} = diameter of primary sand sediment class (mm)

d_{sl} = diameter of primary silt sediment class (mm)

E_r = enrichment ratio

$f_{cl.la}$ = mass portion of large aggregate sediment class composed of clay (fraction)

$f_{cl.sa}$ = mass portion of small aggregate sediment class composed of clay (fraction)

$f_{om,la}$ = mass portion of large aggregate sediment class composed of organic matter (fraction)

$f_{om,sa}$ = mass portion of the small aggregate sediment class composed of organic matter (fraction)

$f_{sd,la}$ = mass portion of large aggregate sediment class composed of sand (fraction)

$f_{sl,la}$ = mass portion of large aggregate sediment class composed of silt (fraction)

$f_{sl,sa}$ = mass portion of small aggregate sediment class composed of silt (fraction)

F_{cl} = mass portion of sediment at point of detachment composed of primary clay sediment class (fraction)

F_{la} = mass portion of sediment at point of detachment composed of large aggregate sediment class (fraction)

F_{sa} = mass portion of sediment at point of detachment composed of small aggregate sediment class (fraction)

F_{sd} = mass portion of sediment at point of detachment composed of primary sand sediment class (fraction)

F_{sl} = mass portion of sediment at point of detachment composed of primary silt sediment class (fraction)

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 for all soil textures

k_{t68} = base soil texture subfactor in soil erodibility nomograph when $P_{sl} + P_{vfs} > 68\%$.

K = soil erodibility factor[40]

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 for summer periods

K_r/K_i = rill to interrill soil erodibility ratio

$K_{s(j)}$ = soil erodibility factor computed with equation 4.14

O_m = inherent soil organic matter (percent)

P_a = annual precipitation (inches)

P_{cl} = portion of soil mass composed of clay based on total soil primary particles (percent)

P_j = average daily precipitation (inches)

P_{om} = 100 times ratio of mass of organic matter in soil to mass of soil mineral particles

P_r = soil profile permeability class used in soil erodibility nomograph

P_s = average precipitation for the RUSLE2 summer period (inches)

P_{sd} = portion of soil mass composed of sand based on total soil primary particles (percent)

P_{sl} = portion of soil mass composed of silt based on total soil primary particles (percent)

P_{vfs} = portion of soil mass composed of very fine sand based on total soil primary particles, not the portion of sand content (percent)

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[40] US customary units used for K and associated variables

$r_{om,cl}$ = mass portion of the primary clay sediment class composed of organic matter (fraction)

S_s = soil structure class used in soil erodibility nomograph

S_{sed} = specific surface area of sediment

S_{soil} = specific surface area of soil subject to erosion

t_c = time to soil consolidation (years)

T_j = average daily temperature for the *jth* day (^oF)

T_s = average temperature for the RUSLE2 summer period (^oF)

Indices

j - day

5. TOPOGRAPHY

This section describes mathematical consequences of RUSLE2's equation structure rather than providing additional equations except for the 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 provide RUSLE2's fundamental, underlying mathematical structure. Those equations accommodate spatial variability in soil, steepness, cover-management, and 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 Foster, 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

RUSLE1 requires users to select a slope length exponent value, m in equation 2.10, based on land use classes [AH703, (Renard et al., 1997); Toy and Foster, 1998]. The RUSLE1 slope length exponent is time invariant and thus does not change as cover-management conditions change temporally. Overland flow path steepness is the only variable considered in adjusting the slope length exponent in the USLE [AH537 (Wischmeier and Smith, 1978)].

A RUSLE2 major improvement is that it computes slope length exponent values as a function of overland flow path steepness, soil, and cover-management conditions. Consequently, the RUSLE2 slope length exponent varies as cover-management conditions vary temporally. RUSLE2 automatically computes slope length exponent values from basic input data rather than the user selecting a value as required by RUSLE1.

The slope length exponent should vary with position along the overland flow path according to erosion theory (Foster and Meyer, 1975). However, equation 2.10 is based on the assumption that the slope length exponent is a not a function of position x. The slope length exponent not varying with position greatly simplifies RUSLE2 mathematics and numerical procedures (see **Section 2.3**) and gives RUSLE2 increased robustness for overland flow paths longer than 150 ft (see **Section 5-Appendix I**).

If equation 2.10 is used to compute erosion for a slope length exponent that varies with position, RUSLE2 computes erroneous erosion values for a uniform overland flow path divided into segments, even if conditions are the same for all segments. Computed erosion should be independent of the number and length of segments used to represent a uniform overland flow path.

Some of the sediment produced by interrill erosion is deposited in "rill" areas when overland flow path steepness is low and interrill erosion is sufficiently high. RUSLE2 computes no rill erosion when it computes deposition. RUSLE2 computes this local deposition[41] 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). Interrill erosion is computed with equation 2.11, dT_c/dx is computed using equation 2.17, and deposition and net erosion is computed using equation 2.16 and its companion equations. RUSLE2-computed net erosion does not vary with distance along the overland flow path as expected (Renard and Foster, 1983; Meyer and Harmon, 1985).

Erosion values computed with equations 2.16 and 2.17 differ from values computed by the empirical USLE, which is equation 2.10. This inconsistency, which should not occur, results from RUSLE2 combining the empirical USLE equation with a process-based sediment transport capacity equation. These equations do not work well together for this condition. A choice must be made as to whether the USLE based erosion value or the process-based erosion value will be the RUSLE2-computed value.

A RUSLE2 development principle is that RUSLE2 compute erosion values agree with USLE computed values (see **Section 1**). The conflict between equation 2.16 and the USLE equation forms, therefore, is resolved by having RUSLE2 produce the same results as the USLE. However, RUSLE2 uses equation 2.16 to compute how local deposition change sediment characteristics.

This procedure works well for local deposition on a uniform overland flow path not subdivided into segments. Subdivision without changing any of the segment variable values should not affect computed erosion and sediment values. Subdivision does not

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[41] 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.

affect computed erosion values but does affect computed enrichment ratio values when RUSLE2 computes local deposition. The RUSLE2-computed enrichment ratio value is correctly computed when a uniform overland flow path is not subdivided.

RUSLE2 was constructed so that its remote deposition computations are independent of segment subdivision. An example of remote deposition is the deposition that occurs at the upper end of a 0.5 percent segment downslope from a one percent steep segment. RUSLE2 also computes local deposition on the 1 percent steep segment if interrill erosion is sufficiently great.

RUSLE2 makes these computations correctly if the upper one percent segment is not subdivided. However, if that segment is subdivided, it will compute erroneous enrichment ratio values, especially if the subdivision is near the upper end of the segment. The erosion values are affected only very slightly 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 sediment transport capacity equation used in RUSLE2. The enrichment ratio error could have been prevented by developing RUSLE2 entirely from process-based equations. However, RUSLE2's power of giving the well-accepted, empirically derived USLE values would have been lost. RUSLE2 was derived, developed, 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 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. Examples include the intersection a landfill's top with a sideslope and the intersection of a hillslope cut with a flat area. RUSLE2 assumes a step change in steepness to accommodate step changes in steepness common to constructed slopes. The effect of step changes in representing gradual soil and steepness changes along an overland flow path is minimized by dividing the overland flow path into several segments (see the RUSLE2 User's Reference Guide).

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.

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 to this problem is to have derived RUSLE2 using process-based 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 produce satisfactory results 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 **Sections 5.2** and **5.Appendix I**. The slope length exponent should be a function of upslope drainage area. If the slope length exponent is used as a function of upslope drainage area, the proper numerical procedure must be used. The irregular slope procedure derived by Foster and Wischmeier (1974) assumes that the slope length exponent does not vary with position along the overland flow path. If the slope length exponent is varied with the Foster and Wischmeier irregular slope procedure, erroneous erosion values will be computed (see **Sections 5.3** and **5.Appendix I**).

RUSLE2 is much more complex than the USLE or RUSLE1 regarding the rill to interrill erosion ratio used to compute slope length exponent values. RUSLE2 may be used in GIS applications to represent complex topography where distance along an overland flow path is assumed to be comparable to upslope drainage area. Such applications should be made ***only*** **where infiltration rate varies little spatially and where convergence or divergence of overland flow is minimal.**

A much better approach than using the RUSLE2 equations is to derive separate rill erosion, interrill erosion, and deposition equations using RUSLE2 assumptions, concepts, and equations. In this 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 independent of upslope drainage area.

A common error in using the USLE and RUSLE1 in GIS applications is that excessively long overland flow path lengths are assumed. Inadequate resolution in topographic data, 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 is collected in concentrated flow areas within 200 ft on most farm fields (Foster, 1985).

When using GIS applications to compute erosion, deposition, and sediment yield, separate relationships should be used to compute sediment production and sediment transport capacity needed to compute deposition. Desmet and Govers (1996) illustrate this procedure.

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 (see **Section 5.2**).

5.5.2. 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 = 0.5 (McCool et al., 1989, 2002); [AH703, (Renard et al., 1997)]. 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 Req locations. 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 ^{o}F early in the year to the day average daily temperature falls to 35 ^{o}F late in the year (see **Section 4.5.1**).

5.6. Steepness effect on rill-interrill erosion

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

An interrill erosion steepness factor is used in equation 2.11 and 6.13 to compute interrill erosion and to compute the rill to interrill erosion ratio in several equations (e.g., equations 2.13). A steepness relation for rill erosion is needed to compute rill erosion (e.g., equation 6.13) and the rill to interrill ratio in several equations including equations 2.13. Also, a steepness factor equation is needed to compute rill-interrill erosion combined in equation 2.10.

The same equation used for interrill erosion in RUSLE1 is also used in RUSLE2 [Foster, 1982; AH703 (Renard et al., 1997)]:

$$S_i = 3s_i^{0.8} + 0.56 \qquad [5.1]$$

where: S_i = the interrill erosion steepness factor, s_i = steepness of the interrill area (sine of slope angle). Equation 5.1 is referenced to the unit-plot steepness so that the equation gives a value of 1 for nine percent steepness. The interrill steepness is the same as the overland flow path steepness in RUSLE2. However, the overland flow path steepness and the interrill steepness are not always the same as the land steepness. An example is when RUSLE2 is used to compute erosion on ridge side slopes, where the interrill and overland flow path steepness equals the steepness of the ridge side slopes (see RUSLE2 User's Reference Guide).

A simple rill erosion equation is assumed to compute the rill to interrill erosion ratio (Foster and Meyer, 1975). The steepness factor for rill erosion is:

$$S_r = s_r / 0.0896 \quad [5.2]$$

where: S_r = the rill erosion steepness factor and s_r = steepness of the rill area (sine of slope angle). This steepness factor is normalized to the nine steepness of the unit plot. The steepness of the rill area is the same as the overland flow path steepness, which can differ from the land steepness.

A third steepness factor is used to compute rill-interrill erosion in equation 2.10. The relationship of rill-interrill erosion for a wide range of studies is shown in Figure 5.1 (McCool et al., 1987). These erosion data were normalized to the erosion for 20 percent steepness rather than to the unit plot nine percent steepness.

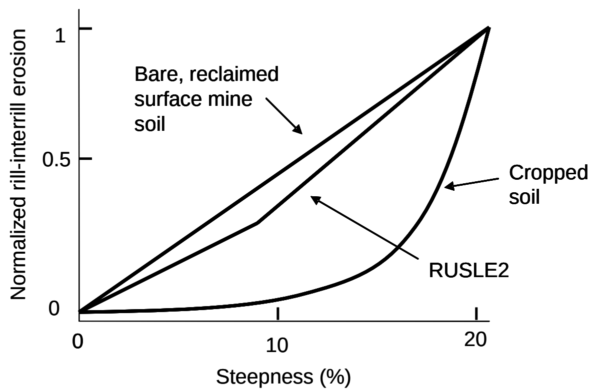

Figure 5.1. Effect of slope steepness on rill-interrill erosion.

The steepness factor for rill-interrill differed greatly among cover-management conditions. At one extreme is where erosion varied linearly for a bare reclaimed, surface mine soil. Steepness had little effect on runoff in this case. At the other extreme is erosion for a cropped soil where the relationship between erosion and steepness is very non-linear. In this case, runoff increased as steepness increased. 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 resulting rill erosion equation would have 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., 1975b; Foster, 1982; Graf, 1971; Foster et al., 1980a).

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)]:

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

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

where: S = steepness factor in equation 2.10, s = overland flow path steepness (sine of slope angle) and s_p = overland flow path steepness (100 times tangent of slope angle). Equations 5.3 and 5.4 give a value of 1 referenced to the unit plot 9 percent 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)]:

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

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

where: 0.0896 = the sine of the angle for 9 percent unit plot steepness. Equations 5.4 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)

Equation 2.10 does 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., 1975ab). Therefore, equation 2.10 is 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 5.1, 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 $(15/72.6)^m S_i$ where S_i 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 5.1, 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 5.1. 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 5.1, 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 5.1, at a 3 ft overland flow distance to the rill-interrill steepness factor, equation 5.4, at a 15 ft overland flow distance. This interpolation is computed as:

$$\alpha_3 = (3/72.6)^m S_i \qquad [5.7]$$

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

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 5.1, is used to compute and S = the rill-interrill steepness factor, equation 5.3, 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 an 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). Erosion control practices resulting in an estimated erosion rate that is less than the allowable erosion rate are considered to provide adequate erosion control for the site. Soil loss tolerance (T) values assigned to soil mapping units in the USDA-NRCS Soil Survey are widely used for allowable erosion rate on croplands.[42] Other values for the erosion control criteria are used when RUSLE2 is applied to other lands including construction sites and rangelands. For example, very low soil loss tolerance values are used for very fragile soils that are easily damaged by erosion. Soil loss tolerance values larger than those used for cropland are often used for construction sites for the disturbance and reclamation periods. However, cropland soil loss tolerance values are used for the after-reclamation period where maintenance of the soil for long-term vegetation production is the primary erosion control concern.

Erosion is not considered 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 for the entire overland flow path, rather than maximum erosion rate, 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 the 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 ($x = \lambda$). Therefore, erosion rate over the approximate lower one half of uniform overland flow paths 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 along an overland flow path 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 value puts conservation planning on the same basis for non-uniform overland flow paths as for a uniform overland flow path. The adjusted soil

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[42] Soil loss tolerance (T) values have a specific definition in the NRCS Soil Survey and NRCS RUSLE2 applications. However, T in general RUSLE2 applications refers to the erosion control criteria used in a specific RUSLE2 application. This value can be quite different from the assigned NRCS T value depending on the application. See the RUSLE2 User's Reference Guide.

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)]:

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

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 the position of the *jth* segment along the overland flow path, x_j = distance to the lower end of the *jth* segment, m_j = slope length exponent for the *jth* segment, and λ = 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 the location where the deposition occurs along the overland flow path. This type of deposition, which is referred to as remote deposition, occurs on concave overland flow path 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**.

Partial credit for deposition as soil saved also is taken with terraces. The deposition credit decreases as terrace spacing increases beyond 90 ft. However, the credit for deposition remains constant for terrace spacing closer than 90 ft.

High ridges spaced about 3 ft apart on a uniform, nearly flat grade act like small terraces. RUSLE2 can be applied to the ridge side slopes just like RUSLE2 is applied to the inter-terrace interval. The furrows between the ridges act like terrace channels. The deposition in the furrows should be treated as local deposition rather than remote deposition. The conservation planning soil loss that RUSLE2 computes for this case incorrectly assumes that this deposition is remote deposition. The user should ignore the conservation planning soil loss and use sediment yield as the conservation planning soil loss.

5.10. List of symbol

a = coefficient that is product of terms that do not vary with x in $D = ax^m$

a_e = product of terms that do not vary with x in $D = a_e x_e^m$ when x_e is the overland flow distance adjusted in proportion to upslope drainage area for converging runoff surface

a_p = product of terms that do not vary with x in equation $D = a_p x^m$ when runoff streamlines are parallel

a_T = product of terms that do not vary with x in sediment transport capacity equation $T_c = a_T q$

A = average combined rill-interrill erosion rate for the slope length λ (mass/area·time)

D = combined rill-interrill erosion (detachment) rate at location x along an overland flow path (mass/area·time)

D_i = interrill erosion rate (mass/area·time)

D_r = rill erosion rate (mass/area·time)

D_{rc} = capacity rill 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

g = sediment load (mass/width·time)

g_λ = sediment load at end of overland flow path

k_c = product of terms that do not vary with x in equation $A = k_c \lambda^m$

k_r = product of terms that do not vary with x in rill erosion equation $D_r = k_r x$

m = slope length exponent

q = discharge rate (volume/width·time)

q_c = discharge rate at which runoff shear stress applied to soil equals the soil's critical shear stress

s = overland flow path steepness (sine of slope angle)

s_i = interrill area steepness (sine of slope angle)

s_p = overland flow path steepness (100 times tangent of slope angle)

s_r = rill area steepness (sine of slope angle)

S = combined rill-interrill erosion steepness factor

S_i = interrill erosion steepness factor

S_r = rill erosion steepness factor

T = soil loss tolerance (mass/area·time)

T_c = runoff's sediment transport capacity (mass/width·time)

$T_{c\lambda}$ = runoff's sediment transport capacity at end of overland flow path (mass/width·time)

W = width of runoff surface at location x (length)

x = distance along overland flow path (length)

x_e = distance along overland flow path that is proportional to upslope drainage area for converging runoff surface (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 a particular steepness

α_{15} = combined distance and steepness factor for 15 ft overland flow path length at a particular steepness

Δ = change in a variable

β = ratio of rill erosion sediment load to interrill erosion sediment load

λ = overland flow path length

λ_u = unit plot overland flow path length (72.6 ft, 22.1 m)

ρ = term in equation $\beta = \rho x$

σ = excess rainfall rate (length/time)

Indices

j – segment

5.Appendix 1. Slope length exponent that varies with position

5.Appendix 1.1. Derivation of equations

The RUSLE2 slope length exponent m does not vary with position along the overland flow path. The topographic equations for the slope length exponent m varying with position along the overland flow path are much more complex than the equations used in RUSLE2. The additional complexities and reduced robustness did not warrant their use in RUSLE2 for routine erosion-control planning in local field offices. However, a variable slope length exponent m that varies with position along the overland flow path is very important for applying RUSLE2 to landscapes where surface runoff converges or diverges. Representation of flow convergence/divergence must be considered when RUSLE2 equations are used in GIS models applied to three dimensional landscapes.

In the 1940's when erosion prediction was first developed as an erosion-control planning tool, the following simple empirical equation became widely accepted for describing how erosion varies with overland flow path length for uniform slopes (Zingg, 1940).[43]

$$A = k_c \lambda^m \qquad [V.1]$$

where: A = average erosion rate (mass/area·time) for the slope length λ, k_c = a term that combines the other terms used to compute A that are not a function of λ, and m = the slope length exponent. Equation V.1 is a derived equation. The equation that actually represents the measured field data is:

$$g_\lambda = k_c \lambda^{m+1} \qquad [V.2]$$

where: g_λ = the sediment load (mass/width·time) at the end of the slope length λ, which was the measured sediment discharge from the plots used to measure erosion. The term A in equation V.1 was determined by dividing equation V.2 by the slope length λ. Soil loss A was the variable needed in erosion-control planning.

Equation V.2, not equation V.1, is the starting point for developing RUSLE2 (and the USLE and RUSLE1) equations that represent spatial variability along overland flow paths (Foster and Wischmeier, 1974). The equation for detachment at any point along a uniform overland flow path can be derived by differentiating equation V-2 as:

$$D = dg/dx \qquad [V.3]$$

where: D = detachment rate (mass/area·time) at the location x along an overland flow path. The derivation of a detachment equation is simple where the slope length exponent m is not a function of position x along the overland flow path. By inspection, equation

[43] Uniform means that steepness does not vary with x and the surface runoff streamlines are parallel.

V.2 is recognized to compute sediment load g (mass/width·time) at any position x along a uniform slope as well as sediment load at the end of the overland flow path. If m does not vary with position, the detachment equation is:

$$D = (m+1)k_c x^m \quad \text{[V.4]}$$

Equation V.4 is equation 2.10 with terms except x and m combined in k_c. **Thus, equation 2.10 is based on the assumption that m does not vary with x**. Consequently, the rill to interrill erosion ratio term in equation 2.13 does not contain a distance (x or λ) term. Equation V.4 does not correctly compute detachment if m is varied by segment. If that computation is attempted, sediment load values at the end of the overland flow path for a uniform overland flow path become a function of how many segments and their lengths that are used to divide the overland flow path even if conditions do not vary between segments. **Therefore, if the slope length exponent m is to vary with position x, a new detachment equation must be derived to replace equation 2.10**.[44]

The slope length exponent m was observed to vary from about 0 to 1 for measured ersion data (McCool et al., 1989). Other than m increasing with slope steepness up to five percent steepness, possible reasons for m varying did not seem to be understood when the USLE was developed (Wischmeier and Smith, 1975; Foster and Meyer, 1975).

As early as the mid 1940's, detachment on overland flow areas was recognized to be caused by raindrop impact and surface runoff (Ellison, 1947). Detachment by flow varied much more along the overland flow path than detachment by raindrop impact. These terms are written as (Meyer and Wischmeier, 1969; Foster and Meyer, 1975):

$$D = D_r + D_i \quad \text{[V.5]}$$

where: D_r = rill erosion (mass/area·time), D_i = interrill erosion (mass/area·time), and D = the total of rill and interrill erosion (mass/area·time) at the location x. Interrill erosion is assumed not to vary along a uniform overland flow path, while rill erosion is assumed to vary with (Foster and Meyer, 1975):

$$D_r = k_r x \quad \text{[V.6]}$$

where: k_r = a product of terms that do not vary with x. The combined equation for rill-interrill erosion is therefore:

[44] RUSLE2 did not have the slope length exponent m as a function of x to avoid extrapolation too far beyond the experimental data. Only two sets of plots used to derive RUSLE2 had overland flow path lengths greater than 150 ft. Not having the slope length exponent vary with position x significantly increases RUSLE2's robustness, which is important for an erosion control planning tool.

$$D = k_r x + D_i \qquad [V.7]$$

Equation V.4 was chosen as the basic RUSLE2 detachment equation because a wide array of empirically derived and **accepted** factor values are available for that form (see **Section 1**). Equation V.7 was used to extrapolate equation V.4 to conditions beyond that represented in the USLE plot data.

The RUSLE2 approach was to start with equation V.4 and mold it to equation V.7 as much as possible. However, the difference in equation form between equations V.4 and V.7 causes conflict within RUSLE2. Rules were established to deal with those conflicts (see **Section 2.3.8.3**).

The m value for equation V.7 increases from 0 at x = 0 to 1 as either x or k_r becomes large or D_i becomes small (McCool et al., 1989). Mathematical analysis of equation V.7 shows that the slope length exponent m varies from 0 to 1 and is a function of the rill to interrill erosion ratio as (Foster and Meyer, 1975):

$$m = \beta / (\beta + 1) \qquad [V.8]$$

where: β = the ratio of rill sediment load to interrill erosion sediment load, which is equation 2.12. The equation for β from equation V.7 is:

$$\beta = \frac{(k_r x / 2)}{D_i} \qquad [V.9]$$

which is equation 2.13 with an x term in the numerator.

Equation V.9 can be simplified to:

$$\beta = \rho x \qquad [V.10]$$

where: $\rho = k_r/2D_i$. Substitution of equation V.10 into equation V.8 gives:

$$m = \rho x / (\rho x + 1) \qquad [V.11]$$

Substitution of equation V.11 into equation V.2 gives:

$$g = k_c x^{[\rho x / (\rho x + 1)] + 1} \qquad [V.12]$$

The equation form for sediment load when the slope length exponent m varies with position x differs significantly from equation V.2, which is the RUSLE2 form. An equation for D can be derived by differentiating equation V.12 with respect to x. The resulting equation is much more complicated than equation V.4 used in RUSLE2. However, equation V.12 can be solved numerically to determine values for average detachment for a segment to route sediment downslope as described in **Section 2.3**. However, equation V.12 was not used in RUSLE2 because of concerns about its robustness.

Equation V.12 is based on the assumption that equation V.6 describes rill erosion. Equation V.6 could be written as:

$$D_r = k_r q \qquad [V.13]$$

where: q = discharge rate (volume/width·time), q = σx where σ = excess rainfall rate (length/time) that is assumed to be constant along the overland flow path, and k_r = a collection of terms that do not vary with x.

A case can be made for two other rill erosion equation forms. One form is (Meyer et al., 1975):

$$D_r = k_r (q - q_c) \qquad if\,(q \le q_c) D_r = 0 \qquad [V.14]$$

where: q_c = the discharge rate where runoff shear stress applied to soil exceeds the soil's critical shear stress and rill erosion begins and k_r = the collection of terms that do no vary with x.

A case can also be made for (Foster and Meyer, 1975):

$$D_r = D_{rc} (1 - g / T_c) \qquad [V.15]$$

where: D_{rc} = detachment capacity (mass/area·time) computed with equation V.6 or V.14 and T_c = runoff's sediment transport capacity (mass/width·time). Transport capacity is computed with:

$$T_c = a_T q \qquad [V.16]$$

where: the term a_T is the product of terms that do not vary with position x. Equation V.15 reduces rill erosion as transport capacity becomes filled with sediment on long overland flow paths or where sediment production rate by rill or interrill erosion is very high.

As Figure V.1 shows, the ax^m form (equation 2.10) fits well the equation form D_i+k_rx except for short overland flow paths. This deficiency is corrected as described in Section 5.7. However, neither of these two equation forms fits V.14 or V.15, an equation form that involves a critical shear stress term for estimating rill erosion.

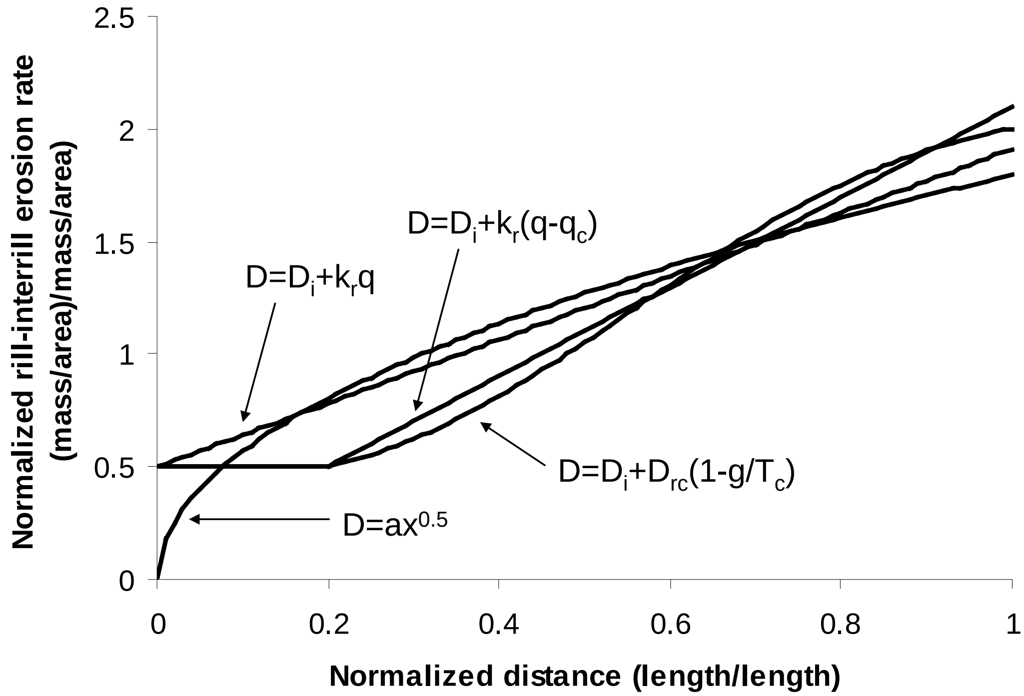

Figure V.1. Variation of detachment along an overland flow path for various rill erosion equation forms.

These advanced rill erosion equation forms greatly complicate RUSLE2 mathematics and further reduce RUSLE2's robustness of. A questionable gain in accuracy while losing robustness is not a wise choice for RUSLE2 as an erosion control planning tool. Choices were made in RUSLE2 that favor robustness for erosion control planning. RUSLE2 may not be as accurate as it could be but it is less likely to give poor results because of uncertainties when extrapolated.

5.Appendix 1.2. Implications for use of RUSLE2 in GIS models

A sediment transport capacity equation should be included with RUSLE2 detachment equations when RUSLE2 is used in a GIS model that computes that computes the spatial variability in erosion and deposition over the landscape. Equation 2.10 is used to compute sediment production (detachment) and equation 2.17 and other equations are used to compute deposition. A sediment transport capacity is required to compute deposition, and a deposition equation like equation 2.16 should be used also. The RUSLE2 sediment production equation (i.e., equation 2.10) does not and can not be used to compute deposition that occurs on the toe of many natural hillslopes.

Also, the RUSLE2 detachment equation 2.10 should be modified to compute how erosion varies with either converging or diverging surface runoff. Applying equation 2.10

without varying the slope length exponent m can result in significant error, even when the overland flow path length is varied in proportion to upslope drainage area.

5.Appendix 1.2.1. Computing detachment and sediment transport capacity

RUSLE2 computes sediment transport capacity per unit width as a function of discharge rate per unit width. An equivalent overland flow path length can be used to represent a converging or diverging landscape to compute discharge rate per unit width and sediment transport capacity per unit width. However, RUSLE2 does not compute the proper sediment production (detachment) values because equation 2.10 does not contain a runoff term. The equivalent overland flow path length that works for computing sediment transport capacity is not the equivalent length required to compute detachment. Furthermore, even though the overland flow path length is adjusted, the slope length exponent m also should be varied with position along the overland flow path to properly represent convergence/divergence in computing detachment with equation 2.10.

5.Appendix 1.2.2. Equations for RUSLE2 in a GIS model

A simple erosion model can be used to evaluate the behavior of RUSLE2 equations in a GIS model. The watershed for a single rill on a hillslope where the streamlines are parallel is a rectangle of width W and length λ. The watershed for a single rill on a converging surface is pie (wedge) shaped. The width at the upper end is 2W and 0 at the lower end. Figure V.2 shows a plot of computed erosion along the overland flow path where streamlines are parallel and where streamlines converge. Erosion was computed with the equation form D_i+k_rq using discharge rate computed by multiplying the excess rainfall rate by the upslope area divided by the watershed width at x. This equation form is assumed to give the desired values, and thus the other equation forms are compared against this one.

The x in the ax^m equation form in Figure V.2 is proportional to upslope drainage area. As Figure V.2 shows, the ax^m approximation does well where streamlines are parallel except for short overland flow paths. In contrast, the ax^m approximation does not work well where the streamlines converge.

When discharge is assumed to be a broad sheet flow across the individual rill watersheds, discharge rate rapidly increases and approach infinity as x approaches λ, the overland flow path length. A corresponding increase in rill erosion is computed. An infinite discharge rate per unit width at x = λ computes an infinite rill erosion rate. Such high erosion rates near the end of converging surfaces are not observed in the field. Consequently, the broad sheet flow assumption should not be used without carefully constructed limits on converging surfaces. This problem does not exist on diverging surfaces.

A better approach than assuming broad sheet flow across the entire rill watershed is to assume that surface runoff is concentrated in defined rills. The overland flow path ends where the interrill path length becomes zero, which is where the rill edges meet. Discharge rate (volume; not volume per unit width) does not go to infinity, which means that rill erosion rate does not go to infinity (Toy and Foster, 2000).

The other equation form evaluated in Figure V.2 is equation V.12 where the slope length exponent varies with distance along the overland flow path. This equation was solved numerically to compute detachment along the overland flow path. In these computations, the slope length exponent m was varied with discharge rate rather actual distance to reflect the increase in rill erosion as the surface runoff converges. This approach, while improved, is less than satisfactory.

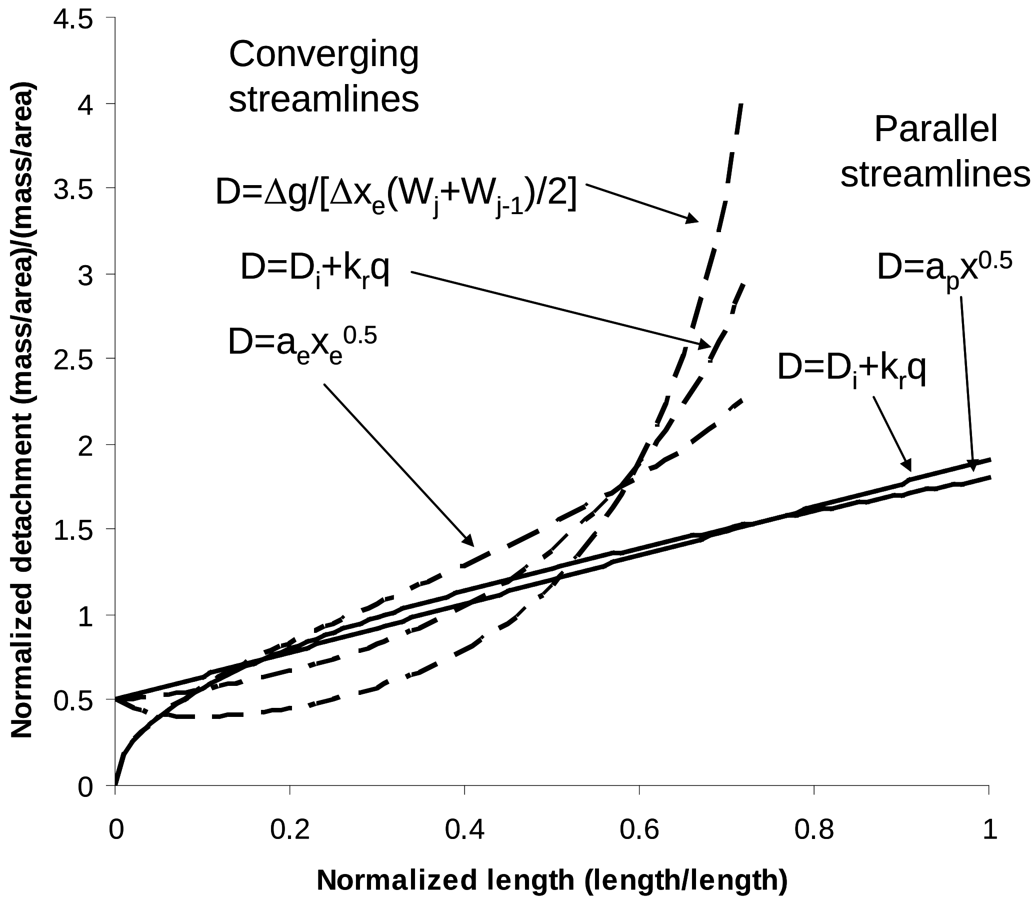

Figure V.2. Erosion along the overland flow paths for parallel and for a converging streamlines.

None of the approximations compare well to the preferred erosion equation that has separate terms for rill and interrill erosion. The best approach in applying RUSLE2 in a GIS model is to devolve the equation 2.10 into separate terms for rill and interrill erosion. Discharge rate can be computed and used directly in both the detachment and sediment transport equations without having to make the overland flow path length proportional to upslope drainage area. This approach would significantly simplify RUSLE2 and would remove the inconsistencies between equation forms.

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:[45]

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

where: c = daily cover-management factor, c_c = daily canopy subfactor, g_c = daily ground (surface) cover subfactor, daily s_r =soil surface roughness subfactor, r_h = daily ridge height subfactor, s_b = daily soil biomass subfactor, s_c = daily soil consolidation subfactor, and s_m = daily antecedent soil moisture subfactor used when RUSLE2 is applied in Req zones (see RUSLE2 User's Reference Guide). A daily cover-management c factor value is computed using daily values for each of the subfactors in equation 6.1.[46]

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} = daily effective canopy cover (fraction) and h_f = daily 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:

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

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

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[45] The RUSLE2 subfactor procedure is an extension of the RUSLE1 procedure [AH703 (Renard et al., 1997)]. The RUSLE2 procedure has several scientific improvements and added capability, and it uses of a daily time step rather than the RUSLE1 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).

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

about a 3 mm drop diameter compared to 1.5 mm for median drop diameter of raindrops (Wischmeier, 1975). Therefore, canopy must be sufficiently close to the ground surface for waterdrops falling from canopy to have reduced impact velocity to offset the increased 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, (e.g., 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 driven rainfall in conjunction with vegetation affects erosion.[47]

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.

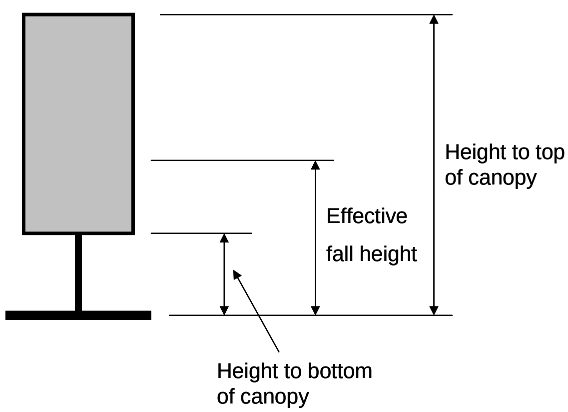

Figure 6.1. Effective fall height for a cylindrical shaped, uniform gradient canopy.

RUSLE2 also includes an equation that can be used to compute effective fall height. The equation is a function of canopy shape, vertical gradient of vegetative surface area, and heights to the bottom and top of 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

[47] 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 a_s used to estimate effective fall height as a function of canopy	
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 a_g 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

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.

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 height 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 **9.3.3.3)**.

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

$$f_{ec} = f_c(1 - f_g) \quad [6.5]$$

where: f_c = daily canopy cover (fraction) and f_g = daily net ground cover, which takes into account the overlap of different types of ground (surface) cover (see **Section 10.2.4**). 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 when ground cover equals 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):

$$g_c = \exp[-bf_g(0.24/R_a)^{0.08}] \quad [6.6]$$

where: **b** = a coefficient (percent^{-1}) that describes the relative effectiveness of the ground (surface) cover for reducing erosion, f_g = net 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 concern is 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 Colvin, 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**).

Many of the **b** values reported in the literature were determined by plotting erosion solely a function of ground cover. The RUSLE2 **b** values used in equation 6.6 are not the same as the literature **b** values. The RUSLE2 **b** values are smaller than the literature values because the literature **b** values include other effects not included in equation 6.6. Erosion values were computed with RUSLE1 for a range of corn yields for mulch-till and no-till cropping systems to illustrate this difference. The net **b** value for equation 6.6 without the surface roughness terms fitted to erosion values plotted as a function as cover immediately after planting was 0.058. In comparison, the **b** values used in equation 6.6

as used in RUSLE1 were 0.031 for the mulch till systems and 0.04 for the no-till systems. The conclusion of this preliminary analysis using RUSLE1, which uses a similar but simpler cover-management subfactor method, is that **b** values used in the RUSLE2 subfactor method can not be compared to widely reported literature values. Also, terms in addition to ground cover are needed in the RUSLE2 subfactor procedure to adequate how cover-management affects erosion, even for the same cover-management practice.

6.2.1. b value (ground cover effectiveness index)

6.2.1.1. Literature b values

Research shows that **b** values derived from measured erosion data range from approximately 0.025 to greater than 0.1 (Box, 1981; Colvin and Gilley. 1987; Dickey et al., 1983; Gilley et al., 1986; Laflen et al., 1980; Laflen and Colvin, 1981; Mannering and Meyer, 1963; Meyer and Mannering, 1967; Meyer et al., 1970; Meyer et al., 1972; Simanton et al., 1984). The reason for a variation in **b** is obvious in some cases. For example, Mannering and Meyer (1963) and Meyer and Mannering (1967) conducted two similar studies involving 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 soil surface roughness and residue incorporation were lumped with the ground cover effect.

6.2.1.2. Rill-interrill effect on b values

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 in equation 2.13 that represents the effect of ground cover on the rill to interrill erosion ratio is:

$$\frac{g_{cr}}{g_{ci}} = \left[\frac{\exp(-b_r f_g)}{\exp(-0.025 f_g)} \right] \qquad [6.7]$$

where: g_{cr} = the surface cover subfactor for rill erosion, g_{ci} = the surface cover subfactor for interrill erosion, b_r = the coefficient for how ground cover affects rill erosion and 0.025 = the value for the coefficient for how ground cover affects interrill erosion.[48] 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

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[48] Although not used in RUSLE2 an improved approach would be to 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.

erosion was derived from the Lattanzi et al. (1974) and McGregor et al. (1988) data (Foster, 1982).

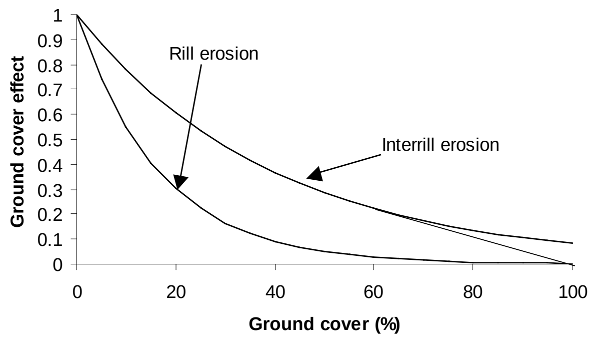

Figure 6.2. Effect of ground cover on rill and interrill erosion

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 values reported in the literature, partly because RUSLE2 accounts for other subfactor effects that researchers included in a ground-cover type effect. Also, the 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 conservation planning purposes.

The coefficient b_r is assumed to increase in RUSLE2 from 0.05 to a maximum of 0.06 as ground cover increases, buried residue in the soil accounting depth increases, and the soil consolidation subfactor decreases. Mechanical soil disturbance is assumed to disrupt macro-pores and large aggregates, which increases runoff and increases erosion for a given ground cover. Conversely, biomass accumulates in a shallow, undisturbed soil surface layer with time after a mechanical soil disturbance increases infiltration, which in turn reduces runoff and rill erosion. 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 = coefficient for the combined effect of buried residue and soil consolidation on ground (surface) cover effectiveness in relation to rill erosion. The equation for c_a is:

$$c_a = 3.52 \times 10^{-6} B_{rs}^2 (1 - s_c) \text{ if } c_a > 1 : c_a = 1 \qquad [6.9]$$

where: B_{rs} = buried residue mass (dry basis) density [lbs_m/(ac·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:

$$d_{rs} = 1 + 2(s_c - 0.45)/0.55 \quad [6.10]$$

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 which 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 intervals further in making its buried residue density computations.

6.2.1.3. RUSLE2 b value equations

RUSLE2 uses a series of equations to compute a **b** value for equation 6.6 based on the fundamental concept that **b** values are a function of the rill to interrill erosion ratio. The starting point for developing these equations is the simple equation that computes erosion when ground cover is present as:

$$D_c = D_b \exp(-bf_g) \quad [6.11]$$

where: D_c = rill-interrill erosion when ground (surface) cover is present and D_b = rill and interrill erosion when ground cover is not present (bare soil). Therefore, a **b** value is computed by rearranging equation 6.11:

$$b = -\ln(D_c / D_b) / f_g \quad [6.12]$$

The equation for rill-interrill erosion D_c when ground cover is present is:

$$D_c = D_{ib}(3s^{0.8} + 0.56)\exp(-0.025 f_g) + D_{rb}(s/0.0896)\exp(-b_r f_g) \quad [6.13]$$

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:

$$D_{rb} = [\alpha/(\alpha+1)] \quad [6.14]$$

where: the term α in equation 6.14 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 $(3s^{0.8} + 0.56)$ adjusts for the effect of overland flow path steepness on interrill erosion and the term s/0.0896 adjusts for the effect of overland flow path steepness on rill erosion.[49] 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:

$$D_{ib} = 1 - D_{rb} \qquad [6.15]$$

The term D_b in equations 6.11 and 6.12 is computed as:

$$D_b = D_{ib}(3s^{0.8} + 0.56) + D_{rb}(s / 0.0896) \qquad [6.16]$$

The next step is to compute a value for the rill to interrill erosion ratio for bare soil as:

$$\alpha = (K_r / K_i) a_2 a_4 \qquad [6.17]$$

where: the rill to interrill soil erodibility ratio (K_r/K_i) is computed using equation 4.12 and 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 for the purpose of computing a **b** value.

The coefficient a_2 is given by:

$$a_2 = a_1 + a_b \text{ if } a_2 > 8 : a_2 = 8 \qquad [6.18]$$

where: the coefficient a_1 is given by:

$$a_1 = 1 - \{0.9[(1 - s_c) / 0.55][1 - \exp(-0.0022 B_{rt})]\} \qquad [6.19]$$

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. This coefficient reflects how soil consolidation and root biomass affect rill erosion differently than it does interrill erosion.

The coefficient $a_{b,}$ which represents how soil consolidation and buried residue affects the rill to interrill erosion ratio, is given by:

$$a_b = 1.76 x 10^{-5} B_{rs}^2 (1 - s_c) \qquad [6.20]$$

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[49] No adjustment is made for overland flow path length 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.

The a_b coefficient computes the effect of buried residue on the b value increasing as 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.

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; 1971; 1972].

RUSLE2 computes this effect assuming that the lost of ground (surface) effectiveness is determined by how well the mulch material conforms to the soil surface and stays in place. 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:

$$a_4 = a_3 + (1 - a_3)[1 - \exp(-0.0055 B_{rt})] \qquad [6.21]$$

where: the equation for a_3 is given by:

$$a_3 = \exp[-\psi(\lambda / s^{1/2})^{0.6} s] \qquad [6.22]$$

where: λ = the overland flow path length and ψ = a coefficient that describes conformance of ground cover to the soil surface.

Three classes of ground (surface) cover conformance that vary with material properties are used in RUSLE2 (see RUSLE2 User's Reference Guide). 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 woody 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., 1982a). 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**. Values for the prior land use residual effect term in equation 2.13 are computed with:

$$c_{pr} / c_{pi} = 0.45 + 1.55(s_c s_b)^2 \qquad [6.23]$$

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:

$$f_{ge} = f_g(0.4 + 0.6\delta) \qquad [6.24]$$

where: the cover adjustment term δ is given by:

$$\delta = (b_r - 0.05)/0.01 \qquad [6.25]$$

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 on b and m equations

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 of 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 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 soil biomass content. 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:

$$s_r = \exp[-0.66(R_a - 0.24)] \qquad [6.26]$$

where: R_a = daily adjusted roughness value (inches) 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 of 0.24 (6 mm) 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 give s_r values less than 1. However, some soil surfaces are smoother than the unit plot. Equation 6.26 gives s_r values up to 1.17 for soil surface roughness smoother than 0.24 inches, the roughness value assumed for unit-plot conditions. Mechanical soil disturbing operation such as roto-tilling that finely pulverizes soil, cutting and filling with a blade, and rolling a finely pulverized soil surface produces a 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.[50] The only essential difference in soil conditions between these two short periods is soil surface roughness.

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[50] 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 first tilled with a primary tillage tool such as a moldboard plow and when the soil is first 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 soil surface roughness subfactor s_r				
		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

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 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 soil surface roughness subfactor s_r 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:

$$R_{ib} = 0.24 + (R_{it} - 0.24)\{0.8[1 - \exp(-0.0015 B_{td})] + 0.2\} \qquad [6.27]$$

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_{td} = 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 the 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 an 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:

$$R_{aa} = (1-\xi)(R_{ae} - R_{ib}) + R_{ib} \qquad [6.29]$$

where: R_{aa} = the adjusted roughness immediately after a soil disturbing, ξ = tillage intensity for the operation, R_{ae} = existing adjusted roughness immediately before the operation, and R_{ib} = the input roughness for the soil disturbing operation after adjustment for soil biomass and soil texture, which is computed with 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 roto-tillers. 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 diminishes (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)]:

$$f_r = \exp[-0.07(P_d + I) - 0.006 r_d c_c g_{ci})] \qquad [6.30]$$

where: f_r = the fraction of the current roughness greater than 0.24 inch that remains, P_d = the daily precipitation amount (inches), I = daily amount (inches) of water added by irrigation, 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:

$$g_{ci} = \exp(-0.025 f_g) \qquad [6.31]$$

where: f_g = the net ground cover (percent). Daily adjusted roughness used in equation 6.26 is computed as:

$$R_a = 0.24 + f_r(R_{ap} - 0.24) \qquad [6.32]$$

where: R_{ap} = 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 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 in 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 value greater than 0.24 inch. If an input final roughness value greater than 0.24 inch is entered in the RUSLE2 database for a soil disturbing operation, RUSLE2 uses that value instead of 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 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:

$$R_l = 0.24 + (R_{alf} - 0.24)/\{1 + \exp[(0.5 - t_d / t_c)/0.1]\} \qquad [6.33]$$

where: R_l = daily long term roughness, R_{alf} = 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_{alf} is computed using equations 6.27and 6.28 using 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 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.

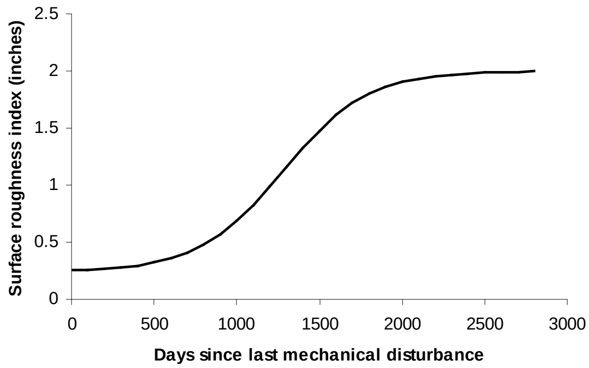

Figure 6.3. Development of long term roughness as a function of time since last mechanical soil disturbance.

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 soil surface roughness subfactor value.

6.3.9. Accounting for spatial variability in roughness

RUSLE2 can take soil surface roughness spatial variability partially 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 soil surface roughness subfactor values for both the undisturbed and disturbed areas and the overall soil surface roughness 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 on roughness subfactor

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 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 by 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 primarily 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. This effect 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 measured.

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 3**) 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).[51] The RUSLE2 ridge height subfactor equations derived from experimental data are:

$$r_{h6} = 0.9(1 + 0.0582H^{1.84}) \quad H \le 3 \text{ inches} \qquad [6.34]$$

$$r_{h6} = 2.136[1 - \exp(-0.484H)] - 0.336 \quad H > 3 \text{ inches} \qquad [6.35]$$

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

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[51] 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, Mississippi.

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 for a ridge height of 1.42 inch, which represents unit plot conditions except for the difference between 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 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 model was used to develop equations for the ridge height subfactor for overland flow path steepness greater than six percent. That simple equation is:

$$D_t = 0.5[(s/0.0896) + (3s_i^{0.8} + 0.56)] \qquad [6.36]$$

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 $(3s_i^{0.8} + 0.56)$ represents the effect of steepness on interrill erosion. Steepness s_i of the interrill area is greater than the steepness s of the rill area because ridge height increases interrill steepness (i.e., the ridge sideslope steepness).

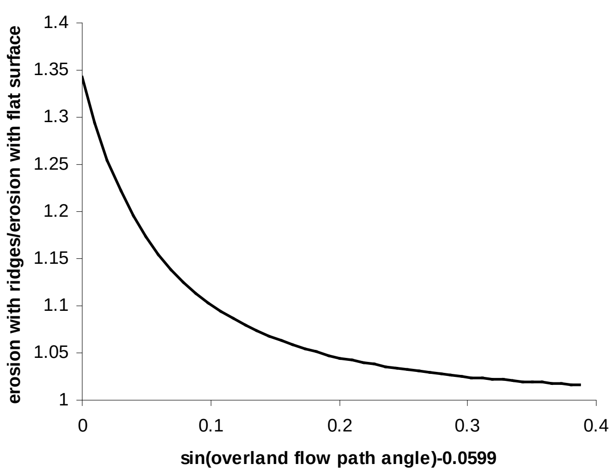

Figure 6.4. Effect of overland flow path steepness on the ratio of erosion with a 20% ridge sideslope to erosion from a flat surface.

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:

$$r_h = r_{h6} \quad s_p < 6\% \qquad [6.37]$$

$$r_h = 1 + (r_{h6} - 1)\exp[-a_h(s - 0.05989)] \quad s_p \geq 6\% \qquad [6.38]$$

where: s_p = overland flow path steepness (100 times tangent of slope angle) and a_h is computed from:

$$a_h = 16.02 - 0.927H \quad H \leq 10 \text{ inches} \qquad [6.39]$$

$$a_h = 6.75 \quad H > 10 \text{ inches} \qquad [6.40]$$

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) decreases 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:

$$r_h = 0.9 - (0.9 - r_{h,u\&d})g_r^2 \quad r_{h,u\&d} \leq 1 \qquad [6.41]$$

$$r_h = 0.9 + (r_{h,u\&d} - 0.9)g_r^2 \quad r_{h,u\&d} > 1 \qquad [6.42]$$

where: $r_{h,u\&d}$ = the ridge height subfactor value when ridge orientation is parallel to the overland flow path, which are computed equations 6.37 and 6.38 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).[52] Thus, the initial ridge height left by a soil disturbing operation is divided into two parts as:

$$H = H_s + H_e \quad [6.43]$$

where: H_s = daily ridge height component associated with settlement and H_e = daily 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:

$$H_s = H_{sp} \exp = [-0.2343(P_d + I)] \quad [6.44]$$

where: H_{sp} = the daily ridge height associated with settlement from the previous day. The daily interrill erosion ridge height is computed as:

$$H_e = H_{ep} - a_e r_d c_c g_{ci} \quad [6.45]$$

where: H_{ep} = ridge height associated with interrill erosion for the previous day and the coefficient a_e is computed as:

$$a_e = 0.033 - 0.002 H_i \quad H_i \le 10 \text{ inches} \quad [6.46]$$

$$a_e = 0.013 \quad H_i > 10 \text{ inches} \quad [6.47]$$

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 is a function of ridge height is the RUSLE2 assumption that high ridges have a wide base so that the overall loss of ridges having a wide base 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.[53]

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.

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[52] K.C. McGregor. 1999. Field observations of ridge height decay in the Mississippi Delta. Personal communtation. Scientist (retired), USDA-National Sedimentation Laboratory, Oxford, Mississippi.

[53] McGregor, K.C. 1999. Loss of ridge heights in the spring in the Mississippi Delta. Personal communication. Scientist (retired), USDA-National Sedimentation Laboratory, Oxford, Mississippi.

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 be taken into account in RUSLE2 by creating multiple soil disturbing operation decriptions having a range of ridge height values. The user then selects a particular operation description for RUSLE2 input that gives the desired ridge height for the given situation.

6.4.8. Comments on ridge height subfactor

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., 1985c; 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 decreases 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 no 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:

$$s_b = 0.951\exp(-0.0026B_{rt} - 0.0006B_{rs} / s_c^{0.5}) \quad s_b \le 0.9035 \qquad [6.48]$$

$$s_b = \exp[-1.9785(0.0026B_{rt} + 0.0006B_{rs} / s_c^{0.5})] \quad s_b > 0.9035 \qquad [6.49]$$

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 were obtained by fitting the equation to soil biomass subfactor values estimated from research-based soil loss ratio values. The values points for no-till and mulch (reduced) till were obtained from the literature.[54] The other values selected from AH537 (Wischmeier and Smith, 1978). These values 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.

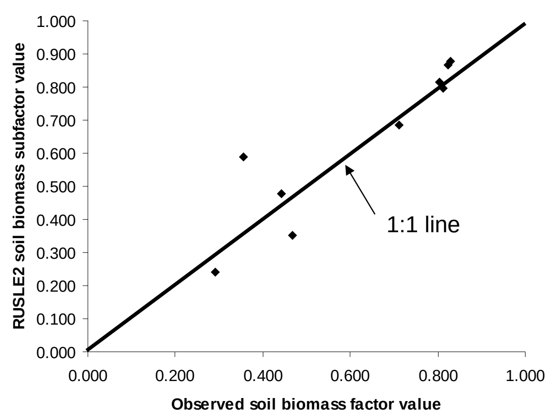

Figure 6.5. Comparison of RUSLE2 soil biomass values to observed values

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,

[54] 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**.

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 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.

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).

Table 6.5. Soil biomass subfactor values used to derive RUSLE2 subfactor equation

			Soil biomass factor	
Cover-management (yield)	Data source	Seedbed soil loss ratio	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	literature	0.028	0.47	0.35
mulch till corn 112 bu/ac	literature	0.24	0.44	0.48

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 and 6.49is 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 and 6.49. 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 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.

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 equations 6.48 and 6.49 were for cropped conditions 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.

Table 6.6. Effect of manure additions on erosion at Clarinda, Iowa

Cover	Yield (bu/ac)	Manure application (tons/acre wet basis)	Ratio of erosion with manure to erosion without manure: Obs	Ratio of erosion with manure to erosion without manure: 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, Wisconsin

Cover	Yield (bu/ac)	Manure application (tons/acre wet basis)	Ratio of erosion with manure to erosion without manure: Obs	Ratio of erosion with manure to erosion without manure: 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

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.

Table 6.8. Effect of biomass additions on erosion with cotton at Statesville, North Carolina				
			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

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, 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 not to affect rill-interrill erosion in RUSLE2. 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 affects the RUSLE2 estimated ratio of erosion with incorporated biomass to erosion without biomass incorporation. Increasing incorporation depth from 10 to 6 inches increases the erosion ratio 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

The equations for the soil biomass subfactor, equations 6.48 and 6.49, are considered to apply to all land use conditions (i.e., that is RUSLE2 is land-use independent). 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.[55] 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. [56]

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 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

[55] 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, [AH703 (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.

[56] Data from the WEPP study (Simanton et al., 1991) were used in the analysis to compute 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. However, 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 Guide).

equation 6.1, substituting c_p values for c and values for the subfactors, and solving for the soil biomass subfactor s_b value.

An effective root biomass value was computed by rearranging equation 6.48 and assuming no buried residue effect (i.e., assuming $B_{rs} = 0$). RUSLE2 does not consider a buried residue effect when using a single average annual input for root biomass. This RUSLE2 application method 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 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 on mechnanically disturbed lands such as construction sites, reclaimed mined lands, rangelands, military training grounds, and logged and burned forest lands. 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, are much more uncertain 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 10.3.** 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 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 of increase 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 particulate 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. Consequently, thus the RUSLE2 time to soil consolidation variable 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 for 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 typical no-till corn cropping in comparison to almost 30 percent being added for a completely undisturbed soil condition (e.g., a pasture or rangeland).

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 RUSLE2 soil 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.

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.

Research to directly determine the effect of buried residue on rill-interrill erosion has been limited and incomplete (Van Liew and Saxton, 1983; Brown et al., 1989; McGregor et al., 1990; Box, Jr. and Bui, 1993). Research to measure soil buried residue and its characteristics as they affect rill-interrill erosion is difficult and is very incomplete.

However, 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.

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 and other subfactor equations were 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 computed 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., 1982c).

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., 1985c; 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 10 and 30 inches (see **Section 4.8**).

The soil consolidation effect is based on a comparison of erosion from a soil in the unit plot condition to erosion of the same soil that has not been mechanically disturbed for some time after 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:

$$s_c = 0.45 + \exp\{-3.314[0.1804 + (t_d / t_c)^{1.439}]\} \qquad [6.52]$$

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.[57] 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.

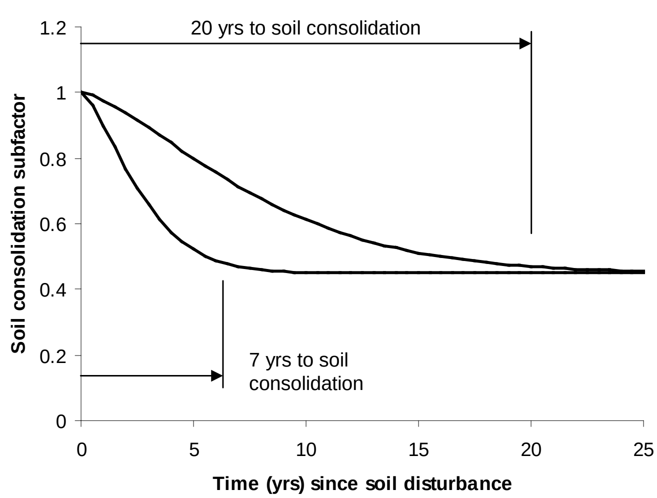

Figure 6.6. Variation of the soil consolidation subfactor as a function of time after last mechanical soil disturbance.

Experimental erosion studies on mine spoil and reconstructed shoed that compaction can increase rill-interrill erosivity by as much as 40 percent (Barfield et al.,

[57] 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**).

1988). About half of this effect can be captured in RUSLE2 by inputting a 0 soil surface roughness value for the soil disturbing operation used to describe the compaction. The 0 input value for soil surface roughness represents a smooth soil surface that is assumed to result from the compaction. This value is increased to represent the roughness effect left by a compactor such as a sheep's foot roller that leaves some soil surface roughness.

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 (see **Section 8.3.1**). The time since last soil disturbance is reset to this effective 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., 1982c). 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., 1982c).

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 decrease 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

(Graf, 1971). Available research information was not sufficient to include a RUSLE2 relationship that computes erosion as a function of soil bulk density. An input value less tha 0.24 inches for soil surface roughness can be used to represent increase in erosion caused by compaction. Also, the soil erodibility factor value can be reduced to represent decreased erosion caused by compaction of high clay soils.

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. RUSLE2 soil erodibility are based on the tilled unit plot condition.

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]. High soil moisture significantly increases erosion during the winter 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:

$$R_m = 0.5/182 \quad P_a \leq 10 \text{ inches} \qquad [6.53]$$

$$R_m = [0.5 + 0.062(P_a - 10)]/182 \quad 10 < P_a \le 18 \text{ inches} \qquad [6.54]$$

$$R_m = 1/182 \quad P_a > 18 \text{ inches} \qquad [6.55]$$

where: R_m = an index (dimensionless) for daily moisture replenishment rate, P_a = average annual precipitation (inches), and 182 = number of days over which replenishment occurs.

$$s_m = s_{mp} + R_m \quad if\,(s_m > 1): s_m = 1 \qquad [6.56]$$

where s_m = daily antecedent soil moisture subfactor and s_{mp} = the soil moisture subfactor on the previous 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 is assumed to occur. Example values for ϕ_m are given in Table 6.9.

$$s_m = s_{mp} - D_m \quad if\,(s_m < 0): s_m = 0 \qquad [6.58]$$

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:

$$s_m = s_{mp} \qquad [6.59]$$

6.7.2.4. Initial s_m value

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

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 in cycles). 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.

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 illustrated in Figure 3.16 (also, 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.

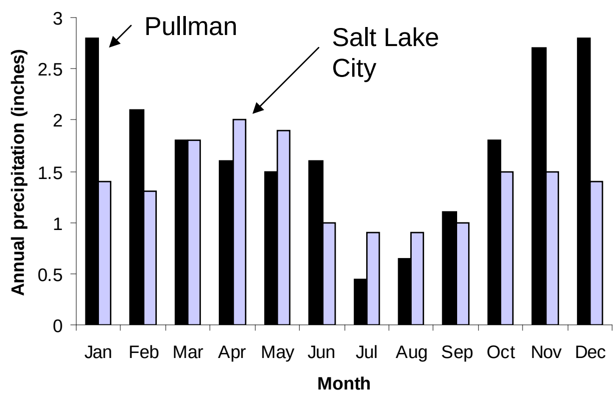

Figure 6.7. Distribution of monthly precipitation at Pullman, Washington (P_a = 20.9 inches) and Salt Lake City, Utah (P_a = 16.9 inches)

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.

The RUSLE2 antecedent soil moisture subfactor should be used only 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 locations. 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 estimated 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 (see **Section 12.23**).

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, Mississippi.

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, Mississippi.

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

6.9. List of symbols

a_b = coefficient related to buried residue and soil consolidation used to compute a_2

a_e = coefficient used to compute loss of ridge height by interrill erosion (inch/customary US erosivity unit)

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 = coefficient related to soil biomass and soil consolidation used to compute a_2

a_2 = coefficient, along with a_4, for how soil consolidation, soil biomass, and conformance of ground cover to the soil surface affect rill to interrill erosion ratio

a_3 = coefficient related overland flow path length and steepness and conformance of ground cover to soil used to compute a_4

a_4 = coefficient, along with a_2, for how soil consolidation, soil biomass, and conformance of ground cover to the soil surface affect rill to interrill erosion ratio

A_p = measured erosion from simulated rainfall applied to plots used to determine c_p factor values (mass/area)

b = coefficient for how ground (surface) cover affects rill-interrill erosion (percent^{-1})

b_r = coefficient for how ground cover affects rill erosion (percent^{-1})

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_{td} = total mass (dry basis) density of buried residue and live and dead roots averaged over soil disturbance depth after the operation (lbs_m/acre·inch)

c = daily cover-management factor

c_a = coefficient for combined effect of buried residue and soil consolidation on ground cover effectiveness in relation to rill erosion

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 (inches)

D_b = rill-interrill erosion when ground cover is not present (bare soil) (mass/area)

D_c = rill-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 = waterdrop impact energy (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 = daily canopy cover (fraction)

f_{ec} = daily effective canopy cover (fraction)

f_g = ground (surface) cover (fraction or percent when used to compute g_c)

f_{ge} = effective ground cover used to compute values for slope exponent m (percent)

f_{gn} = net ground cover, portion of soil surface covered

f_r = fraction of today's soil surface roughness greater than 0.24 inch that remains after today's loss of roughness

g_c = daily ground (surface) cover subfactor

g_{ci} = interrill erosin ground (surface)cover subfactor

g_{cr} = rill erosion ground (surface)cover subfactor

g_r = relative row grade (grade along the ridges/overland flow path steepness)

h_b = height to canopy bottom (length)

h_f = daily effective fall height (feet)

h_t = height to canopy top (length)

H = daily ridge height (inches)

H_e = ridge height component associated with interrill erosion (inches)

H_{ep} = previous day ridge height component associated with interrill erosion (inches)

H_s = ridge height component associated with settlement (inches)

H_{sp} = previous day ridge height component associated with settlement (inches)

I = daily amount of water added by irrigation (inches)

K_n = soil erodibility value determined from standard soil erodibility nomograph using soil property values measured at each site (mass/erosivity unit)

K_r/K_i = rill to interrill soil erodibility ratio

m = slope length exponent

m_d = waterdrop mass

P_a = average precipitation (inches)

P_{cl} = mass portion of soil composed of clay (percent)

P_d = daily precipitation (inches)

P_{sl} = mass portion of soil composed of silt (percent)

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_a = daily adjusted sil surface roughness roughness used to compute soil surface roughness subfactor values (inches)

R_{aa} = adjusted soil surface roughness immediately after soil disturbing operation (inches)

R_{ae} = existing adjusted soil surface roughness before a soil discturbing operation (inches)

R_{alf} = adjusted final long term soil surface roughness value after input value for long term roughness adjusted for soil texture and soil biomass (inches)

R_{ap} = adjusted soil surface roughness on previous day (inches)

R_{ib} = initial soil surface roughness after input roughness adjusted for soil texture and biomass (inches)

R_{in} = input soil surface roughness value for reference condition for soil disturbing operation (inches)

R_{it} = initial soil surface roughness after input roughness value adjusted for soil texture (inches)

R_l = daily adjusted long long term soil surface roughness (inches)

Req = equivalent erosivity related to greatly increased soil erodibility during winter months in Nrthwestern US

R_m = index for daily moisture replenishment rate

R_p = erosivity for simulated rainfall applied to plots used to determine c_p factor values (erosivity units)

s = overland flow path steepness (sine of slope angle)

s_b = daily soil biomass subfactor

s_c = daily soil consolidation subfactor

s_i = interrill area steepness (sine of slope angle)

s_m = daily antecedent soil moisture subfactor used in Req zone

s_p = overland flow path steepness (100 times tanget of slope angle)

s_r = daily soil surface roughness subfactor

S_p = slope steepness factor computed from steepness of plots used with simulated rainfall to determine c_p factor values

t_c = time to soil consolidation (days)

t_d = time since the last mechanical soil disturbance (days)

V = waterdrop impact velocity (length/time)

α = rill to interrill erosion ratio for bare soil

δ = cover adjustment term used to compute slope length exponent

ξ = tillage intensity

λ = overland flow path length (length)

λ_p = length of plots used with simulated rainfall to determine c_p factor values

λ_u = unit plot length (72.6, 22.1 m)

ϕ_m = the total soil moisture depletion as a function of vegetation

ψ = coefficient related to conformance ground (surface) cover to soil surface

7. SUPPORT PRACTICES

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 reduced 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 graph 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 other references in **Section 7.1** and **Section 12.2.1**).

Each type of measurement area has shortcomings. A shortcoming of watersheds is that measured sediment from watersheds includes sediment produced by ephemeral gully erosion, which is not estimated by RUSLE2. A shortcoming of plots narrower than about

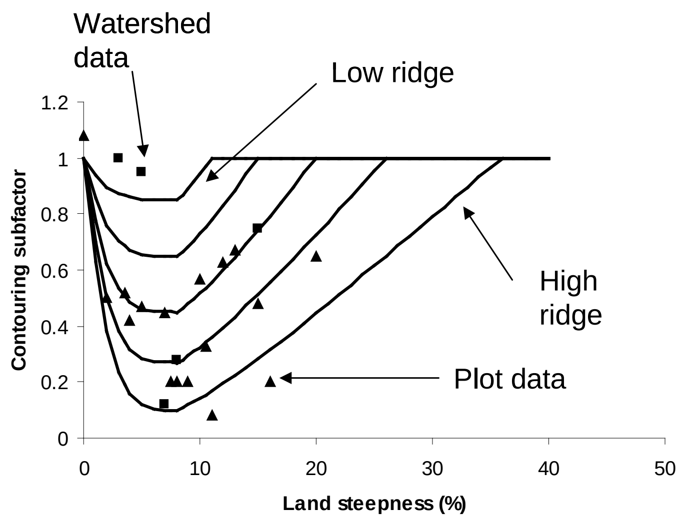

Figure 7.1. Experimental data from plots and small watershed (~ 5 acres) for effect of contouring (ridging) on rill-interrill erosion and fitted lines for effect of ridge height on contouring.

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.

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). 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). These examples of increased erosion are associated with concentrated flow erosion where ridge-breakovers occurred. 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.[58] 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 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 contouring 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:

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[58] These farming conditions differ from current farming practices. Also, these farming practices are not typical of rangelands, surface mine reclamation, construction sites, and other conditions where ridging (contouring) is used to control rill-interrill erosion. RUSLE2 includes procedures to account for these differences.

$$p_b = a_c(s_m - s_c)^4 + p_{bm} \quad s_c < s_m \qquad [7.1]$$

$$p_b = c_c(s_c - s_m)^{1.5} + p_{bm} \quad s_m \le s_c < s_{be} \qquad [7.2]$$

$$p_b = 1 \qquad s_{be} \le s_c \qquad [7.3]$$

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) at which the contouring subfactor reaches 1. Values for the coefficients a_c and c_c are computed from:

$$a_c = (1 - p_{bm}) / s_m^4 \qquad [7.4]$$

$$c_c = (1 - p_{bm}) / (s_{be} - s_m)^{1.5} \qquad [7.5]$$

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):

$$p_{bm} = 0.05 + 0.95\exp(-0.5512 H_e) \;\; if\,(H_e > 8): H_e = 8 \text{ inches} \qquad [7.6]$$

where: H_e = daily effective total ridge height (inches), which is the sum of the daily soil ridge height H (see **Sections 6.4.6 and 8.3.5**) and the daily effective vegetation ridge height H_{vr} (see **Section 9.2.7**). 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:

$$s_{bm} = 4[1 - \exp(-0.7903 H_e)] + 4 \;\; if\,(H_e > 8): H_e = 8 \text{ inches} \qquad [7.7]$$

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:

$$s_{be} = \sin\{\tan^{-1}[(9 + 53.09 H_e / 8)/100]\} \; if\,(H_e > 8): H_e = 8 \text{ inches} \qquad [7.8]$$

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.[59]

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[59] The uncertainty of contouring's erosion control effectiveness at any specific site is greater than for all other erosion control practices. Also, data for the effect of ridge height and other factors on the erosion control effectiveness of contouring are very limited for a wide range of conditions. Contouring using high ridges can be highly effective, especially in low rainfall areas, but result in very high erosion for rarely

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:

$$p_{rm} = p_{bm}(d_r / 4.16) \quad [7.9]$$

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_{10y24h} 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:

$$s_{re} = s_{be} /(d_r / 4.16)^{0.8571} \quad [7.10]$$

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:

$$s_c = s \quad s \le s_m \quad [7.11]$$

where: s = the steepness (sine of slope angle) of the overland flow path. The scaled steepness for $s > s_m$ is given by:

$$s_c = s_{bm} + \frac{(s - s_{bm})(s_{be} - s_{bm})}{s_{re} - s_{bm}} \quad s > s_m \quad [7.12]$$

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.

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occurring intense storms. The 8 inch limit in these equations was chosen based on professional judgment and experience (see **Section 7.1.5**). See the RUSLE2 User's Reference Guide for guidance on using RUSLE2 to evaluate the erosion control effectiveness of contouring (ridging).

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:

$$p_{c0} = 1 - \frac{(1 - p_b)(1 - p_{rm})}{1 - p_{bm}} \quad if\,(p_{c0} > 1): p_{c0} = 1 \qquad [7.13]$$

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_{10y24h} 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).

$$p_c = p_{c0} + (1 - p_{c0})(s_f / s_p)^{1/2} \qquad [7.16]$$

where: p_c = the daily contouring subfactor and s_f = grade along the furrows separating the ridges (row grade) (100·tangent of slope angle). The variable s_f/s_p is designated as the relative row grade and sp =land steepness (100·tangent of slope angle). Measured erosion on 150 ft wide plots on a 5 percent land steepness showed that the 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 observed p_{c0} = 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 0.39 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 breakthrough 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 grade 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, 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 **Sections 2.3 and 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. However, the very low sediment concentration in the runoff leaving the barrier increases runoff erosivity. 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). The RUSLE2 assumption is that these two effects on runoff erosivity offset each other.

The 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 downslope from 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 (see RUSLE2 User's Reference Guide).

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 (Foster et al., 1997, see references this 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 yield 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 yield 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 value of 0.25 for fraction 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 0.20 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 close to the RUSLE2 computed values.

7.2.7. Comments on porous barriers

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 carefully controlled 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., 1980a). Deposition rate is computed in RUSLE2 using (Renard and Foster, 1983):

$$D_{p(k)} = f_{(k)}\left(\frac{\phi_{(k)}}{1+\phi_{(k)}}\right)\left(\frac{dT_c}{dx} - g_o\right) \quad dT_c / dx < g_o \qquad [7.17]$$

$$D_{p(k)} = 0 \quad dT_c / dx \geq g_o \qquad [7.18]$$

$$\phi_{(k)} = 400000 V_{f(k)} / q_o \qquad [7.19]$$

where: $D_{p(k)}$ = deposition rate for the *kth* particle class [mass/(unit channel length·time)], $f_{(k)}$ = fraction, based on mass, of the total incoming sediment load g_0 (mass/unit channel length·time) from the overland flow area made up of the *kth* particle class, T_c = 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 using:

$$dT_c / dx = 450 s_{ch}^{1.16} q_0 \qquad [7.20]$$

where: T_c = transport capacity (lbs_m/sec), s_{ch} = grade (steepness) of the channel (sine of channel slope angle), 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 and λ_o = the length of the overland flow path that discharges into the channel. The sediment delivery ratio for the channel for the *kth* particle class is given by:

$$\omega_{(k)} = 1 - D_{p(k)} / g_{o(k)} \qquad [7.23]$$

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 the five RUSLE2 particle classes (see **Section 4.7**).

7.3.2.2. Comments on channels

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. See the RUSLE2 User's Reference Guide for information on the types of channels represented by RUSLE2.

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:

$$\omega_{(k)} = \exp(-c_i V_{f(k)}) \qquad [7.24]$$

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, 1976b). 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.

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

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 that 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. (See the RUSLE2 User's Reference Guide)

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 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 a flow interceptor is:

$$b_{s(i)} = 0.45\exp[-0.011(\delta_{s(i)} - 100)] \quad \delta_{s(i)} \geq 100 \text{ ft} \qquad [7.25]$$

$$b_{s(i)} = 0.45 \ \ \delta_{s(i)} < 100\,\text{ft} \qquad [7.26]$$

where: $b_{s(i)}$ = the fraction of the deposition that is credited as soil saved for the *ith* flow interceptor and δ_s = flow interceptor spacing (ft). The credit $b_{p(i)}$ for deposition as affected by the *ith* flow interceptor location along the original overland flow path is computed with:

$$b_{p(i)} = 1 - (\lambda_{s(i)} / \lambda_o)^{1.5} \qquad [7.27]$$

where: $\lambda_{s(i)}$ = distance from the origin of overland flow for the original overland flow path to the *ith* 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:

$$g_{cp(i)} = g_{o(i)}[1 - (b_{s(i)} + 0.2b_{p(i)})(1 - \omega_{(i)})] \qquad [7.28]$$

where: $g_{cp(i)}$ = the conservation planning sediment load per unit channel length for the *ith* channel, the $g_{o(i)}$ = the sediment load for conservation planning from the overland flow 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:

$$A_{cp} = \left(\sum_{i=1}^{J} g_{cp(i)} \right) \Big/ \lambda_o \qquad [7.29]$$

where: A_{cp} = the conservation planning soil loss (mass/area) for the area represented by λ_o and i = the index 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.[60] 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 an 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.

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[60] 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:

$$p_d = K_d / K_u \;\; if\,(p_d < 0.2): p_d = 0.2 \qquad [7.30]$$

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:

$$K_b = K_u - 0.025(P_{ru} - 3) \qquad [7.31]$$

where: K_b = a base soil erodibility factor value (US customary units) computed without the permeability subfactor and P_{ru} = the soil profile permeability class for the undrained condition. The soil erodibility factor with subsurface drainage is computed with:

$$K_d = K_b + 0.025(P_{rd} - 3) \qquad [7.32]$$

where: P_{rd} = the soil profile permeability class for the drained condition.

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.

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

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).

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			
	K = 0.20	K = 0.20	K = 0.30	K = 0.55
Location	D to A	D to C	D to A	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

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, decreased soil surface roughness and ridge height, 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.

7.5.1. Effect on soil erodibility

The effect of increased soil moisture on soil erodibility during the irrigation period is computed using equation 4.14 that computes temporal (daily) values for the soil erodibility factor. This equation is modified by adding the daily amount of water added by irrigation to the daily precitation amount as:

$$K_{(j)}/K_n = 0.591 + 0.732[(P_{(j)} + I_{(j)})/0.123] - 0.324(T_{(j)}/62.8) \qquad [7.33]$$

$$If\,(K_{(j)}/K_n) > 2.0 \text{ then } (K_{(j)}/K_n) = 2.0$$

$$If\,(K_{(j)}/K_n) < 0.4 \text{ then } (K_{(j)}/K_n) = 0.4$$

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 $T_{(j)}$ is above 40 ^{o}F, 62.8 = the average temperature during the frost free period (^{o}F), $P_{(j)}$ = daily precipitation (inches), $I_{(j)}$ = average daily water added by irrigation (inches), and 0.123 = average daily precipitation during the frost free period (inches).

The average daily water added by irrigation on the *jth* day is computed from:

$$I_{(j)} = V_{w(j)} - P_{(j)} \;\; if\,(I_{(j)} < 0) : I_{(j)} = 0 \qquad [7.34]$$

where: $V_{w(j)}$ = consumption use (inches) by the vegetation on the *jth* day (Schwab et al., 1966). Plant consumption use values are input for the vegetation descriptions that represent irrigated conditions.

7.5.2. Effect on soil surface roughness, ridge height, and decomposition

The daily amount of water added by irrigation is added to the daily precipitation amount to compute the effect of irrigation on soil surface roughness (see **Section 6.3.6** and equation 6.30), ridge height (see **Section 6.4.6** and equation 6.43), and decomposition (see **Section 10.3.1** and equation 10.5).

7.5.3. Effect on vegetation

Individual vegetation descriptions must be created to describe vegetation under irrigated conditions. These descriptions include values for consumptive water use that are a function of the soil properties and location and location where the RSULE2 computation is being made. Figure 7.2 illustrative consumptive use values for a particular corn crop grown at Lincoln, Nebraska.

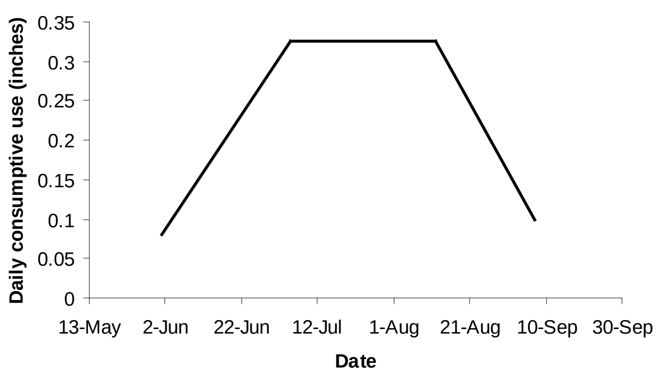

Figure 7.2. Daily consumptive water use for a 120 day corn crop grown at Lincoln, Nebraska.

The 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**).

7.6. List of symbols

a_c = 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)

$b_{p(i)}$ = deposition credit as affected by the *ith* flow interceptor location along the original overland flow path

$b_{s(i)}$ = fraction of the deposition that is credited as soil saved for the *ith* flow interceptor

c_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_{10y24h} storm (inches)

$D_{p(k)}$ = deposition rate for *kth* sediment class (mass/unit channel length·time)

$f_{(k)}$ = mass fraction of the incoming sediment load g_0 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)

$g_{cp(i)}$ = conservation planning sediment load for the *jth* channel (mass/unit channel length)

g_o =total incoming sediment load from overland flow area (mass/unit channel length·time)

$g_{o(k)}$ = incoming sediment load from overland flow area (mass/unit channel length·time)

$g_{o(i)}$ = sediment load for conservation planning from overland area immediately above the *jth* channel (mass/unit channel length·time)

H = daily soil ridge height (inches)

H_e = daily effective total ridge height, which is sum of soil ridge height and effective vegetation ridge height (inches)

H_{vr} = daily effective vegetation ridge height (inches)

I_j = average water added by irrigation on *jth* day (length)

J = number of flow interceptors along an overland flow path

K_b = base soil erodibility factor value computed without the permeability subfactor (US customary units)

K_d = soil erodibility factor for drained condition (US customary units)

K_j = soil erodibility factor on the *jth* day (US customary units)

K_n = soil erodibility factor computed with a RUSLE2 soil erodibility nomograph for frost free period (US customary units)

K_u = soil erodibility factor for undrained condition (US customary units)

p_b = base contouring subfactor value

p_{bm} = minimum base contouring subfactor value

p_c = the daily contouring subfactor

p_{c0} = contouring subfactor for a zero row grade

$p_{c0,min}$ = 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_{rd} = the soil profile permeability class for the drained condition

P_{ru} = the soil profile permeability class for the undrained condition

P_{10y24h} = 10 year-24 hour precipitation amount (length)

q_o = discharge rate at end of the overland flow path (volume/ unit channel length·time)

s = overland flow path steepness (sine of slope angle)

s_{be} = land steepness at which the contouring subfactor reaches 1 (sine of slope angle)

s_{bm} = land steepness at which contouring subfactor value is minimum (sine of slope angle)

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) (100 time tangent of slope angle)

s_f/s_p = relative row grade

s_m = land steepness at which $p_b = p_{bm}$ (sine of slope angle)

s_p = land steepness (100 time tangent of slope angle)

s_{re} = runoff adjusted land steepness above which contouring subfactor equals 1 (sine of slope angle)

T_c = total sediment transport capacity for all sediment classes of the flow in the channel (mass/time)

$V_{w(j)}$ = daily consumption watercuse by vegetation (length)

$V_{f(k)}$ = fall velocity of *kth* sediment class (length/time)

x = distance along the channel (length)

$\delta_{s(i)}$ = *ith* flow interceptor spacing (feet)

λ_o = overland flow path length without flow interceptors (length)

$\lambda_{s(i)}$ = distance from origin of overland flow for the original overland flow path to the *ith* flow interceptor (length)

$\phi_{(k)}$ = a deposition coefficient for the *kth* sediment class ($length^{-1}$)

$\omega_{(k)}$ = sediment delivery ratio for *kth* sediment class

$\omega_{(i)}$ = total sediment delivery ratio for the *ith* flow interceptor

Indices

i – flow interceptor

j - day

k – sediment class

8. OPERATIONS

A RUSLE2 operation is an event that changes vegetation, residue, or soil conditions. RUSLE2 uses a set of rules and 10 processes to represent how operations affect 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 discusses 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 mass basis) of live vegetation to the dead standing residue pool and transfers 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 and leaves both standing and surface residue. The standing and surface residue biomass left by a remove live vegetation process is computed as:

$$\Delta B_{tr} = f_{tl}(f_{lr} B_{al}) \qquad [8.1]$$

$$\Delta B_{sr} = f_{sl}(f_{lr} B_{al}) \qquad [8.2]$$

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 the respective residue pools.

The amount of live aboveground biomass left after a remove live biomass process is computed from:

$$B_{al} = (1 - f_{lr})B_{alp} \qquad [8.3]$$

where: Bal = the mass (dry basis) of the above bround live biomass that is left after the operation and Balp = the mass (dry basis) of the above bround live biomass that exists immediately before 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 first 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:

$$\Delta B_{tr} = f_f B_{tr} \qquad [8.4]$$

where: f_f = the fraction of the existing standing residue that is flattened (i.e., added to the surface biomass pool).[61] The standing residue biomass pool after the operation is computed as:

[61] Flattening, burial, and resurfacing ratios are based on mass, not portion of the soil surface covered (see RUSLE2 User's Reference Guide).

$$B_{tr} = B_{trp}(1 - f_f) \qquad [8.5]$$

where: B_{tr} = mass (dry basis) of the standing residue immediately after the operation and B_{trp} = the mass (dry basis) that existed immediately before 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:

$$\Delta B_{sr} = f_b B_{sr} \qquad [8.6]$$

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 and Nelson, 1995):

$$B_{sr} = (B_{trp} f_f + B_{srp})(1 - f_b) + B_{brp} f_u \qquad [8.7]$$

where: B_{sr} = the surface residue mass (dry basis) immediately after the operation, B_{srp} = the surface mass immediately before the operation, f_u = the fraction of the buried residue mass that is resurfaced and B_{brp} 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:

$$\Delta B_u = f_u B_{br} \qquad [8.8]$$

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 consider the resurfacing of 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 the soil disturbing implement types 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).[62]

8.2.4.3. Effect of speed on surface residue burial

The effect of operation speed on residue burial ratio values is computed using:

$$\alpha_s = [0.6 + 0.4(v_s / v_m)^{1/2}]/[0.6 + 0.4(v_r / v_m)^{1/2}] \quad [8.11]$$

where: α_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:

$$f_b = \alpha_d \alpha_s f_{br} \quad [8.12]$$

where: f_{br} = 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 layer(s). The third step computes the mass distribution by soil layer of the material buried by the

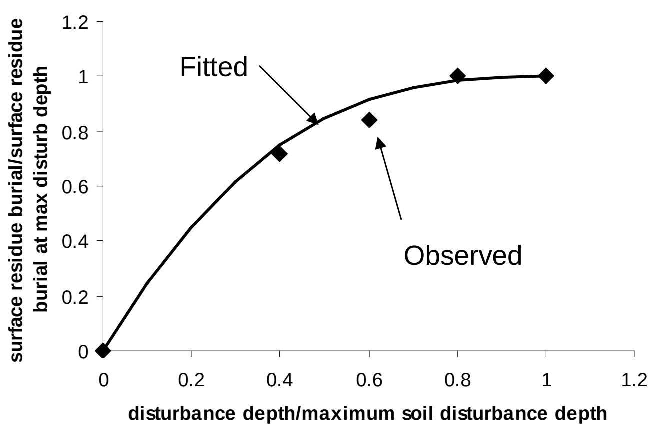

Figure 8.1. Effect of soil disturbance depth on surface residue burial.

[62] 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.

operation.

8.2.5.1. Types of soil disturbance operations

Types types of soil disturbing operations are used in RUSLE2 to describe how these operations distribute bury 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 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. The mixing type also represents materials pressed into the soil by cattle trampling, sheep's foot compactors, and similar operations. Burial of residue by compression does not involve soil disturbance.

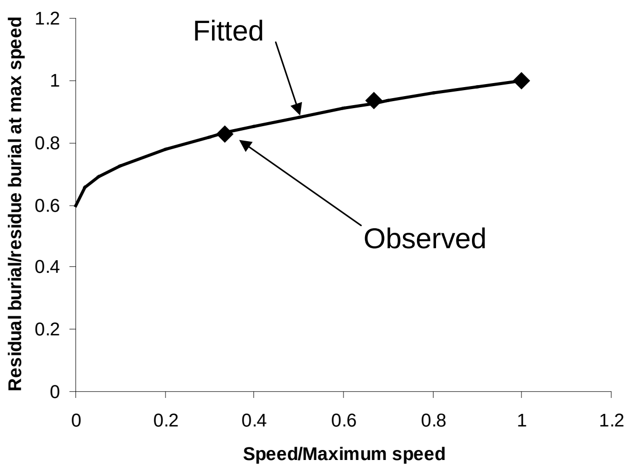

Figure 8.2. Effect of speed on surface residue burial.

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.[63]

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

[63] The RUSLE2 equations used to redistribute buried residue and dead roots are based on empirical data reported in the literature cited in **Section 12.2.4.**

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 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.

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:

$$\Delta B_{(i)} = (1-\phi_{k(i)})(B_{p(i)} + \Delta B_{(i-1)} - R_{(i)}) \quad [8.13]$$

where: $\Delta B_{(i)}$ = the buried material (dry mass/area) that moves from the *ith* soil layer to the *(i+1)th* layer, $\Delta B_{(i-1)}$ = the buried material (dry mass/area) that moves from the (*i-1)th* soil layer to the *)th* layer ϕ_k = the mass fraction of the buried material in the *ith* layer that is retained for the *kth* type soil disturbance operation, $B_{p(i)}$ = existing buried material (mass/area) in the *ith* soil layer, $R_{(i)}$ = the buried residue (dry mass/area) that is resurfaced for the *ith* layer. The soil disturbance depth is divided into 10 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.

The fine roots tightly bound to soil particles dead roots are assumed to have the greatest effect on erosion. Therefore, the RUSLE2 assumption is that dead roots are not resurfaced.[64]

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.

[64] The fact that soil disturbing operations surface dead roots is recognized. However, the fraction of dead roots in the soil that is resurfaced is considered to be much smaller than the fraction of buried residue that is resurfaced.

Table 8.1. Retention coefficient Φ 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

Values for the retention coefficient ϕ are given in Table 8.1. The value of 1 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:

$$M = (y / y_d)^b \qquad [8.14]$$

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 = y_d), y = depth in soil, y_d = soil disturbance depth for a specific soil disturbing operation, 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:

$$M = 0.28\{\exp[1.83(y / y_d) - 1]\} \quad y / y_d \le 0.6 \qquad [8.15]$$

$$M = 1 - 0.441\{[1 - (y / y_d)] / 0.4\}^{1.4} \quad y / y_d > 0.6 \qquad [8.16]$$

Equations 8.14 - 8.16 were derived from observed data where surface material was buried by a single occurrence 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.

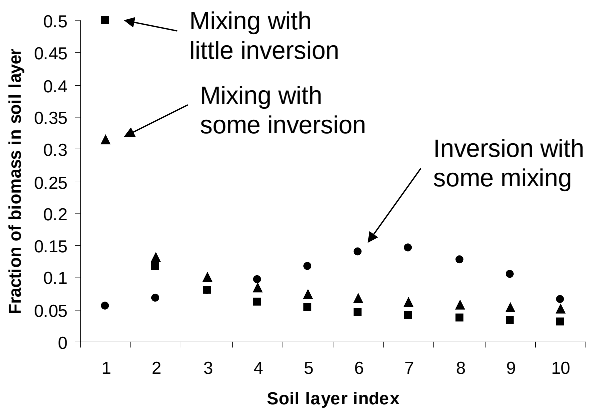

Figure 8.3. Distribution of residue by soil layer when initially buried by a soil disturbing operation.

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, which is added 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 basis) added as well as 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 added in the lower half of the disturbed soil depth in a parabolic distribution. The equations for cumulative mass with depth for material injected into the soil are:

$$M = 6\left[\frac{(2y/y_d - 1)^2}{2} - \frac{(2y/y_d - 1)^3}{3}\right] \quad y/y_d \geq 0.5 \qquad [8.17]$$

$$M = 0 \quad y/y_d < 0.5 \text{ [8.18]} \qquad [8.18]$$

where: m = cumulative normalized mass (cumulative mass above depth in soil/total mass), y = depth in soil, and y_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 grain crops 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:

$$c = c_{\omega}(1 - f_{\mu}) \qquad [8.19]$$

where: c = the c in equations 2.10 and 6.1 used to compute detachment, c_{ω} = the c term in equation 2.10 without the non-erodible cover effect, and f_{μ} = the portion of the soil surface covered by non-erodible cover. Equation 8.19 in effect adds a non-erodible cover subfactor to equation 6.1.

Non-erodible cover also affects runoff. The equations used to adjust cover number values used to compute runoff when non-erodible cover is present 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 removes 40 percent of the non-erodible cover. The remaining non-erodible cover is 43 percent [72·(100-40)/100] 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:

$$f_\mu = f_0 \exp(-\alpha_\mu \Delta t_\mu) \quad [8.20]$$

where: f_0 = the fraction of the soil surface covered by non-erodible cover immediately after an operation affects non-erodible cover (i.e., added or removed) and Δt_μ = the days since the non-erodible cover was affected. The coefficient α_μ = a coefficient (days^{-1}) that describes the rate of loss of non-erodible cover. Equation 8.20 is not written as a function of environmental conditions. To consider the effect of environmental conditions on this cover loss, users select α_μ values that reflect both material properties and local environmental conditions. Consequently, α_μ 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 disturb only 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:

$$s_{cn} = f_d + (1 - f_d) s_{cu} \quad [8.21]$$

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_{de} 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. 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).

Some soil disturbing operations that disturb only a portion of the soil surface. The RUSLE2 procedure that determines an effective surface residue biomass for the entire surface is described in **Section 6.2.3**.

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**.

8.3.4. 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 subsidence (settlement), interrill erosion, and local deposition.

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.

8.3.4.1. 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 **6.3.6** and RUSLE2 User's Reference Guide). Equations given in **Sections 6.3.2, 6.3.3,** and **6.3.5** are used to adjust this initial roughness value for soil texture, biomass, and existing soil surface roughness to represent site specific conditions where RUSLE2 is being applied.

RUSLE2 computes soil surface roughness decay over time as a function of precipitation and interrill erosion using equations given in **Section 6.3.6**. RUSLE2 computes roughness decay 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 entered for operations, such as for fine seedbeds typical of vegetable production or smooth surfaces left by a blading operation on a construction site, that create roughness smoother than that for unit-plot conditions (see **Section 2.1**). 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.

8.3.4.2. 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:

$$s_{rn} = f_d s_{rd} + (1 - f_d) s_{ru} \qquad [8.22]$$

where: s_{rn} = the net soil surface roughness subfactor immediately after a soil disturbing operation that occurs on day t, s_{rd} = the soil surface roughness subfactor for the disturbed portion of the soil surface immediately after the operation on day t, and s_{ru} = the soil surface roughness subfactor for the undisturbed portion of the soil surface on day of the operation. The starting value in equation 6.26 for the roughness subfactor immediately after the operation that is decayed is the s_{rn} 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.

8.3.4.3. 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:

$$R_a = (R_{ae} - R_{ao})(1-\xi) + R_{ao} \quad R_{ao} \le R_{ae} \qquad [8.23]$$

$$R_a = R_{ao} \quad R_{ao} > R_{ae} \qquad [8.24]$$

where: R_a = adjusted roughness after a soil disturbing operation, R_{ae} = existing adjusted roughness immediately before the operation, ξ = tillage intensity, and R_{ao} = the adjusted roughness left by the operation when applied to a smooth surface. Roughness values used in equations 8.23 and 8.24 have been adjusted for soil texture and biomass effects using the procedures described in **Section 6.3**.

8.3.5. 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).

8.4. List of symbols

b = exponent in equation for distribution of buried residue left by an operation

$B_{(i)}$ = buried material in *ith* 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)

B_{tr} = stading residue biomass (mass/area)

c = daily cover-management factor value in equation 2.10 with non-erodible cover effect

c_{ω} = daily cover-management factor in equation 2.10 without non-erodible cover effect

f_b = portion of surface residue that is buried (fraction)

f_{br} = burial ratio for given residue type for reference soil disturbance depth and speed

f_d = portion of the soil surface that is disturbed (fraction)

f_f = portion of existing standing residue biomass that is flattened a flatten standing residue process operation (fraction)

f_{lr} = portion of above ground live biomass that is affected by a **remove live vegetation** process operation (fraction)

f_n = faction of soil surfaced by non-erodible cover

f_{sl} = portion of affected biomass that is left as surface residue by a **remove live vegetation** process operation (fraction)

f_{tl} = portion of affected biomass that is left as standing residue by a **remove live vegetation** process operation (fraction)

f_u = portion of the buried residue biomass in soil disturbance depth that is resurfaced that is resurfaced (fraction)

f_0 = portion of soil surface covered by non-erodible cover immediately after an operation affects non-erodible cover (i.e., added or removed) (fraction)

f_{μ} = portion of soil surface covered by non-erodible cover (fraction)

M = cumulative buried residue normalized with depth (cumulative mass above depth in soil/total mass buried in soil disturbance depth) bured by a **soil disturb** process operation

N = number of data points

$R_{(i)}$ = buried residue niomass that is resurfaced from a soil layer (mass/area)

R_a = roughness after a soil disturbing operation (length)

R_{ae} = existing roughness immediately before the operation (length)

R_{ao} = the roughness left by the operation when applied to a smooth surface (length)

s_{cn} = net soil consolidation subfactor

s_{cu} = soil consolidation subfactor for the portion of soil surface not disturbed by operation

s_{rn} = net soil surface roughness subfactor immediately after a soil disturbing operation that occurs on day t

s_{rd} = soil surface roughness subfactor for disturbed portion of the soil surface immediately after the operation

s_{ru} = soil surface roughness subfactor for undisturbed portion of the soil surface on day t

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_{en} = estimated value for the *nth* data point

y_m = the maximum soil disturbance depth for operation (length)

y_{on} = observed value for the *nth* data point

y_{rc} = reference soil disturbance depth (length)

α_d = adjustment factor for depth

α_s = adjustment factor for speed

α_μ = coefficient that describes rate of loss of non-erodible cover (days^{-1})

δ = function that is minimized

$\Delta B_{(i)}$ = buried material that moves from *ith* soil layer to *(i+1)th* layer (mass/area)

$\Delta B_{(i-1)}$ = buried material that moves from (*i-1)th* soil layer to *i)th* layer (mass/area)

ΔB_{sr} = standing residue added to surface residue biomass pool by a **remove live vegetation** operation process or surface residue biomass transferred to the buried residue pool by a **soil disturb** process operation (mass/area)

ΔB_{tr} = live above ground biomass added to standing biomass pool added by a **remove live vegetation** process operation or biomass lost from standing residue bimass and added to surface bimass by a **flatten standing residue** process in an operation (mass/area)

$\Delta B_{u(i)}$ = residue biomass that is resurfaced from soil disturbance depth by a **soil disturb** process operation (mass/area)

Δt_{μ} = time since non-erodible cover was affected (days)

ξ = tillage intensity

$\phi_{k(i)}$ = portion of buried material in the *ith* layer that is retainedby a *kth* type soil disturbance operation (fraction)

Indices

i – soil layer

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

Input values for the 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 values for 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).

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 **Section 12.2.5**). 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:

$$M_r = y[24.24y\exp(-5.50y) + 0.778] \quad y \le 0.533333 \qquad [9.1]$$

$$M_r = 0.783391 + 0.147688(y - 0.533333) \quad 0.533333 < y \le 2 \qquad [9.2]$$

$$M_r = 0 \quad 2 < y \qquad [9.3]$$

where: 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.

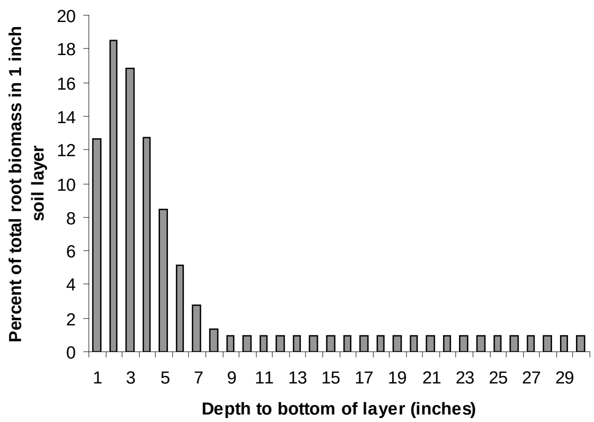

Figure 9.1. Fraction of total root biomass in 1 inch soil layers.

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 runoff curve values, b values for effect of ground (surface) cover, slope length exponent, soil surface roughness, and soil biomass subfactor values (see **Sections 3.3.1.2, 6.2.1, 6.2.2, 6.3, and 6.5**).

A major result from the literature review and data analysis was that rooting depth for the roots judged to have the greatest 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 must be judged in terms of RUSLE2's stated purpose of being an easily used guide for erosion control planning. Do RUSLE2's erosion estimates adequately represent the effect of temporal variability in root biomass for purposes of erosion control planning? Such an evaluation described in the RUSLE2 User's Reference Guide shows that RUSLE2 meets that criterion. Capturing the main effects of root biomass rather than all of the details is adequate for RUSLE2 purposes.

RUSLE2 uses average live root biomass density in the upper 10 inch soil depth 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.[65] Temporal live root biomass values given in the RUSLE2 Core Database (see the RUSLE2 User's Guide) were scaled from measured values at plant maturity. RUSLE2 accurately computes expected erosion estimates for times before the vegetation reaches maturity for major agricultural crops (see RUSLE2 User's Reference Guide), which strongly indicates that these assumptions are adequate for RUSLE2 purposes.

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

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[65] A possible RUSLE2 improvement would be to temporally vary rooting depth according to plant community. Similarly, the root distribution should also be varied with plant community and plant growth stage. These improvements were judged to excessively complicate RUSLE2.

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

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.[66]

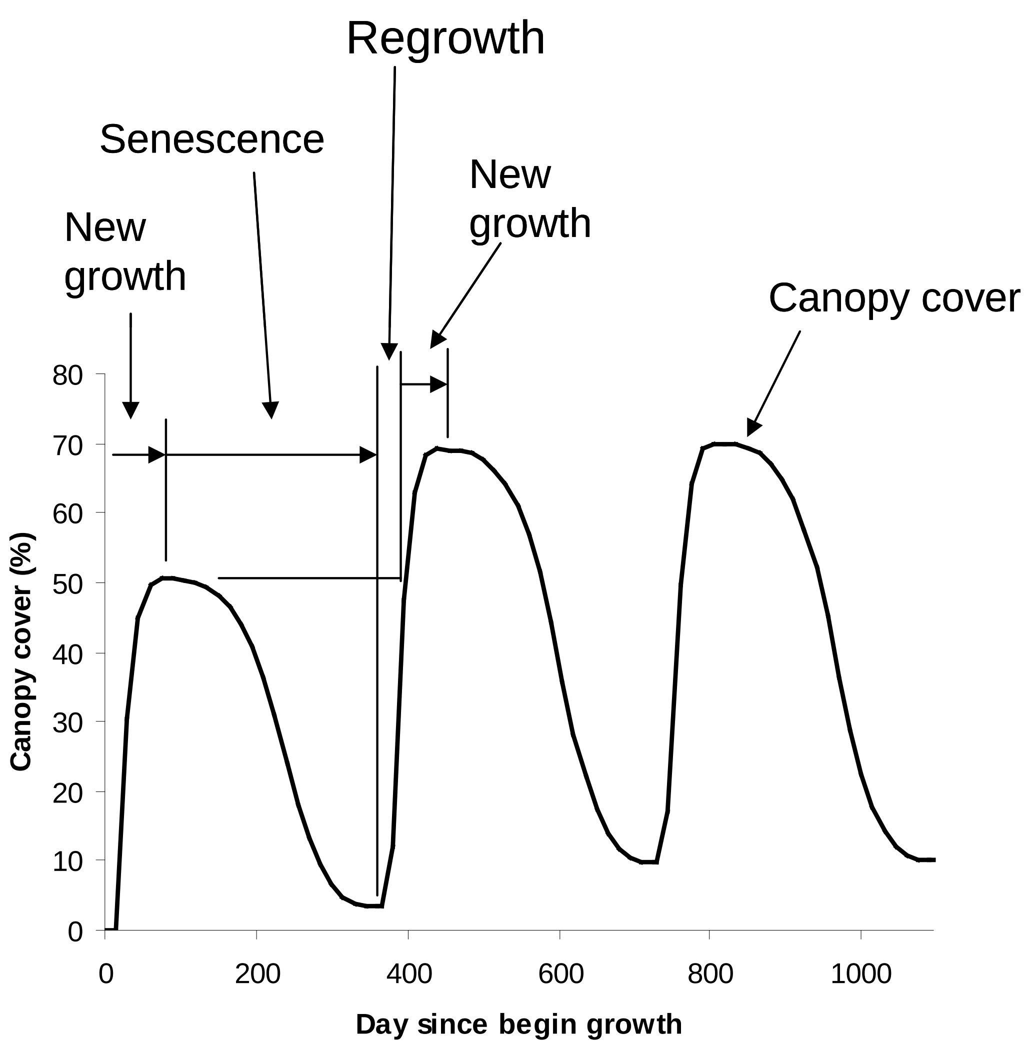

Figure 9.2. Vegetation growth periods used to compute live above ground biomass as a function of canopy cover.

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.

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 for the vegetation 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 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:

$$B_l = B_{lamx}(C/C_{amx})^{1.5} \qquad [9.4]$$

where: B_l = daily live above ground biomass during a new growth period, B_{lamx} = the live above ground biomass at absolute maximum canopy cover for a vegetation description, C = daily canopy cover, and C_{amx} = canopy cover at absolute maximum canopy cover for a vegetation description.

9.2.3.2. Senescence period

A **senescence** period is the time over which canopy cover decreases 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:

$$B_l = B_{lmn(k)} + (B_{lmx(k)} - B_{lmn(k)})[(C - C_{mn(k)})/(C_{mx(k)} - C_{mn(k)})]^{1.5} \qquad [9.5]$$

where: $B_{lmn(k)}$ = live above ground biomass at the *kth* local canopy cover minima, $B_{lmx(k)}$ = live above ground biomass at the *kth* local canopy cover maxima, $C_{mn(k)}$ = canopy cover at the *kth* local minima, and $C_{mx(k)}$ = canopy cover at the *kth* local maxima. The index k 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:

$$B_{lmn(k)} = B_{lamn}(C_{mn(k)} / C_{mn(1)})^{1.5} \qquad [9.6]$$

where: B_{lamn} = the absolute minimum live above ground biomass which occurs at $C_{mn(1)}$ = the first 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.

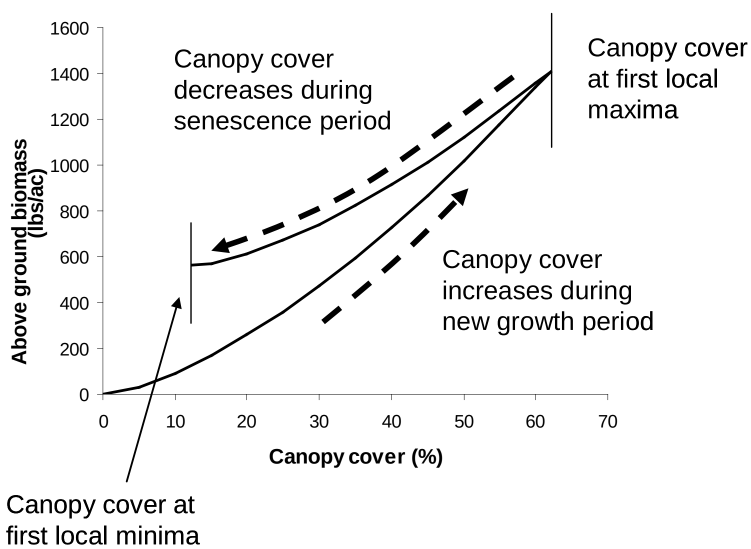

Figure 9.3. Live above ground biomass-canopy cover relationships for new growth and senescence periods during first year.

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 are used in a RUSLE2 cover-management description to describe significant changes in live above ground biomass during periods when canopy cover changes very little. The inputs for these vegetation descriptions are selected so that

RUSLE2 computes a significant change in live above ground biomass for very little change in canopy cover such as from 99.9 percent to 99.5 percent. Such small changes in canopy cover have essentially no effect on canopy subfactor values (see **Section 6.1**). Additional vegetation descriptions are used for times during the cover-management description 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

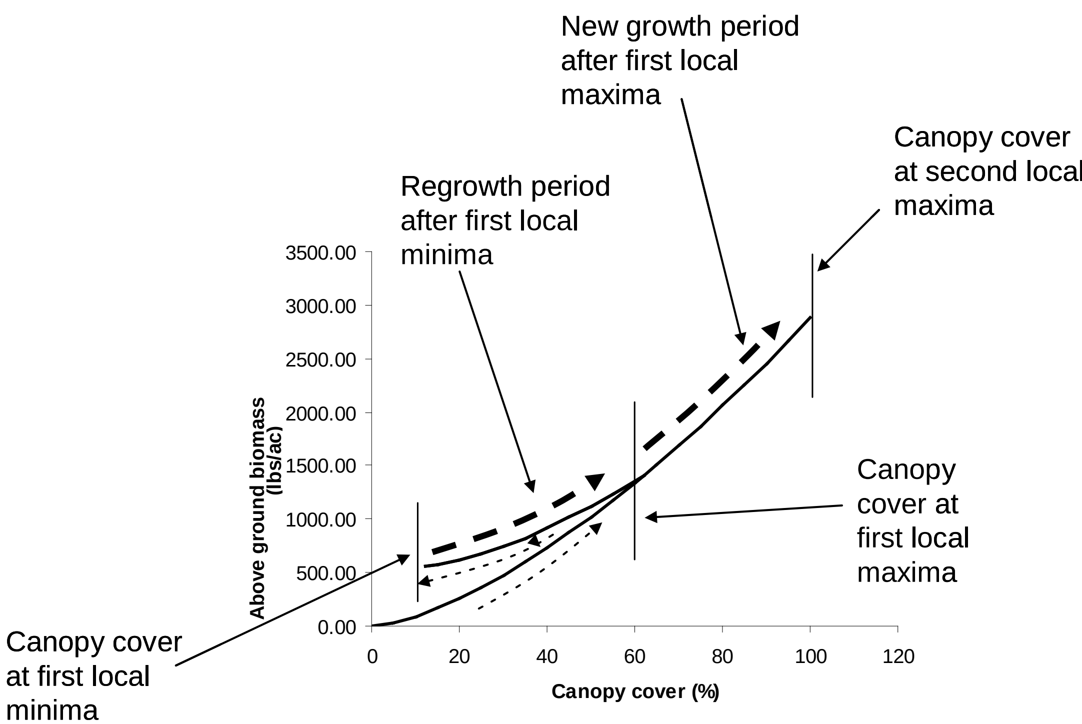

Figure 9.4. Live above ground biomass-canopy cover relationships for regrowth and new growth periods during second year.

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 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.

9.2.4. Litter fall by other processes than senescence

9.2.4.1. Simultaneous birth and death of live above ground biomass

Litter is produced during the increase in growth period before canopy cover begins to decrease by senescence (Dubeux et al., 2005; Thomas and Asakawa, 1993). The litter produced during this period adds substantially to the surface residue produced by litter fall during senescence.

The amount of litter fall during the increase in growth period and into the first part of the senescence period is computed using:

$$L_f = c_f(B_l - B_{lmn(k)}) \quad if\,(B_l < B_{lmn(k)}): L_f = 0 \qquad [9.7]$$

where: L_f = day litter fall rate (mass/area·day) during the birth-death period and c_f = coefficient for birth-death litter fall (day^{-1}). A single value of 0.01 day^{-1} probably can be used almost all vegetation types (Dubeux et al. 2005; Thomas and Asakawa, 1993). However, this conclusion needs further research.

Litter fall is computed using equation 9.7 into the senescence period until the rate of litter falls computed by the difference in above ground biomass in a day exceeds the litter fall rate computed by equation 9.7.

9.2.4.2. Litter fall caused by mechanical traffic

Mechanical traffic by humans, animals, and vehicles can transfer biomass from the canopy to the soil surface that adds to surface residue. That biomass transfer is estimated by:

$$L_m = c_m(B_l - B_{lmn(k)}) \;\; if\,(B_l < B_{lmn(k)}) : L_f = 0 \qquad [9.8]$$

where: L_m = litter fall rate (mass/area·day) caused by mechanical traffic and c_m = a litter fall coefficient (day^{-1}) for the litter fall caused by mechanical traffic. The input value for c_m is based on the user's judgment.

9.2.4.3. Adjustment in above ground biomass for litter fall

RUSLE2 does not adjust live above ground biomass for litter fall. The user entered input values for canopy cover are assumed to represent the canopy that exists in the field regardless of what affects canopy cover. RUSLE2 converts those values to biomass, which like the canopy cover values are the live above ground biomass that exists regardless of how it came to be. RUSLE2's litter fall computations describe the disposition of live above ground biomass.

9.2.5. Operations that affect live vegetation

Operations that include **begin growth**, **kill vegetation**, **remove live biomass, and Process: Perennial biomass & current standing res removal** 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 user explicitly use operations, such as **remove live biomass**, 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**.

9.2.6. 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:

$$n_v = n_{vmx}(h_f / h_{fmx})$$

where: n_v = daily Manning's n contributed by live standing vegetation not including live ground cover, n_{vmx} = maximum Manning's n contributed by live standing vegetation, not including live ground cover, during the period represented by the vegetation description, h_f = daily effective fall height, h_{fmx} = 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 for standing live vegetation was assumed to be best related to effective fall height. The Manning's n contributed by live ground (surface) cover is consider in the relation of Manning's n to net ground (surface) cover (see **Section 3.4.6**)

Table 9.1. Coefficient a_H 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 a_H
Vegetation on ridges	0.25
Wide row (≥ 30 inches)	0.50
Moderate row spacing (15 to 20 inches)	0.75
Narrow row spacing (7 to 10 inches)	1.00
Very narrow row spacing (≤5 inches)	0.50
No rows (broadcast)	0.00

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 3.10. 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.

9.2.7. 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**). 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 erosion reduction (i.e., contouring effect) for effective live standing vegetation ridge height increases as vegetation row spacing increases to a maximum at the narrow row width of approximately 8 inches). Erosion reduction by effective vegetation ridge height decreases as row spacing widens beyond the narrow row spacing. This effect is represented by the coefficient α_h values 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:

$$H_{vmx} = 0.5 a_H R_v \quad if\,(R_v > 7): R_v = 7 \qquad [9.10]$$

where: H_{vmx} = maximum effective live standing vegetation ridge height (inches) for the vegetation description when vegetation strips (rows) are on the contour, a_H = the coefficient that adjusts for row spacing (inches), and R_v = the retardance class at maximum canopy cover in the vegetation description (see **Section 9.3.1**).

Daily effective live standing vegetation ridge height H_v is computed using:

$$H_v = H_{vmx} (h_f / h_{fmx})^{0.3} \qquad [9.11]$$

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 computes 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 for RUSLE2 to make the proper mathematical computations. 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). 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 as a whole over the RUSLE2 computation period, such as the example alfalfa crop.

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:

$$B_{lamx} = a_y + b_y Y_d \qquad [9.12]$$

where: B_{lamx} = 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:

$$Y_d = b_u Y_u \qquad [9.13]$$

where: Y_u = production level (yield) in user defined units and b_u = a conversion factor that RUSLE2 computes from user inputs. The values for the coefficients a_y and b_y in equation 9.12 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).

9.3.2. Retardance at maximum canopy cover

Retardance for live vegetation at maximum canopy cover is computed from:

$$R_v = c_R + d_R Y_u \qquad [9.14]$$

where: R_v = 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_R and d_R in equation 9.14. RUSLE2 uses eight retardance classes that vary with the degree that vegetation grown in strips (rows) on the contour slows runoff (see Table 3.9). Equation 9.14 computes continuous values that are used in equation 3.54 to compute Manning's n values.

Vegetation descriptions are used to describe both live vegetation and porous barriers (fabric fences, gravel bag dams, and similar mechanical devices used on construction sites to trap and retain sediment on site) (see **Section 7.2** and RUSLE2 User's Reference Guide). The yield input for the vegetation description selected 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 based on values computed by the EPIC model (Williams et al., 1989) are used in RUSLE2 to compute values for the temporal variables of root biomass, canopy cover, effective fall height, live ground cover, and consumptive water use.

9.3.3.1. 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:

$$B_{rn(j)} = B_{rb(j)}(B_{lamxn} / B_{lamxb}) \quad [9.15]$$

where: $B_{rn(j)}$ = root biomass value in the new vegetation description for the *jth* data point, $B_{rb(j)}$ = root biomass value for the *jth* data point in the base vegetation description, and B_{lamxb} = absolute maximum live above ground biomass in the base vegetation description. A value for the live above ground biomass at absolute maximum canopy B_{lamxn} in the new vegetation description is computed using equation 9.12 and the production (yield) level value for the new vegetation description.

9.3.3.2. Canopy cover

The equation used to adjust canopy cover values for production (yield) level is:

$$C_{n(j)} = C_{b(j)}(B_{lamxn} / B_{lamxb})^{0.5} \quad [9.16]$$

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.

9.3.3.3. Effective fall height

The equation used to adjust effective fall height values for production (yield) level is:

$$h_{fn(j)} = h_{fb(j)} (B_{lamxn} / B_{lamxb})^{0.2} \quad [9.17]$$

where: $h_{fn(j)}$ = effective fall value for the *jth* data point in the new vegetation description and $h_{fb(j)}$ = corresponding effective fall height value for the *jth* data point in the base vegetation description.

9.3.3.4. Live ground cover

The equation used to adjust live ground cover values as a function of production (yield) level is:

$$f_{\lg cn(j)} = f_{\lg cb(j)} (B_{lamxn} / B_{lamxb})^{0.5} \quad [9.18]$$

where: $f_{lgcn(j)}$ = live ground cover value for the *jth* data point in the new vegetation description (percent) and $f_{lgcb(j)}$ = corresponding live ground cover value for the *jth* data point in the base vegetation description (percent).

9.3.3.5. Consumptive water use

Consumptive 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:

$$V_{wn(j)} = V_{wb(j)} (B_{lamxn} / B_{lamxb}) \quad [9.19]$$

where: $V_{wn(j)}$ = consumptive water use value for the *jth* data point in the new vegetation description and $V_{wb(j)}$ = corresponding values for consumptive water use value for the *jth* data point in the base vegetation description.

9.4. List of symbols

a_y = coefficient used to compute live above ground biomass at absolute maximum canopy cover for a vegetation description

a_H = coefficient used to computed effective vegetation ridge height from vegetation retardance (inches)

b_u = coefficient used to convert user defined yield units to dry mass

b_y = coefficient used to compute live above ground biomass at absolute maximum canopy cover for a vegetation description

B_l = daily live above ground biomass (dry basis) during a new growth period (mass/area)

B_{lamn} = live above ground biomass (dry basis) at first minimum canopy cover $C_{mn(1)}$ for a vegetation description (mass/area)

B_{lamx} = absolute maximum live above ground biomass (dry basis) at absolute maximum canopy cover for a vegetation description (mass/area)

$B_{lmn(k)}$ = live above ground biomass (dry basis) at *kth* local canopy cover minina in a vegetation description (mass/area)

$B_{lmx(k)}$ = live above ground biomass (dry basis) at *kth* local canopy cover maxima in a vegetation description (mass/area)

B_{lamxb} = live above ground biomass at absolute maximum canopy cover in base vegetation description (mass/area)

B_{lamxn} = live above ground biomass at absolute maximum canopy cover in new vegetation description (mass/area)

$B_{rb(j)}$ = root biomass value for the *jth* data point in the base vegetation description (mass/area in upper 4-inch depth)

$B_{rn(j)}$ = root biomass value for the *jth* data point in the new vegetation description (mass/area in upper 4-inch depth)

$B_{t,mn}$ = 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_f = coefficient for birth-death litter fall (day^{-1})

c_m = cooefficient fr litter fall caused by mechanical traffic (day^{-1})

c_R = coefficient used to compute retardance from user input yield

C = daily canopy cover (fraction)

C_{amx} = canopy cover at absolute maximum canopy cover for a vegetation description (fraction)

$C_{mn(k)}$ = canopy cover at the *kth* local canopy minima (fraction)

$C_{mx(k)}$ = canopy cover at the *kth* local canopy maxima (fraction)

$C_{b(j)}$ = canopy cover value for *jth* data point in base vegetation description (fraction)

$C_{n(j)}$ = canopy cover for *jth* data point in new vegetation description (fraction)

d_R = coefficient used to compute retardance from user input yield

$f_{lgcb(j)}$ = live ground cover value for *jth* data point in base vegetation description (percent)

$f_{lgcn(j)}$ = live ground cover value for *jth* data point in new vegetation description (pecent)

h_f = daily effective fall height (length)

$h_{fb(j)}$ = effective fall height value for the *jth* data point in the base vegetation description (length)

$h_{fn(j)}$ = effective fall value for *jth* data point in new vegetation description (length)

h_{fmx} = maximum effective fall height for a vegetation description (length)

H_v = daily effective live standing vegetation ridge height (inches)

H_{vmx} = maximum effective live standing vegetation ridge height for a vegetation description

L_f = daily litter fall during birth-death period (mass/area·day)

L_m = daily litter fall caused by mechanical traffic (mass/area·day)

M_r = cumulative root biomass (dry basis) above the depth y (mass/area)

n_v = daily Manning’s n contributed by live standing vegetation not including live ground cover

n_{vmx} = maximum Manning’s n contributed by live standing vegetation not including live ground cover for a vegetation description

R_v = vegetation retardance class at maximum canopy cover for a vegetation description

$V_{wb(j)}$ = corresponding values for consumptive water use value for *jth* data point in base vegetation description (inches)

$V_{wn(j)}$ = consumptive water use value for *jth* data point in the new vegetation description (inches)

y = normalized depth in soil from soil surface Y/15 inches

Y = depth in soil from soil surface (inches)

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

Indices

j – data point

k - refers to canopy cover maxima-canopy cover minima combination where canopy cover minima occur after a canopy cover maxima

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, surface, and buried residue pools that account for material produced when live above ground biomass is converted to standing residue (**Sections 6.1, 6.2, 6.5, and 9.2.5**). RUSLE2 accounts for the movement of residue 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 residue pool results from live root biomass associated with a vegetation description being transferred to the dead root biomass pool (see **Sections 6.5.6 and 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 (see **Section 10.2.5**).

Crop residue and plant litter are composed of diverse components including stems, leaves, seed pods, and chaff. Similarly, dead roots vary from very fine to coarse roots. A single residue description is used to represent a composite of these components for a particular vegetation description

10.2. Relation of portion of soil surface covered to surface residue mass

10.2.1. Size criteria for counting residue

To be counted as ground cover, soil surface material must remain in place, not be moved downslope by surface runoff during a rainstorm, and not be moved away by wind. The minimum size required to be counted as ground cover for RUSLE2 purposes must meet this criteria. **No single size should be used for all ground cover material in all situations**. For example, small pieces of residue will stay in place at the upper end of an overland flow path that would be moved at the lower end of a long overland flow path. Similarly, residue will be stable on a very flat overland flow path that would be moved on a steep overland flow path. Small residue pieces can be stable among a gradation of residue sizes but be unstable when the residue is uniformly composed of the small pieces. Small residue pieces that are stable at high residue surface covers may be unstable at low residue surface covers.

Equations that compute the hydraulic stability of mulch and crop residue were considered for RUSLE2 but were rejected because the equations were judged not to be sufficiently robust for RUSLE2 purposes (Foster et al., 1982a, 1982b).

Rock fragments on the soil surface require special consideration. The same stability considerations for other surface residue also apply to counting surface rock fragments as surface cover. Another factor is whether the rock fragments are a part of the soil matrix or simply “loose” rock on the soil surface that acts like surface cover. An approximate guideline is that rock fragments must be larger than 5 mm on coarse textured soils in arid and semi-arid regions where runoff is low and larger than 10 mm in other regions to be counted as ground cover.

10.2.2. Equation for computing residue cover from residue mass

RUSLE2 tracks surface residue (material in direct contact with the soil surface) on a dry mass basis (mass/area). However, the portion of the soil surface covered is the major variable used in equation 6.6 to compute how ground cover (surface residue) affects rill-interrill erosion. The RUSLE2 equation that computes portion of the soil surface covered by surface residue is:

$$f_g = 1 - \exp(-\alpha B_s) \qquad [10.1]$$

where: f_g = fraction of the soil surface covered by residue 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 rearranged and user entered values for the residue mass that provides 30, 60, or 90 percent soil cover.

A typical example of surface residue mass-cover data is illustrated in Figure 10.1. A common feature of these data is their high variability, which in turn greatly affects the variability in computed erosion estimates. For example, cover ranges from 0.70 to 1.0 percent in Figure 10.1 at a mass of 150 g/m^2. This range in cover gives ground cover subfactor values for g_c in equation 6.6 (**b** = 0.04 percent^{-1}and R_a = 0.24 inches) that range from 0.018 to 0.061. The portion of the soil surface covered ranges from 0.55 to 0.85 percent for a residue mass of 50 g/m^2, which gives values of 0.033 to 0.11 for g_c. In both cases, erosion

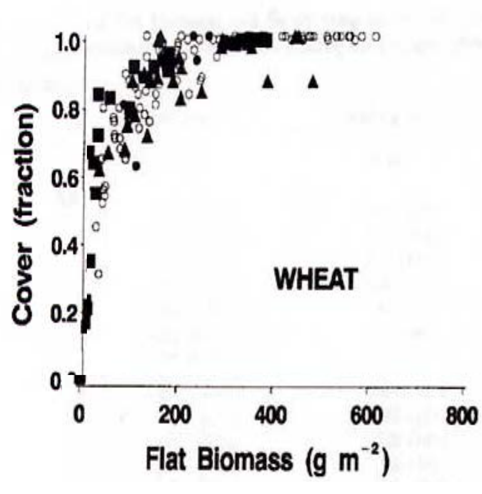

Figure 10.1. Measured data for relationship of residue cover to surface residue mass. (Source: Steiner et al., 2000).

can differ by a factor of 3 for a given surface residue mass. Therefore, even if RUSLE2 could estimate surface residue mass perfectly, RUSLE2's estimated portion of the soil surface covered, and its corresponding estimated erosion, could be significantly in error when compared to an individual measurement of soil surface cover.

Given this variability, the best that RUSLE2 can represent is differences in major residue types. Expecting RUSLE2 to accurately estimate percent residue cover at a particular location on a landscape at a particular point in time is unreasonable.

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 in 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 that differ from the RUSLE2 values. For example, surface cover ranged from about 65 percent to 100% for a flat wheat residue mass of about 1500 lbs/acre (168 g/m^2) in the Steiner et al. (2000) study, which is significantly greater than the 58 percent that the RUSLE2 Core Database values compute for the same residue mass. The RUSLE2 Core Database values for wheat straw 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).

The variation among some plant varieties is so great than different mass-cover relationships should be used for major variety types. For example, Stott (1995) noted that α values for corn varied from about 0.00023 to 0.00045 $(lbs/acre)^{-1}$ for corn residue based on her measurements and data reported in the literature. Stott 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 $(lbs/acre)^{-1}$ (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.

Another example is that soybean varieties grown in the Midwest US differ from those grown in the Mid-South US. The RUSLE2 Core Database mass-cover value for soybeans varieties grown in the Midwestern US is that 600 lbs/acre of soybean residue gives 30 percent soil surface cover [AH703 (Renard et al., 1997)] while the mass-cover value for the variety of soybeans grown in the Mid-South US is that 1460 lbs/acre of soybean residue gives 30 percent soil surface cover (Mutchler and Greer, 1984).[67]

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[67] K.C. McGregor. 1994. Mass-cover data for soybeans grown at Holly Springs, Mississippi. Personal communication. Scientist (retired) at the USDA-National Sedimentation Laboratory, Oxford, Mississippi.

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 and Oschwald (1976)			
2. Dickey et al. (1985)			
3. Lindstrom and Onstad (1984)			
4. Laflen et al. (1978)			
5. McIsacc et al. (1990)			
6. McIsaac et al. (1991)			
7. Shelton et al, (1986)			
8. Jasa et al. (1986)			

The RUSLE2 Core Database values for surface residue mass-cover relationships should be used 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 to measured erosion values using the values in the RUSLE2 Core Database. That is, RUSLE2 was calibrated to give expected erosion values. **Unexpected serious error in RUSLE2 computed erosion estimates can occur when input residues values are improperly changed from those in the RUSLE2 Core Database (see the RUSLE2 User's Reference Guide). If a change is made in residue input values, RUSLE2 computed erosion values with the new input values should be compared against erosion measured with the residue represented in the new input values.**

10.2.3. Reasons for variability in the surface 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 studies of residue mass-residue cover, may have masked temporal changes in the residue mass-residue cover relationship.

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 are 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).

10.2.4. Overlap of residue

The user assigns a single residue description to each vegetation description and to each operation description in a cover-management description that adds material to the soil surface (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 applications to compute net ground cover. The RUSLE2 assumption is that 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 (e.g., crop residue or mulch and rock) is computed as:

$$f_{gn} = f_{gr} + f_{gm}(1 - f_{gr}) \qquad [10.2]$$

where: f_{gn} = net ground cover (fraction), f_{gr} = ground cover (fraction) computed with equation 10.1 provided by the rock surface residue cover assuming no other material is present, and f_{gm} = 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. The overall net ground cover value is used in equations 6.6, 6.7, and related equations to compute the effect of surface residue cover on rill and interrill erosion. A ground cover subfactor g_c is not computed for each residue description.

10.2.5. Inputs for non-organic residue

In some cases, a material is applied to the soil surface that significantly affects erosion but has less effect on erosion when incorporated into the soil than routine plant residue. 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 in the soil 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 is that RUSLE2 uses desired ground cover values to compute ground cover subfactor values using equation 6.6 but uses such small residue mass values that soil biomass factor values computed with equation 6.48 are hardly affected if the material is incorporated into the soil (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's 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 a 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 et al., 1990; Stott et al., 1995], which are a simplification of the decomposition equations used in the erosion prediction model WEPP (Laflen et al., 1991b; Flanagan and Nearing, 1995).[68] The main decomposition equation is:

$$B = B_p \exp(-\beta D) \qquad [10.3]$$

where: B = the mass in a particular residue/dead root pool after decomposition B_p= the mass in the pool on the previous day, and D = the number of days in the period over

[68] Also, see references listed in the **Decomposition Subsection** of the **References Section**.

which decomposition is being computed, which is a single day in RUSLE2 (i.e., D = 1 day). A daily value for 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 on a particular day is limited by either moisture or temperature 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. RUSLE2 does not compute moisture in residue/dead root pieces or in the soil that contacts residue/dead roots. Decomposition rate decreases if moisture decreases below the moisture content for optimum decomposition. RUSLE2 does not take into account reduced decomposition at excessively high moisture contents. Daily values for the moisture function W_f are computed from:

$$W_f = (P + I)/P_b \quad if[(P + I)/P_b > 1]: W_f = 1 \qquad [10.5]$$

where: P = daily precipitation (inches), I = daily amount (inches) of water added by irrigation, and P_b = base daily precipitation (inches) at which optimum decomposition occurs. A value of 0.173 inch (4.4 mm) was determined by fitting the RUSLE2 decomposition equations to the field data identified in Table 10.2.

Decomposition also varies with temperature. Decomposition decreases as temperature decreases below 32 ^{o}C, the optimum temperature at which decomposition rate is maximum. Similarly, decomposition decreases as temperature increases above 32 ^{o}C. Daily values for the temperature function are computed from:

$$T_f = \frac{2(T + A)^2 (T_o + A)^2 - (T + A)^4}{(T_o + A)^4} \quad if(T < -10): T_f = 0 \qquad [10.6]$$

where: T = daily air temperature (^{o}C), T_o = the optimum temperature (^{o}C) for decomposition (32 ^{o}C), and A = 8 ^{o}C. The value for A was set so that when air temperature becomes less than – 10 ^{o}C, the temperature function is set to zero.[69] The reason that the temperature function does not become zero at a higher temperature, such as near 0 ^{o}C, 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

[69] An adjustment should have been made to equation 10.6 to flatten the top of the curve around the 32 ^{o}C 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. (2002).

function because soil temperature data are not readily available for use in RUSLE2. Like precipitation, air temperature is an indicator variable rather than the actual temperature that the decomposing material experiences. Values for the RUSLE2 decomposition coefficient ϕ differ from values for decomposition coefficient in similar equations used in other 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.

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 (see **Section 10.3.3** for discussion of the reasons for this decision). 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 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) (see **Section 10.3.3** for discussion of the reasons for this decision).

10.3.2. Calibration of equations

Values for the daily base precipitation P_b in equation 10.5 and values for the decomposition coefficient ϕ were determined by fitting the decomposition equations to measured data. Resulting P_b and ϕ values are given in Table 10.2.

The decomposition equations were fitted to the field data using daily average precipitation and temperature values disaggregated (see **Section 3.1**) from long term average monthly precipitation and temperature rather than actual precipitation and temperature values. Using long term-averages in these computations had a smoothing effect. Also, RUSLE2 uses average daily precipitation regardless of whether precipitation actually occurs, and thus values determined for P_b and ϕ are a function of RUSLE2's mathematical structure. Furthermore, the RUSLE2 purpose is to

Table 10.2. Values for P_b and Φ determined by fitting decomposition equations to measured data

Location	Crop	Daily precipition above which W_f = 1 P_b (mm)	Decomposition coefficient Φ (day^{-1})	Placement	Reference
Columbia, MO	corn	4.4 assumed	0.016	buried, in bags	(1)
Columbia, MO	corn	4.4 assumed	0.010	surface, in bags	(1)
Columbia, MO	corn	4.4 assumed	0.010	buried, in bags	(2)
W. Lafayette, IN	corn, conventional till	4.4 assumed	0.016	surface, determined from surface samples removed from plots, not in bags	(3)
W. Lafayette, IN	corn, no-till	4.4 assumed	0.016	same	(3)
Treynor, IA	corn, till plant	4.4 assumed	0.011	same	(4)
Bushland, Tx	corn	4.4 assumed	0.006	surface, in bags	(5)
Columbia, MO	soybeans	3.6	0.029	buried, in bags	(2)
W. Lafayette, IN	soybeans	4.4 assumed	0.025	surface, determined from surface samples removed from plots, not in bags	(3)
W. Lafayette, IN	soybeans	4.4 assumed	0.025	same	(3)
Griffin, GA	soybeans	4.4 assumed	0.025	same	(5)
Holly Springs, MS	soybeans	10.0	0.015	estimated from measured portion of soil surface covered and mass-cover equations	(6)
Holly Springs, MS	soybeans	2.7	0.013	same	(6)

Table 10.2. Values for P_b and Φ determined by fitting decomposition equations to measured data (continued)

Location	Crop	Daily precipition above which $W_f = 1$ P_b (mm)	Decomposition coefficient Φ (day^{-1})	Placement	Reference
W. Lafayette, IN	wheat	4.2	0.0064	surface, determined from surface samples removed from plots, not in bags	(7)
W. Lafayette, IN	wheat	4.4	0.008	same	(7)
Bushland, TX	wheat	3.7	0.0081	same	(7)
Bushland, TX	wheat	4.4	0.008	same	(7)
Griffin, GA	wheat	4.4 assumed	0.008	same	(5)
Twin Falls, ID	wheat	1.8	0.012	buried, in bags	(8)
Twin Falls, ID	wheat	4.4 assumed	0.021	same	(8)
Pullman, WA	wheat	0.5	0.0099	surface, determined from surface samples removed from plots, not in bags	(7)
Pullman, WA	wheat	0.5	0.0098	same	(7)
Pullman, WA	wheat	0.5	0.0097	same	(7)
Pullman, WA	wheat	4.4 assumed	0.019	same	(7)
Pullman, WA	wheat	4.4 assumed	0.019	same	(7)
Pullman, WA	wheat	4.4 assumed	0.019	same	(7)
Holly Springs, MS	cotton	4.4 assumed	0.015	estimated from measured portion of soil surface covered and mass-cover equations	(9)
Holly Springs, MS	cotton	10.0	0.029	same	(10)
Holly Springs, MS	cotton	3.0	0.010	same	(10)
Holly Springs, MS	cotton	2.7	0.026	same	(10)
Holly Springs, MS	cotton	6.3	0.011	same	(10)
Holly Springs, MS	cotton	5.4	0.017	same	(10)
Holly Springs, MS	cotton	6.6	0.03	same	(10)
Holly Springs, MS	cotton	5.0	0.012	same	(10)

Table 10.2. Values for P_b and Φ determined by fitting decomposition equations to measured data (continued)

Location	Crop	Daily precipition above which W_f = 1 P_b (mm)	Decompo sition coefficient Φ (day^{-1})	Placement	Refere nce
Bushland, TX	grain sorghum	4.4 mm assumed	0.007	surface, in bags	(11)
Griffin, GA	alfalfa	4.4 mm assumed	0.015	surface, determined from surface samples removed from plots, not in bags	(5)
Melfort, SK	alfalfa	4.4 mm assumed	0.015	same	(12)
Akron, CO	blue stem hay	4.4 mm assumed	0.015	surface, in bags	(13)
Akron, CO	blue stem hay	4.4 mm assumed	0.015	buried, in bags	(13)
SW Australia	Eucalypt litter	4.4 mm assumed	0.002	surface, determined from samples	(14)

References:
(1) Parker (1962)
(2) Broder and Wagner (1988)
(3) Stott (1995)
(4) Alberts and Schrader (1980)
(5) Schomberg and Steiner (1997)
(6) Mutchler and Greer (1984)
(7) Stott et al. (1990)
(8) Smith and Peckenpaugh (1986)
(9) Mutchler et al. (1985)
(10) Mutchler, personal communiction
(11) Schomberg et al. (1994)
(12) Schomberg et al. (1996)
(13) Hunt (1977)
(14) Birk and Simpson (1980)

capture the main differences in decomposition between locations rather than to precisely compute decomposition as a function of soil and cover-management. Furthermore, empirical data available to calibrate RUSLE2's decomposition equations were not sufficient to empirically determine coefficient values that are functions of soil and cover-management.

The RUSLE2 decomposition equations should be calibrated with several years of data at a location for a particular residue type and placement so that the data represent the expected range of climatic conditions at that site over a 10 to 30 year period. Unfortunately, most residue decomposition studies involve only a single year. Even when only single years of data were available, the RUSLE2 average daily precipitation and temperature values were used to calibrate the RUSLE2 decomposition equations.

Data sets were assembled from as many locations for each residue type as were available. Field residue mass-area and decomposition data are highly variable. Multiple sets of data for the same residue type were used as much as possible. The RUSLE2 decomposition equations were fitted to averages of these data by residue type and location.

Calibration of the RUSLE2 decomposition equations involved fitting them to field data to determine values for the base precipitation P_b and the decomposition coefficient ϕ. The first step in the fitting was to allow both P_b and ϕ to vary. The results for some of those fittings are shown in Table 10.2 for the P_b entries other than "4.4 assumed." A consideration was whether both P_b and ϕ varied by residue type and location. Based on an inspection of the fitted P_b and ϕ values, the conclusion was that a constant value of 4.4 mm (0.173 inches) could be used for P_b for the entire US except in the Palouse region (Req region, see **Section 3.2.5**) in the Northwestern US.

The use of a constant P_b = 4.4 mm value also was evaluated qualitatively by making computations for numerous locations across the US for several residue types. The 4.4 mm value worked well everywhere except for the Req region where a 0.5 mm value worked better. As Table 10.2 shows for the Pullman, WA location, use of the 0.5 mm P_b value gave ϕ values of 0.01 day^{-1} for wheat residue that are comparable to 0.008 day^{-1} values determined in other parts of the country. The reason for the low P_b values in the Req region is that the soil is highly saturated during the winter months when almost all of the erosion occurs and moisture does not limit decomposition even though daily precipitation is not high. If the 4.4 mm P_b value is used in the Req region, the ϕ value for wheat is 0.017 day^{-1} rather than the 0.008 day^{-1} for other parts of the US (see **Section 10.3.3.9**).

Table 10.3. Recommended values for the decomposition coefficient Φ in RUSLE2 with A = 8 ^oC and P_b = 4.4 mm (0.173 inches) based on fitting decomposition equations to measured data.

Crop	Decomposition Coefficient Φ (day^{-1})
Alfalfa	0.015
Blue stem hay	0.012
Corn	0.016
Cotton	0.015
Sorghum	0.016
Soybeans (Midwest US)	0.025
Soybeans (Mid South US)	0.015
Wheat in Eastern US (soft white wheat)	0.008
Wheat in Northwest Wheat and Range Region (NWRR) (hard red wheat)	0.017

Note: If P_b = 0.5 mm, then Φ = 0.01 day^{-1} for NWRR wheat

Once the P_b value was set at 4.4 mm, the calibration was repeated where values of ϕ were determined by fitting the decomposition equations to the field data. Table 10.2 entries for the "4.4 assumed" value for P_b are where the decomposition equations were fitted to the data with the P_b value fixed at 4.4 mm. The fitted values for ϕ were inspected and the ϕ values chosen for the RUSLE Core Database are shown in Table 10.3. Figure 10.2 shows how well RUSLE2 decomposition equations fit field data using the 4.4 mm P_b value and Table 10.2 ϕ values for surface residue. Decomposition of buried residue is discussed in **Section 10.3.3.3**.

The ϕ value for the Eucalypt litter was determined using a different calibration approach from the one used to determine the ϕ values shown in Table 10.2.

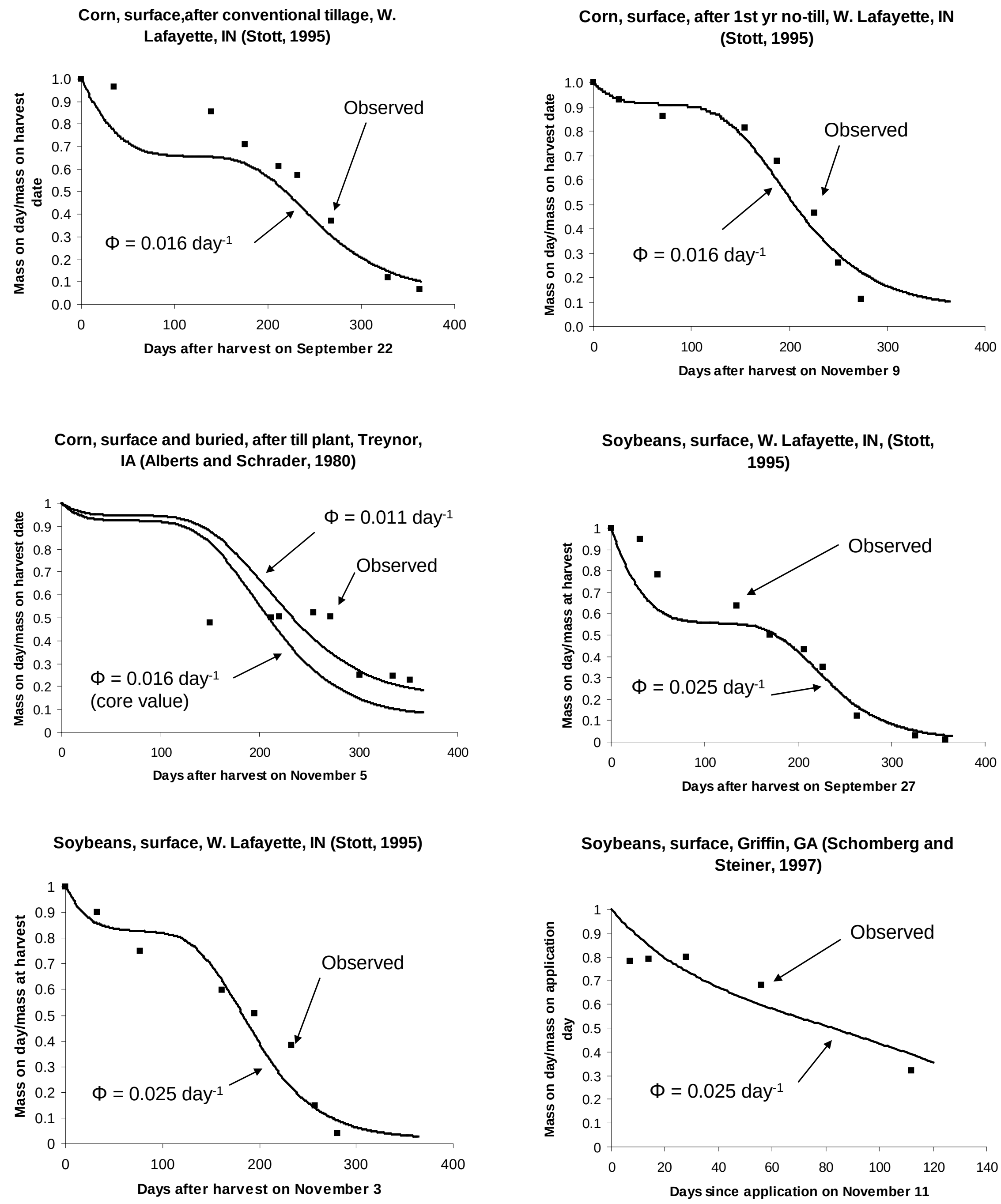

Figure 10.2. Comparison of RUSLE2 decomposition estimates using RUSLE2 Core Database values in comparison with field data.

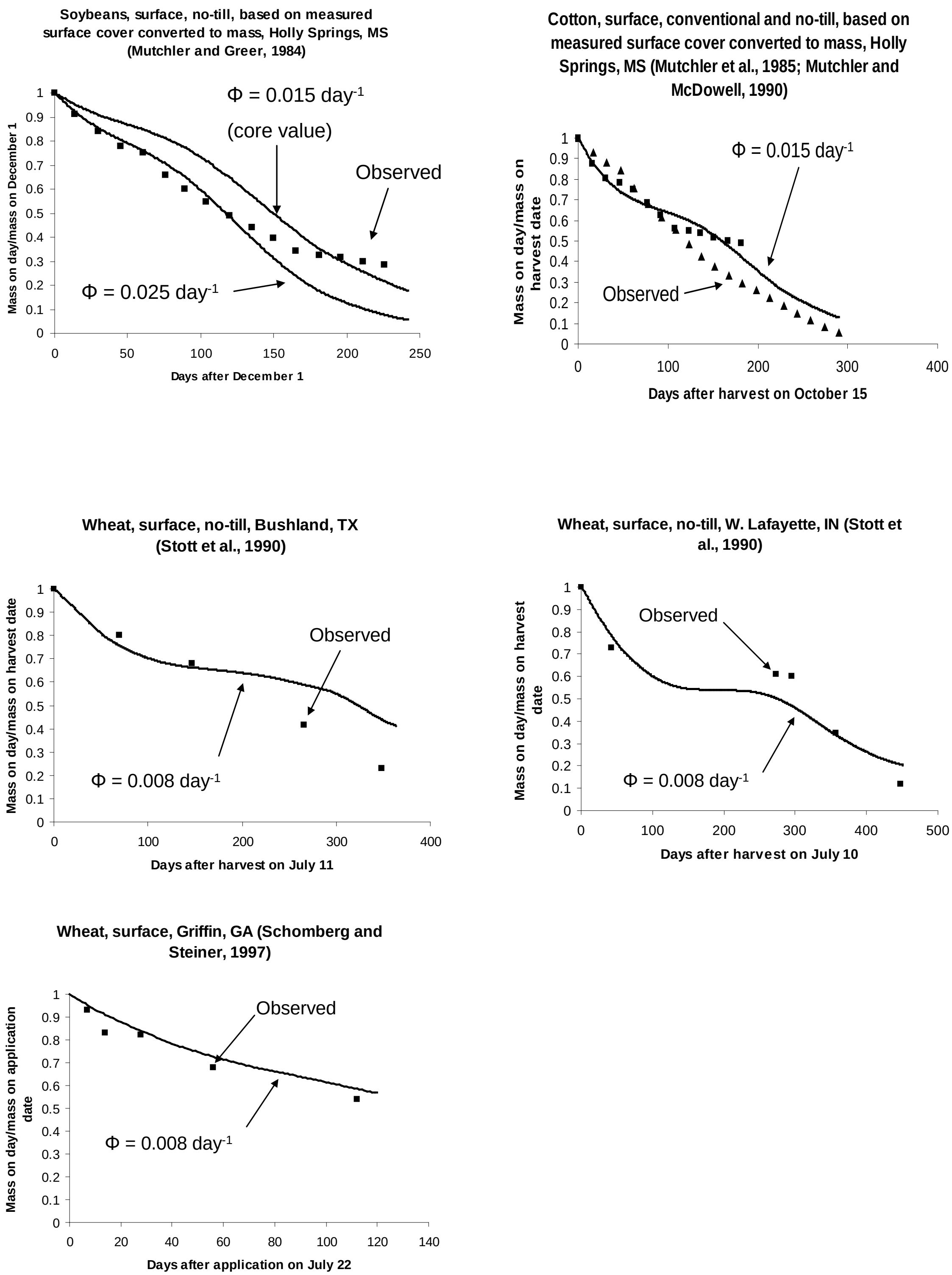

Figure 10.2. Comparison of RUSLE2 decomposition estimates using RUSLE2 Core Database values in comparison with field data. (continued)

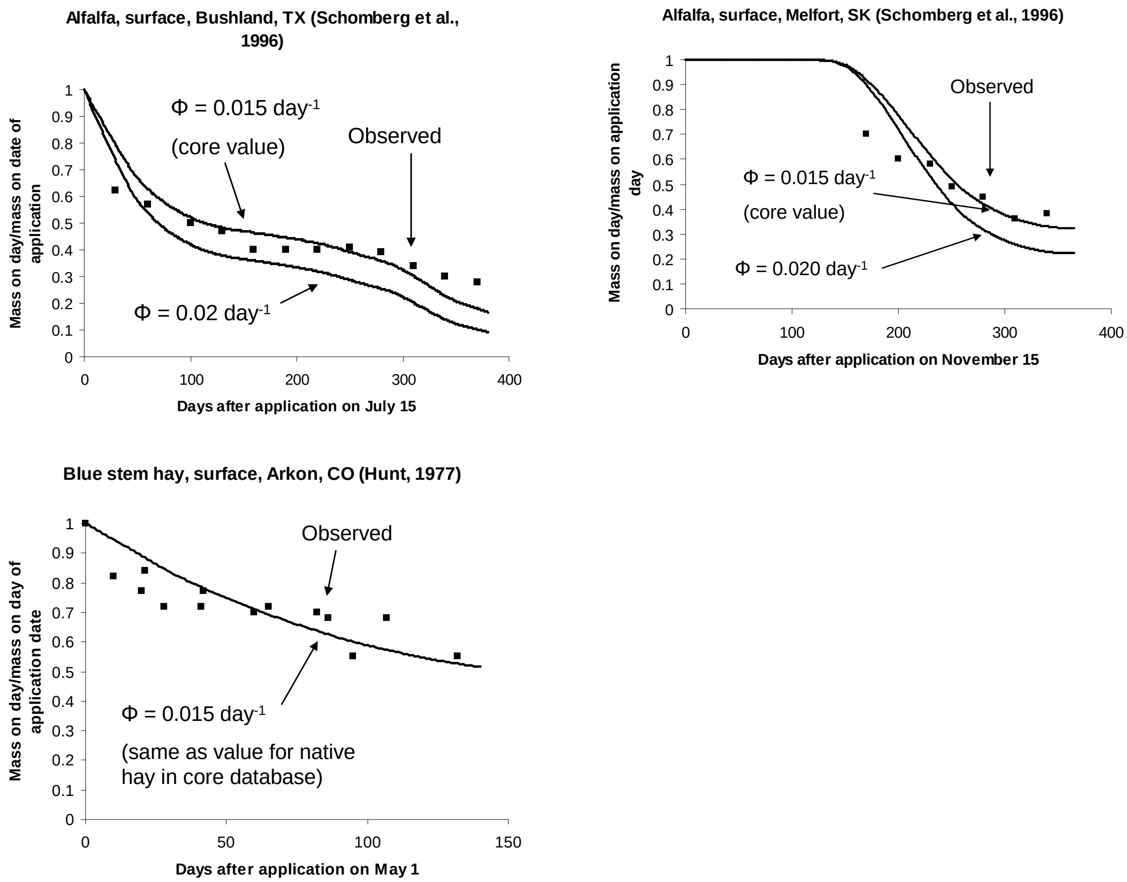

Figure 10.2. Comparison of RUSLE2 decomposition estimates using RUSLE2 Core Database values in comparison with field data. (continued)

Rather than fitting the RUSLE2 decomposition equations to the loss of residue mass over time, a ϕ value was determined for the Eucalypt litter by fitting RUSLE2 decomposition equations to an increasing residue mass over time until the mass reached a stable maximum. The Eucalypt litter data shown in Figure 10.3 are for surface residue (litter) accumulation following a forest fire in the Southwestern Australian Eucalypt forest (Birk and Simpson, 1980). This application illustrates RUSLE2's capability for computing both the accumulation of a surface litter layer where the biomass input is produced by aboveground senescence and the accumulation of a similar below ground biomass pool produced by root growth and death (root senescence, turnover).

An inspection of Figure 10.2 shows that RUSLE2 captures well the effect of location and material type on residue decomposition over time. A constant P_b value over almost all of the US works surprisingly well. Also, assuming the same ϕ value for a residue type works well for locations where climate differs greatly. For example, compare the results for alfalfa at both Griffin, Georgia and Melfort, Saskatchewan.

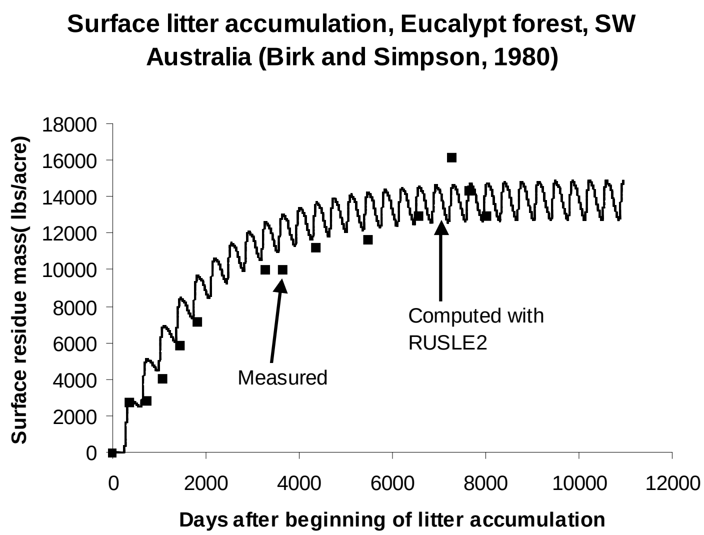

Figure 10.3. Computing the accumulation of a litter layer for an Eucalypt forest in Southwestern Australia.

An expectation is that RUSLE2 database developers can use values in the RUSLE2 Core Database to guide assignment of decomposition coefficient ϕ values for other residue types based on a comparison of residue characteristics. This procedure works but it requires more thought that initially expected. For example, a ϕ value of 0.02 day^{-1} was originally assigned for alfalfa before the ϕ value of 0.015 day^{-1} illustrated in Figure 10.2 was obtained by fitting measured field data. A ϕ value of 0.012 day^{-1} was assigned for native hay before the same ϕ value was determined by fitting measured data for the blue stem hay illustrated in Figure 10.2. The procedure of using values in the RUSLE2 Core Database as a guide in selecting decomposition coefficient values for other residue types will give reasonable RUSLE2 results for erosion control planning provided a careful comparison is made between residue types. The role of stems seems to be a major factor to consider in selecting ϕ values.

10.3.3. Basis for RUSLE2 decomposition decisions

RUSLE2's computation of residue loss is based on decomposition principles even though residue loss occurs by other processes besides decomposition. RUSLE2 is calibrated to field data representative of actual conditions as much as possible. RUSLE2 computations of residue and soil biomass loss are consistent with RUSLE2's purpose to be a **guide** to erosion control planning. Many decisions involved judgment during the formulation and calibration of RUSLE2's residue loss (decomposition) equations. This section describes the basis for those decisions.

10.3.3.1. User expectations

RUSLE2 computes residue decomposition and portion of the soil surface covered essentially using RUSLE1 procedures. Based on the RUSLE1 experience, some users will scrutinize RUSLE2's computed values for ground (surface, flat) residue cover more closely than RUSLE2's computed erosion values. RUSLE2 users are well aware of the importance of ground cover for controlling erosion. RUSLE2 users can not visually estimate erosion rates but they can visually measure ground (surface) cover. If RUSLE2's computed ground cover values do not meet their expectations, they assume that RUSLE2's erosion computations must also be wrong, which is often a false assumption.

Surface residue cover is a major variable used in judging the adequacy of cropland erosion control measures. USDA-Natural Resources Conservation Service (NRCS) standards and specifications for certain conservation practices require a minimum surface residue cover at planting (e.g., 30 percent). The RUSLE2 decomposition procedures were carefully constructed to ensure that RUSLE2 computes appropriate surface residue cover values for conservation planning, as demonstrated by the values 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).

While RUSLE2 users can easily measure residue cover, which they can compare with RUSLE2 computed values, they must exercise great caution in their measurements and evaluations of RUSLE2's adequacy for computing residue cover and corresponding erosion estimates. Residue mass-cover data are highly variable as illustrated in Figure 10.1. The cotton data in Table 10.2 illustrates the variability in decomposition data among multiple data sets collected under near identical conditions for the same residue type. Making a few field measurements is not the proper way to evaluate RUSLE2's computed residue cover values. The RUSLE2 User's Reference Guide provides information on how to adjust RUSLE2 inputs to obtain particular RUSLE2 computed residue cover values.

10.3.3.2. Residue sampling method

RUSLE2's computation of residue loss is based on dry mass, which requires field measurements of residue mass over time are needed to calibrate RUSLE2. The mesh bag and the "grab" sample are the two techniques used most often to determine surface residue mass in decomposition experiments. The mesh bag method involves inserting residue in a mesh bag and placing the bag on the soil surface or in the soil. The grab sample method involves removing amd unconfined residue from a sample area. Each method has significant drawbacks (Dabney, 2005).

The residue loss measured by the mesh bag method is a function of mesh size (Dabney, 2005). The mesh bag method tends to underestimate residue loss. The residue loss determined using the common 1 mm mesh bags has to be multiplied by a factor that ranges from 1 to greater than 2 to represent the loss of unconfined residue.

Conversely, the grab sample method tends to overestimate residue loss and has its own shortcomings including the difficulty of removing soil particles attached to the residue. Another difficulty is retrieving the entire residue from the sample area because fragile residue pieces can be broken and not recovered.

The difference in measured residue loss by sampling methods is very significant as illustrated in Figure 10.4. Using the RUSLE2 Core Database values, RUSLE2 computes that a 150 bu/acre corn crop produces 8200 lb/acre of residue. The corn residue mass remaining after 12 months at Bushland, Texas measured by the bag method would be 4100 lbs/acre (Schomberg et al., 1995, 1997) (see Figure 10.4). The percent soil surface cover provided by this residue mass is 79 percent and the ground cover subfactor value computed with equation 6.6 is 0.042.

The RUSLE2 decomposition equations were fitted to corn residue loss at W. Lafayette, Indiana measured using the grab sample method (Stott, 1995). The RUSLE2 computed value for residue mass remaining after 12 months using climate data for Bushland, Texas is 1480 lbs/acre. The percent soil surface cover provided by this residue mass is 43 percent and the ground cover subfactor value is 0.18, which is four times the value based on mesh bag measurements. Consequently, RUSLE2 computes greatly different erosion estimates depending on which set of data is used to calibrate RUSLE2's residue loss (decomposition) equations.

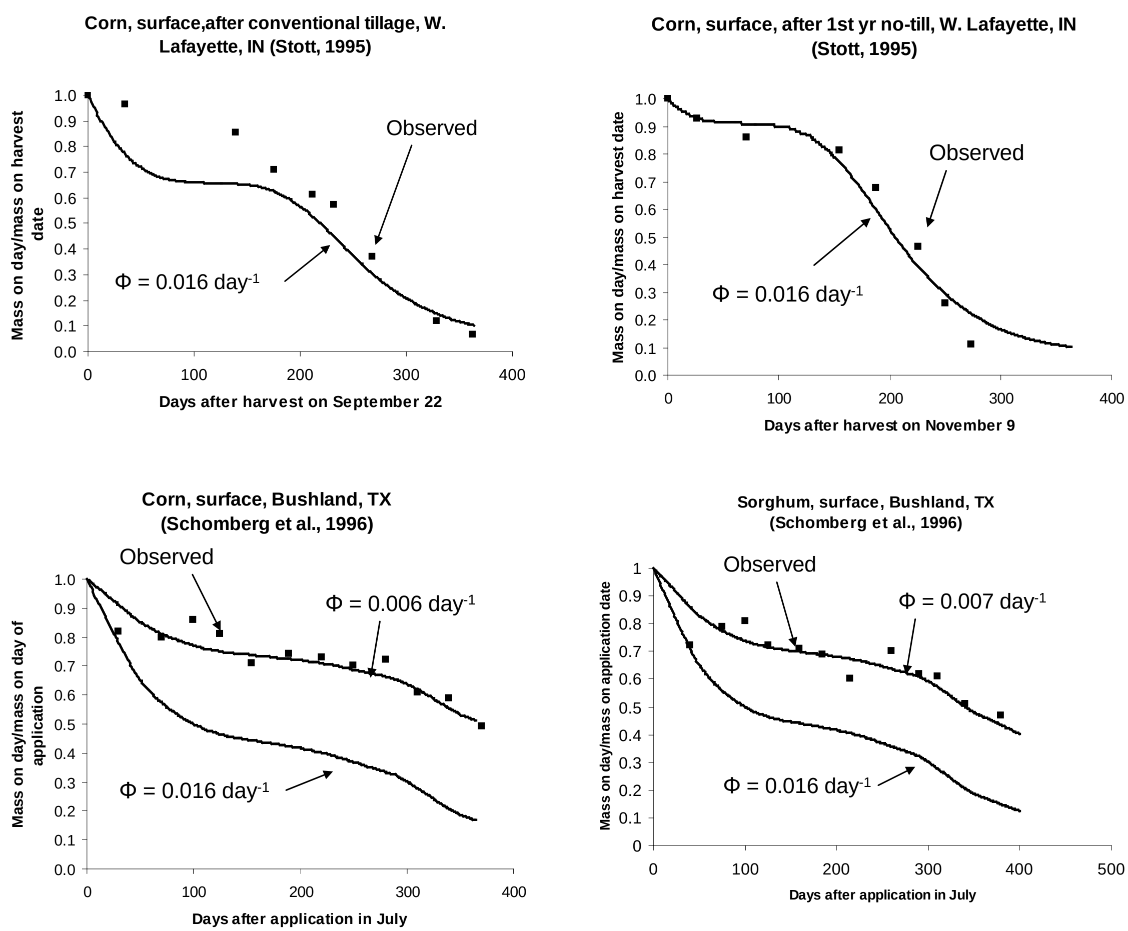

Figure 10.4. Comparison of observed and RUSLE2 computed decomposition of corn residue at W. Lafayette, Indiana and corn and sorghum residue at Bushland, Texas.

The difference in the measured Bushland, Texas data for corn and the RUSLE2 computed values based on a calibration to corn data measured at W. Lafayette, Indiana is not attributable to the RUSLE decomposition equations not performing equally well at the two locations. When wheat straw decomposition was measured by grab sampling from the soil surface (Stott et al., 1990; Stott, 1995; Stenier et al., 1999), measured decomposition at Bushland, Texas was consistent with data collected at W. Lafayette, Indiana and the RUSLE2 decomposition equations performed equally well at both locations (see Figure 10.2).

The difference in measured residue loss between the mesh bag and the grab sampling method is too large too ignore, which required a choice of one sampling method over the other. The grab sampling method was chosen for the development of RUSLE2. The conditions represented by this method, including the loss of residue by wind and other processes besides decomposition, better represent actual field conditions than does the mesh bag method. The differences between the two sampling methods seemed to be greatest for corn and wheat and much less for soybeans and forage crops. Decomposition coefficient ϕ values were determined for corn and wheat from the grab sample method while decomposition coefficient values were determined for forage crops from the mesh bag method.

Surface residue cover data were used to determine decomposition coefficient ϕ values for cotton and soybeans at Holly Springs, Mississippi. These data are field measured values for ground cover, which are the values most important in computing the effect of surface residue on rill-interrill erosion. These field data were considered to be superior to residue loss data measured with the mesh bag method.

The RUSLE2 decomposition coefficient ϕ value determined for corn is assumed to apply to grain sorghum based on the similarity in decomposition of corn and sorghum residue measured at Bushland, Texas by the mesh bag method. While the absolute decomposition values determined by the mesh bag method are not considered acceptable for RUSLE2 use, the mesh bag method is useful for determining relative differences in decomposition among residue types.

Other experimental procedures besides use of the mesh bag can affect decomposition results. The Ghidey and Alberts (1993) dataset includes decomposition values for roots and buried, surface, and above surface residue. Their data differ significantly from data considered best for RUSLE2 as illustrated in Figure 10.5. Oven drying the residue at 65 ^{o}C for 24 hours before placing the residue in the field may have contributed to the differences illustrated in Figure 10.5 in addition to mesh bags being used to measure residue loss.

10.3.3.3. Residue placement

RUSLE2 considers three placements of residue: (1) standing above ground, (2) soil surface, and (3) buried in the soil.

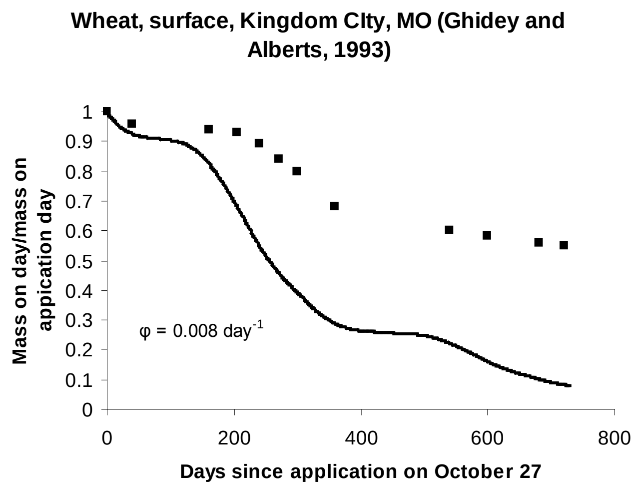

Figure 10.5. Difference in decomposition between that measured by Ghidey and Alberts (1993) and other data considered better for RUSLE2.

The RUSLE2 decomposition coefficient ϕ value used for above ground biomass is 0.3 times the ϕ value used for surface and buried residue. The decomposition coefficient ϕ value for above ground residue should be about 0.75 times the surface/buried residue ϕ value based on data collected by Douglas et al. (1980) and Ghidey and Alberts (1993). However, these data are questionable because the bundled residue samples used in these experimental studies do not represent individual pieces of standing stubble residue. Standing residue would retain much less moisture than the bundled residue samples. The 0.3 value performed satisfactorily in RUSLE2's computation of loss of standing residue (see **Section 10.4.1**)

The RUSLE2 assumption is that buried residue is lost at the same rate that soil surface residue is lost, although the common assumption is that buried residue decomposes more rapidly than does surface residue (Dabney, 2005). An example of measured data illustrating this apparent difference is shown in Figure 10.6. Like other residue aspects, the difference in decomposition rates for surface and buried residue varied greatly in the data reviewed by Dabney (2005) with no clear trend. Overall, the apparent decomposition rate for buried residue, regardless of residue type, was 1.3 times the decomposition rate of surface residue. Additional adjustment is required to obtain decomposition estimates of unconfined residue because the mesh bag sampling method was used in 10 out of 12 studies reviewed by Dabney (2005).

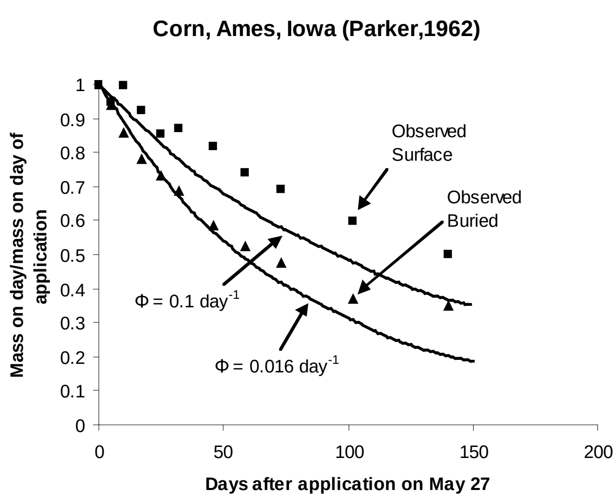

Figure 10.6. Difference in decomposition of residue in bags buried in the soil and placed on the soil surface.

Just as discussed in **Section 10.3.3.2** for surface residue, an adjustment also must be made for the mesh size effect on measured buried residue decomposition.

Instead of multiplying the mesh bag measured residue loss by 2 to obtain an estimate of unconfined surface residue loss, the measured mesh bag buried residue loss should be multiplied by 1.3 to estimate unconfined buried residue loss. Assume that the mesh bag measured surface residue loss is 1000 lbs/acre. The estimated actual loss is 2·1000 = 2000 lbs/acre. The measured mesh bag loss for buried residue is 1.3·1000 = 1300 lbs/acre based on the data reviewed by Dabney (2005), where the 1.3 factor accounts for the apparent higher decomposition rate for buried residue than for surface residue. Next, the 1300 value needs to be multiplied by the 1.3 factor to account for mesh bags underestimating the loss of unconfined buried residue. The buried residue loss of unconfined residue is therefore 1.3·1300 = 1700 lbs/acre. Consequently, these computations show that surface residue is lost at a greater rate (2000 lbs/acre versus 1700 lbs/acre) than is buried residue when the different effect of mesh size on decomposition of surface and buried residue is properly considered. The problem with these computations and with the mesh bag sampling method is the uncertainty involved in adjusting for mesh size and other factors related to how well decomposition in mesh bags represents actual field conditions.

The RUSLE2 intent is not to capture soil differences or placement within soil differences because RUSLE2 does not use soil moisture accounting routines. The buried residue studies cited by Dabney (2005) involved residue mesh bags placed 6 inches deep, which only partly simulates residue burial with a moldboard plow. A moldboard plow distributes residue throughout the disturbed soil layer even though most of the residue is buried in the lower half of the disturbed soil depth (see **Section 8.2.5.2**). Conservation tillage tools like disks, chisel plows, and field cultivators used for primary tillage leave most of the residue in the upper half of the disturbed soil depth (see **Section 8.2.5.2**), which residue buried at six inches does not represent. Furthermore, RUSLE2 uses the residue mass buried in the upper two or three inches to compute the effect of buried residue on erosion (see **Section 6.5**). The soil is drier at this shallow depth than at the six-inch measurement depth, and thus decomposition in this surface layer would be more like decomposition of surface residue than decomposition of residue buried at six inches. Therefore, mesh residue bags buried six inches deep do not represent typical field conditions.

Similarly, the placement of residue filled mesh bags on the soil surface does not represent typical field conditions. As Parker (1962) noted, a distinct boundary between surface residue and the soil surface does not exist in many cropland situations. For example, many residue pieces are both partially buried and exposed in conventional and mulch-till forms of cropping systems where tillage buries a portion of the residue left from the previous 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 boundary between residue and the soil is not distinct in long-term no-till cropping systems. These effects are not captured by mesh bags placed on the soil surface.

The RUSLE2 objective is to produce reliable erosion estimates for conservation and erosion control planning. Increasing RUSLE2's decomposition rate for buried residue would not improve its erosion estimates but in fact would degrade them. The RUSLE2 computed ratio of erosion during the seedbed period for cropland going from turned sod to conventionally tilled 112 bu/ac yield corn to erosion for the same yield corn continuously cropped is 0.42, whereas the observed value is 0.40 [Table 5-D. AH537 (Wischmeier and Smith, 1978)].[70] However, the RUSLE2 computed ratio value is 0.95 for the second year while the observed value is 0.85. RUSLE2 computes this residual effect from turned sod using buried residue and dead root biomass values in equations 6.48 and 6.49. The first year erosion ratio value is computed well as a function of soil biomass before significant soil biomass loss by decomposition is computed. The fact that an accurate erosion ratio value is computed for the first year indicates that RUSLE2 is computing the proper effect of soil biomass when the estimated soil biomass is accurate. However, the fact that RUSLE2 computes too little soil biomass effect the second year indicates that RUSLE2 is computing too little soil biomass and a corresponding erosion that is too high. Consequently, increasing the decomposition coefficient ϕ value to represent buried residue decomposing more rapidly than surface residue will further degrade RUSLE2's performance for computing the effect of soil biomass.

These RUSLE2 erosion ratio values were computed using a decomposition coefficient ϕ value of 0.0017 day^{-1} for permanent grass vegetation residue. This decomposition coefficient value was originally selected based on comparison with other decomposition coefficient values in the RUSLE2 Core Database. However, recent analysis shown in Figure 10.2 for the blue stem hay shows that 0.012 day^{-1} is an appropriate value for decomposition coefficient ϕ value for blue stem hay. The erosion ratios computed with this ϕ value are now 0.36 compared to the observed 0.4 for the first year and 0.84 compared to the 0.85 observed for the second year, which is a significant improvement.

These results illustrate that the greater requirement is to accurately capture main effects before trying to capture minor effects. No basis exists for RUSLE2 computing decomposition of buried residue at a faster rate than surface residue. The RUSLE2 assumption that surface and buried residue decomposes at the same rate is strongly supported by both data, consideration of actual field conditions, increased accuracy of computed erosion values, and increased RUSLE2 robustness.

10.3.3.4. Roots

Fine roots are the most important roots in RUSLE2. A reasonable assumption is that the decomposition of fine roots is the same as buried residue. This assumption may need

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[70] In this case, conventional tillage refers to a spring moldboard plow used for primary tillage followed two weeks later with a tandem disk and harrow or a tandem disk and field cultivator for secondary tillage used to create a seedbed.

reconsideration. Having the decomposition coefficient values the same for residue and roots gives RUSLE2 increased robustness, especially until additional information is learned about the distribution of root sizes and other root properties in the soil, the birth and death of roots, and how roots affect rill-interrill erosion. The RUSLE2 intent is to empirically capture the main effect of roots as an index rather than be a full description of how roots affect erosion.

10.3.3.5. Interdependence among calibration inputs for residue

No reliable data were found where both soil biomass and erosion were measured in the same experiment. Consequently, observed values for buried residue, dead root, and live root biomass were not used to calibrate the soil biomass subfactor equations 6.48 and 6.49 (see **Section 6.5**). Instead, RUSLE2 computed values for soil biomass were used to calibrate the soil biomass subfactor equations. In addition, “observed” soil biomass subfactor values were back-calculated from observed soil loss ratio values given in Table 5, AH537 (Wischmeier, and Smith, 1978) using RUSLE2 computed subfactor values for ground cover, soil surface roughness, ridge height, and soil consolidation for the seedbed crop stage of a silt loam soil at Columbia, Missouri, the RUSLE2 reference (base) location. Equation 6.1 was rearranged to compute values for s_b, the soil biomass subfactor. Soil loss ratio values from Table 5, AH537 are substituted for c in equation 6.1. Values for the other subfactors in equation 6.1 were RUSLE2 computed for the conditions listed in Table 6.5.

This soil biomass subfactor calibration approach has several consequences. The soil biomass subfactor absorbs the error and uncertainty in the other subfactors for the calibration conditions. The seedbed crop stage is the best crop stage for calibrating the soil biomass subfactor. Calibrating the soil biomass subfactor for this crop stage minimizes errors in the other subfactors because they deviate less from unit-plot conditions for the seedbed crop stage than for any other crop stage.

The only independent cover-management input in the calibration of the soil biomass subfactor, equations 6.48 and 6.49, is crop yield. All other cover-management inputs involved in the calibration are derived from yield, RUSLE2 Core Database values, and RUSLE2 procedures such as residue loss by decomposition and redistribution of soil biomass by mechanical soil disturbance. Therefore, a change in either RUSLE2 Core Database values or a RUSLE2 procedure used to compute subfactor values involved in the soil biomass subfactor calibration invalidates the calibration. **Consequently, a change in one of these items without recalibration produces erroneous RUSLE2 computed erosion estimates**.

The RUSLE2 assumption is that buried residue and dead roots decompose at the same rate as surface residue. This calibration approach has the advantage that it is partially self correcting if these assumptions are wrong. The empirically determined coefficient values in equations 6.48 and 6.49 compensate for erroneous soil biomass estimates used in the calibration as long as the relative values are accurate.

RUSLE2 has been developed and carefully validated to ensure that it computes the desired erosion values across the full range of conditions where RUSLE2 is expected to be used. Therefore, a change made to one RUSLE2 procedure, such as residue decomposition, requires a second change to ensure that RUSLE2 continues to compute expected erosion values.

Interdependence among RUSLE2 residue variables must be considered when changes are made so that RUSLE2 computes different ground (surface) cover values. To illustrate, What if RUSLE2 computed surface cover values seem questionable (see the **RUSLE2 User's Reference Guide** for additional discussion)? What RUSLE2 variable should be changed to improve surface cover estimates? The first step is to ensure that the data or observations being used as the basis for a change represent main effects rather than a minor effect or unexplained variability that RUSLE2 is not designed to capture.

The next step is to assess RUSLE2's computed erosion estimates to determine if these values should be changed along with the change in surface cover values. RUSLE2 was calibrated to give expected erosion estimates with an assumed set of values. A difference between an observed surface cover value and a RUSLE2 computed surface cover value does not necessarily mean that RUSLE2 is computing erroneous erosion estimates. What evidence, other than surface cover values, shows that RUSLE2 erosion estimates also need changing? An independence assessment should be made to determine if different erosion values should also be computed.

Changing decomposition coefficient ϕ values changes RUSLE2 computed surface cover values, but changing ϕ values also affects RUSLE2 computed soil biomass values and even soil surface roughness values that are a function of soil biomass. Therefore, a change in a ϕ value affects erosion in more ways than just changing surface cover. The question that should be asked before changing a ϕ value is: What evidence indicates that different soil biomass values should be computed along with different surface cover values?

Another way to change RUSLE2 computed surface cover values is to change above ground biomass as a function of yield. In addition to changing surface cover values, this change also affects soil biomass and soil surface roughness values. Once again, RUSLE2 computed erosion values are affected by changes in other variables besides surface cover.

The simplest way to change RUSLE2 computed surface cover values is to change surface residue mass-cover input values in the residue description (i.e., values for α in equation 10.1). Changing this relationship directly changes surface cover without changing other residue variables that affect erosion.

RUSLE2 changes should be carefully thought out to avoid unintended consequences.

10.3.3.6. Dealing with multiple component residue descriptions

A single RUSLE2 residue description is assigned to each vegetation description. A residue description represents a composite of the residue components produced by the particular vegetation.

Residue produced by vegetation includes: (1) pieces having a wide range in geometry that affect decomposition (e.g., fine and coarse roots and stems); (2) multiple components (e.g. leaves, stems, seed pods, and chaff); (3) variation in composition within a component (e.g., corn stalks having decomposition resistant exterior shells and easily decomposed interior material); (4) components, especially stems, that decompose from the inside out without changing outside dimensions (e.g., wheat straw); (5) decomposition properties that vary with growth stage (e.g., tender young leaves that decompose much more rapidly than mature leaves); (6) differences between above ground and below ground plant components (e.g., leaves that decompose more rapidly than roots); and (7) multiple species within a plant community (e.g., multiple plant species on rangelands and multiple weed species on permanent, unimproved 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, each having its own α and ϕ values.

Effective RUSLE2 mass-cover coefficient α and decomposition coefficient ϕ values vary temporally as the residue decomposes. Values for these coefficients are functions of the relative composition of residue components that decompose at different rates. Consequently, the assigned RUSLE2 mass-cover and decomposition coefficient values are a compromise. The result is that RUSLE2 computes decomposition rates that are too slow in the beginning and too fast at the end. However, a review of Figure 10.2 shows that a single value decomposition coefficient ϕ works satisfactorily for a year for residue produced by typical agricultural crops, especially considering the unexplained variability in residue data.

Priority was given to fitting RUSLE2 computed decomposition values to observed values within the first year after residue application. Thus, RUSLE2 most accurately estimates decomposition of the easily and rapidly decomposable portions of the residue and not the residue that remains after one year, as illustrated in Figure 10.7. Most RUSLE2 applications involve a substantial annual input of biomass from crop production or senescence by permanent vegetation, which minimizes errors in RUSLE2 decomposition estimates beyond one year after residue application.

An example of a multiple component residue is the residue produced by a cover crop bi-culture of hairy vetch and rye that is killed at corn planning time in central Illinois (Ruffo and Bollero, 2003). The hairy vetch cover crop residue component (ϕ = 0.032 day^{-1}) decomposes much more rapidly than does the rye cover crop component (ϕ = 0.017 day^{-1}).

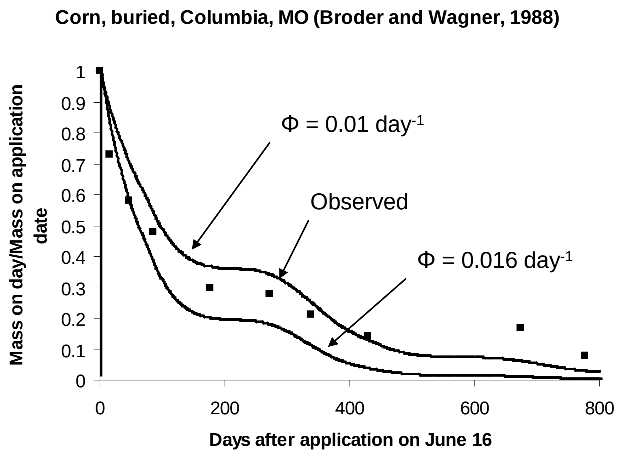

Figure 10.7. RUSLE2's estimate of residue decomposition over a 2-year period.

Figure 10.8 shows RUSLE2 decomposition computations for hairy vetch and rye grown as mono-culture cover crops and a 1:1 bi-culture cover crop based on dry mass on the day that the cover crop is killed. The curve labeled "by-component" is the decomposition that should be computed for the bi-culture. The "by-component" values shown in Figure 10.8 were computed outside of RUSLE2.

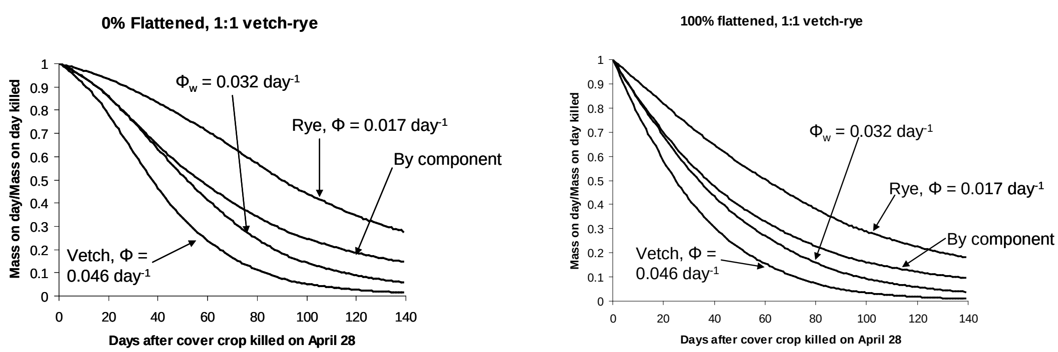

Figure 10.8. RUSLE2 computed decomposition of a 1:1 vetch-rye cover crop killed on April 28 in central Illinois. The Φ_w value is a weighted value based on dry mass on the date that the vegetation was killed.

A single value for the decomposition coefficient ϕ must be entered in the single composite RUSLE2 residue description that must be used to represent the combined residue produced by the hairy vetch and rye. One approach is to enter a weighted ϕ value based on dry mass of the hairy vetch and rye at the time that the cover crop vegetation is killed. As Figure 10.8 shows, initially RUSLE2 accurately computes decomposition but soon computes too much decomposition. The effective decomposition coefficient ϕ value should approach the ϕ value for rye over time as the hairy vetch decomposes much more rapidly than does the rye. An alternative input value for ϕ is an average of the weighted ϕ_w value at the time that the bi-culture cover crop is killed and the ϕ value for rye. RUSLE2 computes too little decomposition initially but computes much improved decomposition values after most of the vetch has decomposed.

Rather than developing a RUSLE2 procedure that adjusts the decomposition coefficient value as decomposition progresses, the best approach would be to modify RUSLE2 to accommodate multiple residue descriptions being assigned to a single vegetation description. In fact, the original RUSLE2 plan was to describe residue by its component parts. Using a residue description for each residue component would significantly improve RUSLE2's computations of residue decomposition and surface residue cover as a function of residue mass. Insufficient data existed 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.

The large decomposition coefficient ϕ values in Figure 10.8 for the hairy vetch and rye cover crops, 0.046 and 0.017 day^{-1}, respectively, illustrate how the decomposition coefficient ϕ is a function of crop stage. The ϕ value for mature hairy vetch residue is 0.020 day^{-1} while the ϕ value for mature rye is 0.0080 day^{-1}. The RUSLE2 decomposition coefficient values are about twice the values when the vegetation is killed as a cover crop when it is approximately half mature in comparison to the decomposition coefficient values for the vegetation after it reaches full maturity.

10.3.3.7. Effect of loading (application) rate

The decomposition coefficient ϕ seems to be a function of residue mass initially added to the soil surface as illustrated in Figures 10.9 and 10.10 (Steiner et al., 1999; Stott et al., 1990). **If initial surface residue mass affects the decomposition coefficient, the decomposition coefficient ϕ must also be a function of surface residue mass at any time after the residue is added to the soils surface.** The trend in both Figures 10.9 and 10.10 is that the decomposition coefficient ϕ decreases as surface residue mass increases. Therefore, Figure 10.9 and 10.10 imply that decomposition accelerates as surface residue mass decreases. However, this implication is inconsistent with the expectation that decomposition slows as the readily decomposable residue components disappear first, leaving the residue components that resist decomposition.

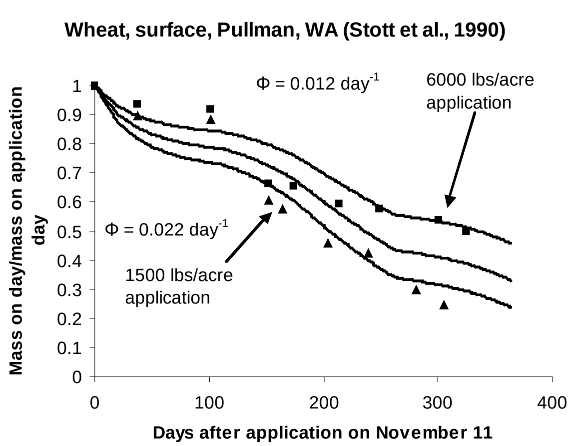

Figure 10.9. Effect of residue application rate on the decomposition coefficient ϕ.

Another concern is the great variability in decomposition coefficient values as illustrated in Figure 10.10. The RUSLE2 decomposition coefficient ϕ is proportional to the k decomposition coefficient in Figure 10.10. The comparable range in

ϕ for the range in k in Figure 10.10 for wheat straw is from 0.004 to 0.012 day^{-1}. RUSLE2 computes that 2100 and 600 lbs/acre of residue remain after 1 year for a 4000 lbs/ace wheat straw application at Columbia, Missouri for the ϕ values of 0.004 and 0.012 day^{-1}, respectively. The respective surface covers are 72 and 30 percent and the respective ground cover subfactor values, assuming **b** = 0.04 percent^{-1} in equation 6.6 (see **Section 6.3**), are 0.0561 and 0.301, which is a 5:1 erosion ratio. The uncertainty in decomposition coefficient ϕ values is much greater than the variation in ϕ as a function of application rate and surface residue mass as shown in Figure 10.10, especially for residue mass less than 6000 lbs/acre (600 g/m^2).

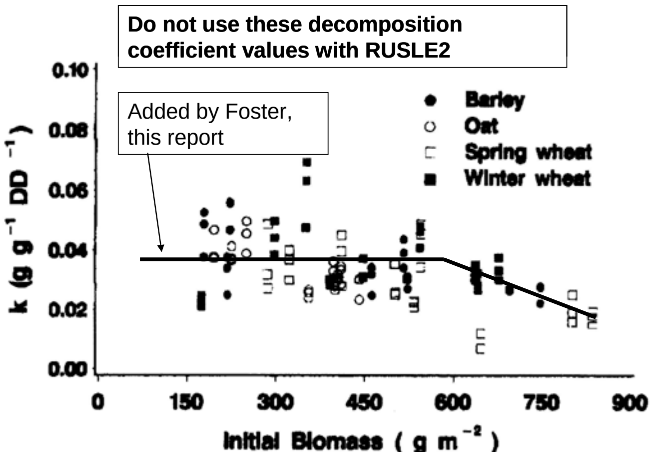

Figure 10.10. Variation of decomposition coefficient k (comparable to ϕ) values from another decomposition model with residue application rate. (Data source: Steiner et al., 1999; Line added by Foster, this report)

Furthermore, are the results illustrated in Figure 10.9 and 10.10 indicative of decomposition of the wide array of vegetation residue including vegetables, corn, wheat, hay, litter on rangelands, Eucalypt forest litter, and erosion control materials used on construction sites? Are the results illustrated in these figures indicative of application conditions that range from wheat straw being blown onto a construction site to wheat straw left in conventionally, reduced, and no-tilled fields?

The conclusion for RUSLE2 purposes is that the decomposition coefficient ϕ is not a function of residue application rate or surface residue mass. The uncertainty illustrated in Figure 10.10 reinforces the conclusion that RUSLE2 represents decomposition differences between major residue and erosion control material types, but not difference in small grain types, for example. An improvement in RUSLE2's decomposition computations can be gained by representing residue components such as legume and grasses and stems, leaves, seed pods, and chaff. Much more research is needed before the RUSLE2's decomposition coefficient ϕ can be made a function of application rate or surface residue mass. Furthermore, a standardized set of decomposition data for a wide range of materials are needed to determine RUSLE2 ϕ values.

10.3.3.8. Effect of irrigation on residue decomposition

RUSLE2's accuracy for estimating increased decomposition caused by irrigation was assessed using data reported by Schomberg et al. (1994) for decomposition of surface and buried alfalfa, wheat, and sorghum residue in mesh bags. Water varying in amounts from 5 to 336 mm was added by sprinkler irrigation during the study year in addition to 305 mm of natural precipitation. The long term average annual precipitation at Bushland, TX is 480 mm. The monthly precipitation and temperature distributions during the study are shown in Figure 10.11. Although monthly temperatures during the study were close to the long term values, the study's monthly precipitation distribution differed significantly from the long average distribution. The water added in each irrigation is given in Figure 10.12.

The objective of this analysis was to determine how well RUSLE2 computes the effect of added irrigation water on residue decomposition, not to determine decomposition coefficient ϕ values. The first step in the analysis was to adjust the decomposition coefficient ϕ value until a good fit was obtained between computed decomposition and

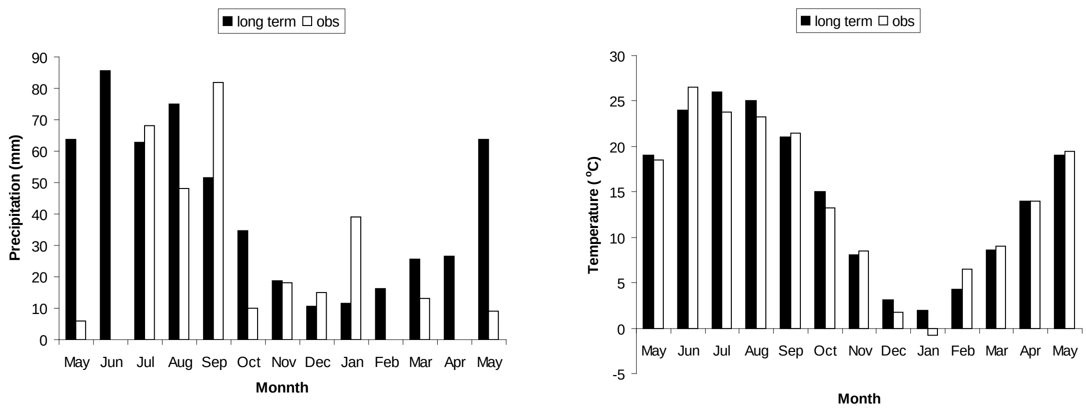

Figure 10.11. Long term average monthly precipitation (480 mm annual) and actual monthly precipitation (305 mm annual) and long term average monthly temperature and actual monthly temperature for Schomberg et al. (1994) study

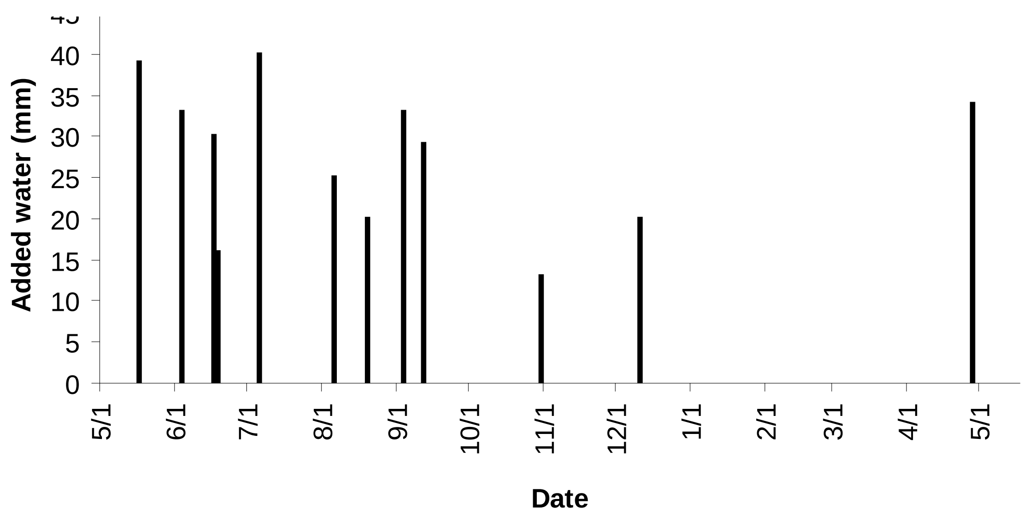

Figure 10.12. Water applied by sprinkler irrigation (total application of 336 mm) in Schomberg et al. (1994) study.

observed decomposition for the no-irrigation (only natural precipitation) condition.

Observed monthly precipitation and temperature values shown in Figure 10.11 were used in the analysis.

The decomposition coefficient ϕ value determined for natural precipitation alone was used to compute decomposition for the 305 mm natural precipitation plus 336 mm of added irrigation water distributed as shown in Figure 10.12. The results of those computations are shown in Figure 10.13.

Variability is a common problem in decomposition data. The data in Schomberg et al. (1994) study also was highly varied. For example, the fraction of surface sorghum residue remaining on December 10 was 53 percent while the fraction remaining on March 10 was 70 percent, which is an obvious error because residue mass does not increase over time. Another problem with these data is that the range in decomposition of surface residue as a function of added irrigation water is not consistent with the range in the observed data for surface sorghum and wheat residue.

As Figure 10.13 shows, the conclusion is that RUSLE2 described well how sprinkler irrigation affects decomposition of both surface and buried residue in the Schomberg et al. (1994) study. Furthermore, RUSLE2 described decomposition well for the natural

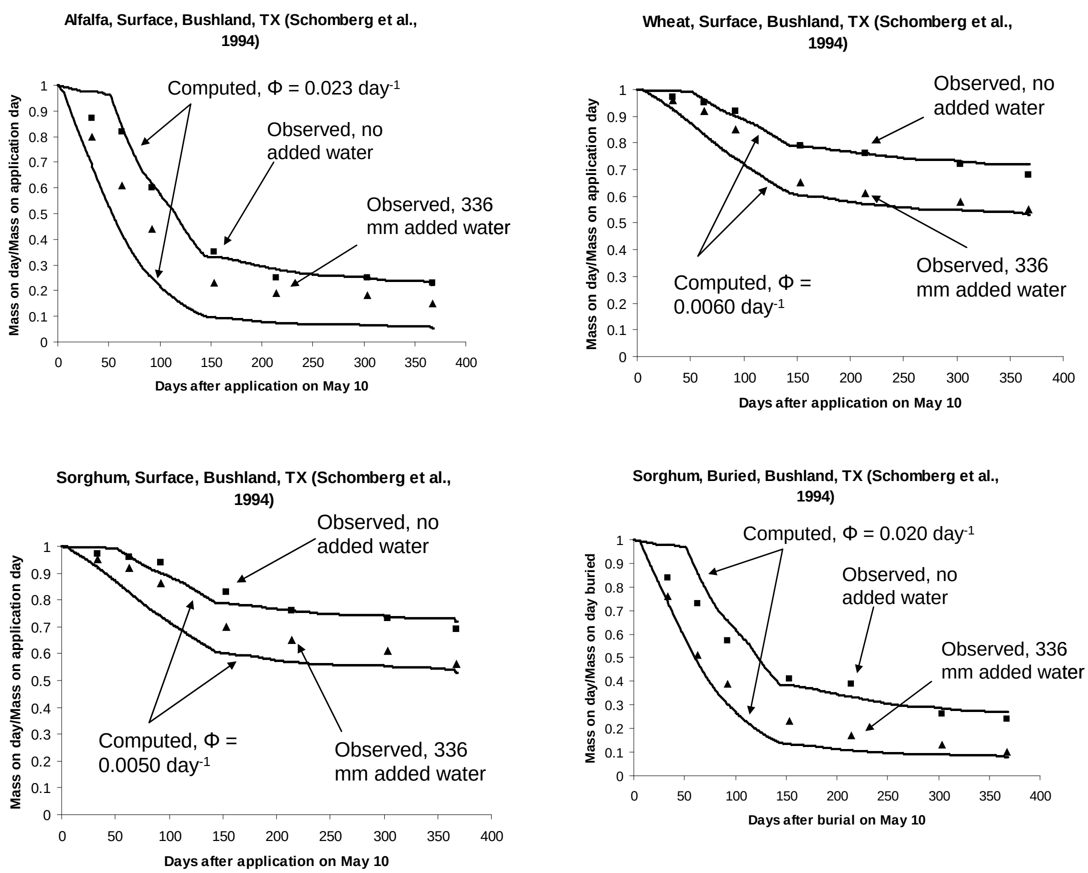

Figure 10.13. Effect of irrigation of buried and surface residue (data source: Schomberg et al., 1994)

precipitation without irrigation even though the actual monthly precipitation distribution did not vary smoothly month to month.

The Schomberg et al. (1994) data show major differences in decomposition rate between surface and buried residue. These differences seem to be a direct result of experimental procedures. That issue is discussed in detail in **Section 10.3.3.2**.

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; Steiner et al., 1999). Decomposition of surface residue seems much more related to local soil moisture at the contact between the residue and soil than was previously considered.

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., 1985a) than does sprinkler irrigation applied water. Irrigation-applied water may 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 at low residue application rates that does not occur with irrigation-applied water.

The type of irrigation should be considered in selecting irrigation inputs for RUSLE2. This decomposition analysis was based on sprinkler irrigation. The irrigation input values for sprinkler irrigation should be based on the water that actually reaches the soil. This amount can be significantly less than the amount discharged from the irrigation nozzles because of wind and evaporation losses.

Also, decomposition may be less on ridges when furrow irrigation is used than with flood irrigation on a smooth surface. Similarly, decomposition of surface residue may be reduced with drip irrigation. However, be careful in making adjustments to irrigation amounts because RUSLE2 uses the same amount in computing decomposition of both surface and buried residue. Also, RUSLE2 uses irrigation input values to compute temporal soil erodibility (see **Section 4.5**).

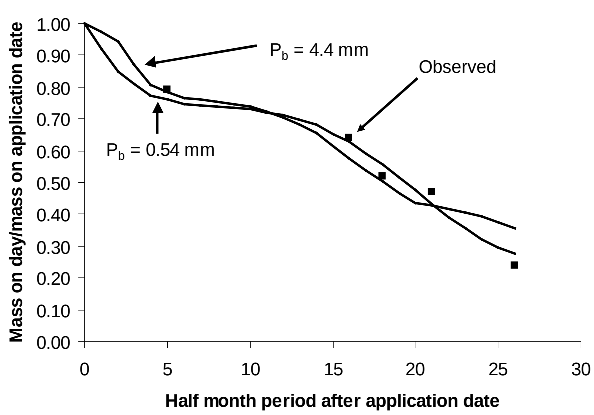

Figure 10.14. Effect of changing the base daily precipitation P_b value in the moisture function used to compute wheat straw residue decomposition at Pullman, Washington.

10.3.3.9. 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 of monthly precipitation amount relative to number of precipitation events (see **Section 10.3.4.2**). 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, Washington. 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 0.54 mm is used for P_b in equation10.5, RUSLE2 computes decomposition being controlled throughout the year by the temperature function (T_f, equation 10.6) at Pullman, Washington. 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 than the temperature function controlling decomposition 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 regions using P_b = 4.4 mm. Consequently, the difference in decomposition coefficient values in Table 10.2 between the NWRR and other regions may not be related to wheat varieties as implied in Table 10.2, 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 Req specific decomposition coefficient values given in Table 10.3 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.

10.3.4. Comparison of RUSLE2, RWEQ, WEPP, and WEPS decomposition

The RUSLE2 water erosion and RWEQ (Fryrear et al., 1998) wind erosion prediction technologies use comparable empirical structures involving long-term average monthly climate and management inputs and both were originally intended for conservation planning in USDA-Natural Resources Conservation Service (NRCS) field offices. The NRCS initially placed a high priority on RUSLE2 and RWEQ using the same equations and parameter values for computing residue mass values. Later the NRCS adopted WEPS (Hagan et al., 1996) instead of RWEQ for field office conservation planning. WEPS is a process-based simulation model that uses stochastic climate inputs. The comparable water erosion prediction model is WEPP (Flanagan and Nearing, 1995).

RUSLE2 and WEPS should compute comparable residue mass values because these models are being implemented by NRCS for routine conservation planning, and WEPP may be implemented in the future. Although erosion prediction clients may not know the residue mass values that these models should compute, clients readily recognize differences in values computed by the models and question differences when none should exist. Such differences reduce the creditability of the models and the conservation plans developed using them.

Decomposition estimates of surface applied residue were computed using RUSLE2, RWEQ, WEPP, and WEPS at the locations listed in Table 10.4.

Table 10.4. Locations for RWEQ, WEPP, and WEPS decomposition computations

Location	Annual precipitation (inches)	Model	Comments
Jefferson City, Missouri	37.8	All	Near Columbia, Missouri
Minneapolis, Minnesota	27.0	ALL	
W. Lafayette, Indiana	37.0	RWEQ	
Scottsbluff, Nebraska	15.1	WEPP/WEPS	
Jamestown, North Dakota	18.3	RWEQ	Used in Figure 10.19
Amarillo, Texas	20.1	RWEQ	Near Bushland, Texas
Borger, Texas	20.7	WEPP/WEPS	Near Bushland, Texas
Denton, Texas	33.1	WEPP/WEPS	
Dallas, Texas	36.0	WEPP/WEPS	
Houston, Texas	46.4	WEPP/WEPS	
Galveston, Texas	39.8	WEPP/WEPS	
Holly Springs, Mississippi	54.2	WEPP/WEPS	
Jackson, Mississippi	53.8	RWEQ	
Gulfport, Mississippi	60.0	WEPP/WEPS	
Mobile, Alabama	62.3	All	
Spokane, Washington	16.0	RWEQ	
Tucson, Arizona (Davis)	11.2	RWEQ	Davis-Monthan Air Force Base
Tucson, Arizona (Campbell)	12.4	WEPP/WEPS	University of Arizona Agricultural Experiment Station on Campbell Avenue
Albuquerque, New Mexico	9.3	RWEQ	Used in Figure 10.19

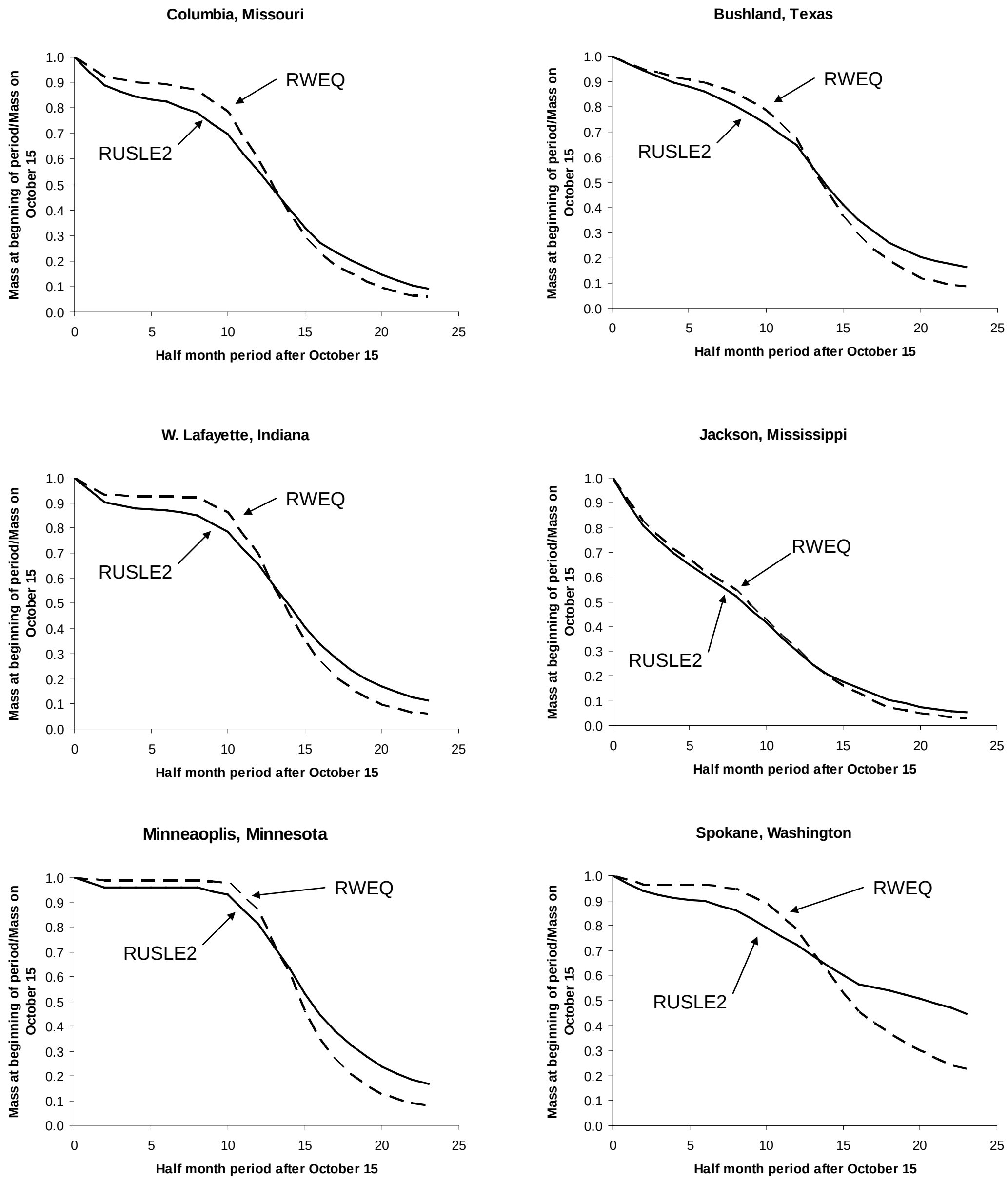

Figure 10.15. Residue decomposition computed with RUSLE2 and RWEQ

For the RWEQ computations, mulch was assumed to be surface applied on October 15 at 4500 lb/acre to a seedbed condition with no existing above ground or below ground biomass for all locations except Tucson, Arizona. The mulch was assumed to be applied on January 1 at Tucson.

The RWEQ decomposition coefficient value was adjusted to give the best fit of computed residue mass to RUSLE2 computed values at Columbia (Jefferson City), Missouri. This RWEQ decomposition coefficient value was used for all other locations, and the same RUSLE2 decomposition value was used for all locations.

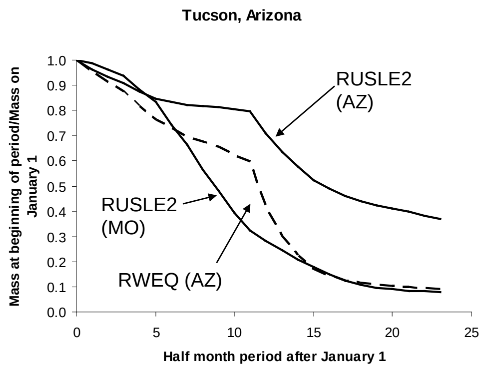

Figure 10.16. Residue decomposition computed with RUSLE2 and RWEQ at Tucson, Arizona

For the WEPP computations,[71] the same 4500 lbs/acre mulch rate was assumed to be applied on May 10, except for Tucson where the mulch was assumed to be applied on January 1. The mulch was applied to a soil that had not been tilled for a year. No above ground or below ground biomass was assumed. WEPP was run for 10 years with the same mulch amount applied each year with no soil disturbance throughout the 10 year simulation period.

WEPP computes daily residue mass for each annual mulch application. Daily computed surface residue mass for each mulch application was averaged for the 10 year simulation period. The WEPP computed residue mass values are equivalent to conducting annual experiments where the fate of mulch applied each year is determined. The WEPP computations represent each annual application placing new mulch on mulch remaining from previous years rather than mulch being applied each year to bare soil.

The RUSLE2 decomposition coefficient ϕ value was adjusted to give the best fit of RUSLE2 computed residue values to WEPP computed values for Columbia (Jefferson City), Missouri for a silt loam soil. This RUSLE2 decomposition coefficient value was used for all locations and the same WEPP decomposition coefficient value was used for the same silt loam soil for all locations.

Decomposition was computed with WEPP at the locations listed in Table 10.4. RUSLE2 computed decomposition values compared well with WEPP computed values for locations where temperature rather than moisture was the factor limiting decomposition. At locations where RUSLE2 computed that moisture limited decomposition, WEPP conputed decomposition amounts that were significantly greater than RUSLE2 computed, which was especially evident a Tucson, Arizona where the WEPP computed decomposition was essentially the same as decomposition computed at Columbia, Missouri even though average annual precipitation at Tucson as only 12 inches in comparison to 38 inches at Columbia, Missouri. Consequently, WEPP seems to be computing too much decomposition in dry locations.[72]

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[71] The WEPP version used in these computations was dated May 18, 2006, which was downloaded from the USA-ARS WEPP Internet site in April 2008. This version is the most recent version available to the public.

[72] These results have been reported to Dennis Flanagan, lead WEPP developer, USDA-Agricultural Research Service, W. Lafayette, Indiana. WEPP developers are investigating whether WEPP may be

The WEPS compuations were made using the WEPS hydrology component rather than WEPS with the WEPP hydrology component.[73] The same 4000 lbs/acre mulch rate was assumed to be annually applied on October 15 at all locations. The management practice used to make the compuations represented a soil tilled with a moldplow plow and a tandem disk that buried all of the previous year's mulch and did not resurface any buried residue. WEPS was run for 15 years. Daily surface residue mass values were averaged

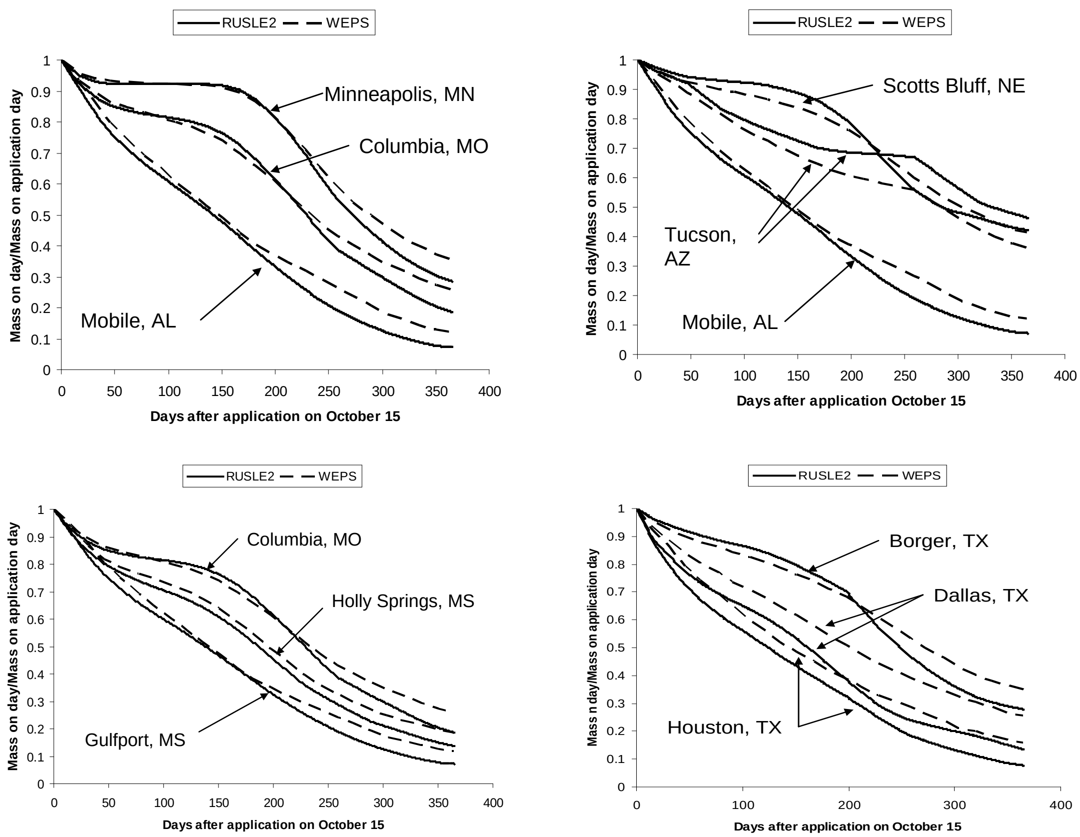

Figure 10.17. Residue decomposition computed with RUSLE2 and WEPS

for the 15 year simulation. The results are plotted in Figure 10.17.

The same WEPS decomposition coefficient value was used for all WEPS computations. The RUSLE2 decomposition coefficient ϕ value was adjusted to give the best fit of

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computing too much decomposition at Tucson and other dry locations. Possible WEPP changes may made sometime soon (May 10, 2008).

[73] The WEPS version used in these computations was dated April 14, 2006, which was provided by Larry Wagner, lead WEPS developer, USDA-Agricultural Research Service, Manhattan, Kansas.

RUSLE2 computed residue values to WEPS computed values for Columbia (Jefferson City), Missouri for the Morley silty clay loam soil. This RUSLE2 decomposition coefficient value was used for all subsequent RUSLE2 computations.

10.3.4.1. Structure of decomposition computations

All four models (RUSLE2, RWEQ, WEPP, and WEPS) use moisture and temperature functions to compute decomposition. RUSLE2, WEPS, and WEPP use equation 10.4 that takes a minimum of the moisture and temperature functions instead of the product of these functions used in RWEQ. The differences in computed decomposition resulting from the RUSLE2 minimum structure and the RWEQ product structure are illustrated in Figures 10.15 and 10.16. With the exception of the Tucson location, the consistent trend is that the product structure computes reduced decomposition during cool periods and increased decomposition during warm periods.

Using a minimum of the moisture and temperature functions was judged to be better than the product of the functions based on an inspection of Figures 10.2 and 10.15.

The minimum of the moisture and temperature functions, which is equation 10.4, is also used in WEPP and WEPS. The Gregory et al. (1985) decomposition model was originally used in RUSLE1, but it was replaced with a modification of the WEPP decomposition model (Stott, 1991; Stott et al., 1995) because the Gregory et al. model also was judged to compute too little decomposition during cool periods and too much decomposition during warm periods.

10.3.4.2. Moisture function

10.3.4.2.1. Comparison with RWEQ

RUSLE2's moisture function used to compute decomposition is given by equation 10.5. The RWEQ moisture function is given by (Fryrear et al., 1998; Schomberg and Steiner, 1997):

$$W_{fwe} = 1.25 N_p / D_p \qquad [10.8]$$

where: W_{fwe} = the RWEQ moisture function used to compute decomposition, N_p = the number of precipitation events in the period D_p (days). 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 and its contact with the soil mass. Similarly, the Schomberg-Steiner assumption 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. The assumption also seems questionable during fall and spring periods when evaporation is reduced. Dew may provide a significant moisture source, even on very hot days (Heilman et al, 1992).

Decomposition was computed with RUSLE2 and RWEQ at the locations identified in Table 10.4, and the computed values are shown in Figures 10.15 and 10.16. Except for the Tucson location, the RUSLE2 and RWEQ moisture functions performed similarly. The reason for the similar performance is that number of precipitation events in a given period in the RWEQ moisture function actually serves as a surrogate for precipitation amount used in the RUSLE2 moisture function. Precipitation amount in a given period is highly correlated with number of precipitation events in the period and the relationship is essentially the same across the eastern US as shown in Figure 10.18. However, a disadvantage of the RWEQ moisture function even in this region is that number of precipitation event is more spatially varied than precipitation amount. Also, 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 Canada (see Figure 10.2) and SW Australia (see Figure 10.3).

The RUSLE2 and RWEQ decomposition estimates differ greatly for Tucson, Arizona as shown in Figure 10.16. In this figure, decomposition was computed at Columbia, Missouri with RWEQ for mulch applied on January 1, the same as for Tucson. RWEQ computed the same decomposition for both Tucson and Columbia even though annual rainfall at Tucson (Davis) was only 11 inches in comparison to 38 inches at Columbia (see Table 10.4). The reason that RWEQ computes the same decomposition at the two locations is that the number of storms is comparable for the two locations even though annual precipitation differs significantly between the locations. Similarly, the number of storms per month in relation to monthly precipitation amount is high at Spokane Washington during the cool period, which is the reason for the difference between decomposition computed by RUSLE2 and RWEQ Spokane being greater than at the other locations in Figure 10.15.

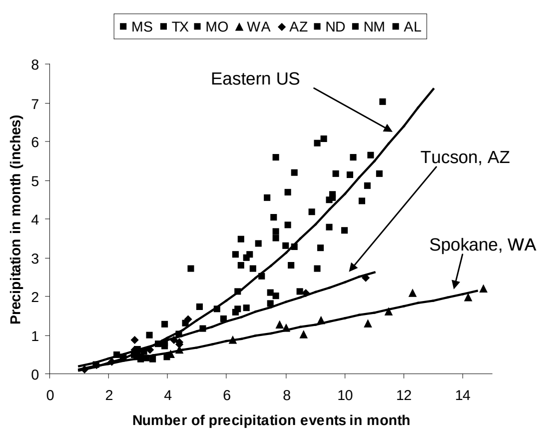

Figure 10.18. Relation of average monthly precipitation to number of precipitation events in a month.

Use of the RWEQ moisture function in RUSLE2 would require varying the decomposition coefficient value with location in the western US. This requirement is similar to the base precipitation value P_b in equation 10.5 needing to be changed so that the same RUSLE2 decomposition coefficient values can be used in the Palouse Region and in the eastern US (see **Sections 3.2.5 and 10.3.2**).

Overall, using precipitation in the RUSLE2 moisture function is judged superior to using number of precipitation events as in RWEQ. Using number of precipitation events would provide no fundamental improvement in RUSLE2's decomposition estimates. Precipitation amount appears to be superior in low precipitation regions in the western

US. Precipitation amounts are much more readily available and spatially stable than number of precipitation events in a given period.

10.3.4.2.2. Comparison with WEPP

The WEPP moisture function is given by (Stott et al., 1995):

$$W_{fwp} = \theta_t / \theta_o \quad [10.9]$$

where: W_{fwp} = the WEPP moisture function used to compute decomposition of surface residue, θ_t = water content (volume of water/volume of bulk soil)[74] of the tilled soil layer and θ_o = the optimum water content (volume water/volume of bulk soil) for decomposition. The WEPP assumption is that the optimum moisture content for decomposition is 0.6 times the soil's pore space (volume pore space/volume of bulk soil). Consequently, the decomposition computed by WEPP should be a function of soil, tillage, and other factors that affect infiltration (e.g., precipitation, soil properties, and cover-management), soil water retention (e.g., soil properties), and soil water extraction (e.g., drainage and evapo-transpiration) (Alberts et al., 1995).

The present WEPP version does not computes the same decomposition amount at Tucson, Arizona as it does in Columba, Missouri, even average annuaj precipitation at Tucson is 12 inches in comparison to 38 inches at Columbia. These WEPP computations were judged tgo be erroneous, thus further computations were not made with WEPP. Changes are anticipated in WEPP to deal with this apparent problem (May 10, 2008).

10.3.4.2.3. Comparison with WEPS

The WEPP moisture function is given by (Hagan et al., 1996):

$$W_{fws} = \theta_s / \theta_f \quad [10.10]$$

where: W_{fws} = the WEPP moisture function used to compute decomposition of surface residue, θ_s = water content (volume of water/volume of bulk soil) of the surface soil layer, which is thinner than the WEPP tilled soil layer, and θ_f = field capacity water content of the surface soil layer (volume water/volume of bulk soil), which is considered to be the optimum water content for decomposition. Soil water content in the surface soil layer is affected by precipitation, infiltration, drainage, and extraction. Consequently, WEPS decomposition should be a function of soil and cover-management.

As illustrated in Figure 10.17, RUSLE2 computed decomposition values compared well with WEPS computed values for locations where temperature rather than moisture was the factor limiting decomposition. However, a difference in trend between the RUSLE2 and WEPS compuated values was apparent at these locations where computed

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[74] Bulk soil includes the volume of both soil particles and pore space.

decomposition rates were less for WEPS than for RUSLE2 during the maximum precipitation period. WEPS computed decomposition was significantly less than RUSLE2 computed decomposition at Tucson, Arizona. RUSLE2 computed less decomposition during the dry periods at Tucson than did WEPS. WEPS computed much less decomposition than did RUSLE2 at Dallas, Texas. The distinguishing feature at Dallas is a double peaked precipitation pattern. Precipitation (≈ 2.1 inches/month) in July and August is about half the precipitation in April and May (≈ 4.6 inches) and September and October (≈ 3.6 inches/month). In contrast to Tucson where RUSLE2 computed less decomposition than did WEPS, RUSLE2 computed more decomposition at Dallas than did WEPS.

Apparently the WEPS soil moisture values are dampened more than are the RUSLE2daily precipitation values used to compute decomposition, even at locations where precipitation is moderately high and greater such as Columbia, Missouri; Holly Springs and Gulfport, Mississippi; and Mobile, Alabama. This same dampening may be responsible for the differences at Tucson and Dallas.

These differences raise questions about the adequacy of the WEPS computed soil moisture values at all locations, but especially at locations where monthly precipitation changes greatly in a short time, and how well the RUSLE2 moisture function performs in dry regions. The decomposition data illustrated in Figure 10.2 are inadequate to definively make a determination about RUSLE2's moisture function used to compute decomposition or to show whether RUSLE2 or WEPS better computes decomposition.

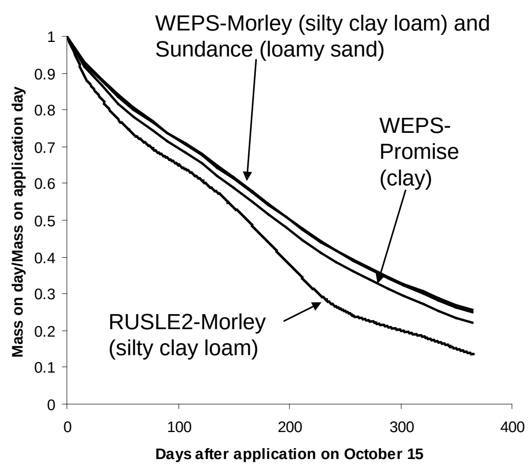

Figure 10.19. Effect of soil texture on WEPS computed decomposition at Dallas, Texas.

Figure 10.19 shows WEPS computed decomposition values for three soil textures at Dallas, Texas. The effect of soil texture on WEPS computed decomposition values are not great. RUSLE2 does not consider soil textue in its decomposition computations.

Figure 10.20 shows the effect of soil disturbance on WEPS computed decomposition. Whether the soil was only moldboard plowed or was moldboard plowed and disked had no effect on WEPS computed decomposition. However, WEPS computed increased decomposition for a soil not disturbed, which is the appropriate direction for computing decomposition for no-till farming practices.

10.3.4.3. Temperature function

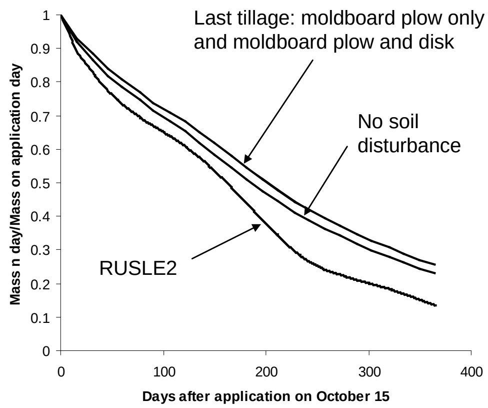

Figure 10.20. Effect of soil disturbance on WEPS computed decomposition

The same basic temperature function, equation 10.6, is used in RUSLE2, WEPP, WEPS, and RWEQ. Both RUSLE2 and WEPP compute a daily temperature function value using average daily temperature computed as the average of the maximum and minimum temperature for the day. RWEQ and WEPS compute a daily temperature function value by computing a temperature function value for both the daily maximum and minimum temperatures and averaging those two temperature function values. RUSLE2 and RWEQ use long term daily and monthly temperature values, respectively, whereas WEPP and WEPS uses stochastically generated daily temperature values.[75]

Each model uses slightly different values for the variables A and optimum temperature T_o in equation 10.6. For example, RWEQ and WEPS use A = 0 ^oC whereas RUSLE2 uses A = - 8 ^oC to compensate for using long-term average daily temperature in RUSLE2. RUSLE2 computes decomposition for a long term average daily temperature as low as -10 ^oC. In WEPP, A = -6.1 ^oC, which compensates for use of daily average temperature in computing a daily temperature function value. The optimum temperature value use in RUSLE2, RWEQ, and WEPS is 32 ^oC while 33 ^oC is used in WEPP.

RUSLE2 and WEPP compute almost identical long term average decomposition for conditions where the temperature function entirely controls rather than the moisture function. Little of the differences between RUSLE2 and WEPS in Figure 10.17 appear to be caused by differences in the temperature functions used to compute decomposition.

The RWEQ/WEPP temperature function approach is superior at high temperatures to the RUSLE2 approach. Flattening the temperature function around the optimum temperature, T_o in equation 10.6 would improve the RUSLE2 temperature function. The best approach would be to replace the RUSLE2 temperature function as described by Schomberg et al. (2002).

The end result is that RUSLE2 computed temperature function values at high temperatures were not a significant factor in fitting the measured decomposition data illustrated in Figure 10.2. In each case, the moisture function was limiting rather than the temperature function when temperatures were high. At low temperatures, the

[75] The RUSLE2 input is long term average monthly that RUSLE2 disaggreagtes into daily temperatures.

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 function 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. Thus, decomposition coefficient values are moisture and temperature function dependent and model dependent in other ways including how soil moisture is computed for example.

10.3.4.4. Summary comments on RUSLE2 decomposition computations

For RUSLE2, WEPS, WEPP to give comparable long term surface residue cover estimates, decomposition data that best represents field conditions must be identified and used to calibrate all these models.

The RUSLE2 decomposition equations use simple inputs so that RUSLE2 is convenient for use in conservation and erosion control planning. The RUSLE2 purpose is not to accurately model residue decomposition processes in a research context. RUSLE2 users must be aware of RUSLE2 procedures and how to select RUSLE2 inputs to best represent residue for each 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.

The RUSLE2 decomposition procedures are better than those in RWEQ, a comparable model for wind erosion. Also, RUSLE2 computes decomposition values that are comparable to those computed by WEPS and WEPP, process-based models for wind and water erosion, respectively, when all three models are calibrated to the same data. The soil moisture computations in both WEPS and WEPP should be reveiwed for dry regions and regions when monthly precipitation is double peaked. Decomposition values computed by WEPS do not appear to vary much with soil texture or soil disturbance. Conquently, decomposition computed by RUSELE2 will not differ significantly from the values computed for WEPS when soil and cover-management vary at a location. Advantages of RUSLE2 are that it is robust, uses simple inputs, gives good results, and is easy to use, important attributes for its intended purpose of guiding conservation and erosion control in local field offices.

The RUSLE2 User's Reference Guide describes steps that should be observed in adjusting RUSLE2 input related to values computed for soil surface residue covered.

10.4. Standing residue

10.4.1. Decomposition

Certain operations convert live vegetation to standing residue (see **Section 8**). 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 ϕ value that is 0.3 of that used to compute surface residue decomposition because reduced moisture is available for decomposition of standing residue.

RUSLE2 computes the decomposition of a unit stem mass assumed to represent decomposition at the base of standing residue stems. This decomposition is computed using equations 10.3 - 10.6 and the same decomposition coefficient ϕ value used to compute surface residue decomposition. That is, decomposition at the stem base is assumed to occur at the same rate as surface residue decomposition.

The portion of the standing residue mass that remains standing over time is assumed to be related to the portion of the remaining unit stem base mass. The RUSLE2 equation for this relationship is:

$$\gamma_t = -2.62\gamma_s^3 + 4.57\gamma_s^2 - 0.95\gamma_s \qquad [10.11]$$

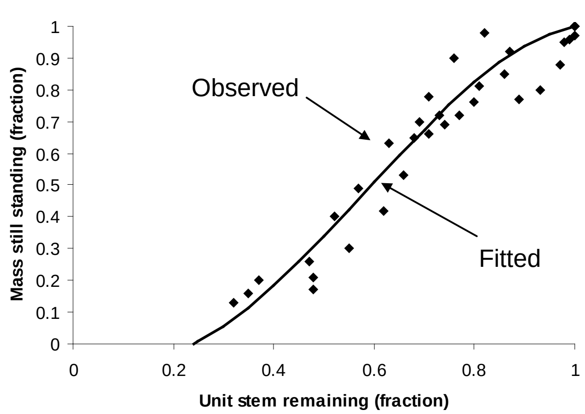

Figure 10.21. Relation of standing residue mass to computed unit stem base mass. (Data source: Steiner et al., 1994)

where: γ_t = portion (fraction) of original standing residue mass that remains and γ_s = portion (fraction) of the original unit stem base mass that remains at any given time. Equation 10.11 was derived by fitting to measured wheat data collected in Texas, Oregon, and North Dakota as illustrated in Figure 10.21 (Steiner et al., 1994). No similar data were found for other vegetation communities. However, equation 10.11 is considered to be adequate for other plant types besides small grain.

10.4.2. Canopy cover-mass relationship

During the live period for a vegetation description, canopy cover is known directly from user input. These canopy cover values are used to estimate temporal values for live above ground biomass (see **Section 9.2.5**).

Once live above ground biomass is transferred to standing residue, the known variable is standing residue mass. This biomass is computed from standing live above ground biomass converted to standing residue on the conversion date, decomposition of standing residue over time, and the amount of the standing residue that has become surface residue computed with equation 10.11.

RUSLE2 computes canopy cover for standing residue using:

$$f_t = \mu B_t^{2/3} \qquad [10.12]$$

where: f_t = canopy cover provided by the standing residue and B_t = daily standing residue biomass (dry mass/area). The value for the coefficient μ is determined from:

$$\mu = f_{to} / B_{to}^{2/3} \qquad [10.13]$$

where: f_{to} and B_{to} = canopy cover and biomass (dry mass/area), respectively, when the standing residue is created from live above ground biomass.

10.4.3. Manning's n, effective vegetation ridge height, and effective fall height for standing residue

Values for the Manning's n and effective ridge height for standing residue are computed using:

$$n_t = n_{to}(B_t / B_{to}) \qquad [10.14]$$

$$H_t = H_{to}(B_t / B_{to}) \qquad [10.15]$$

where: n_t = the daily standing residue Manning's n, n_{to} = the live vegetation Manning's n on the day that the standing residue was created, H_t = daily effective standing residue ridge height (inches), and H_{to} = effective ridge height (inches) of the live vegetation on the day that the standing residue was created. The effective ridge height for standing residue is computed from:

$$h_f = h_{fo}(f_t / f_{to}) \qquad [10.16]$$

where: h_f = the daily effective fall height, h_{fo} = the effective fall height for the vegetation on the day that the standing residue was created, f_t = daily canopy cover, and f_{to} = the canopy cover of the vegetation on the day that the standing residue was created.

Although RUSLE2 uses a single vegetation description on any given day, RUSLE2 tracks multiple standing residue descriptions. RUSLE2 assumes that the overall Manning's n for standing residue and the overall effective ridge height for each standing residue description are the sums of the respective values for each standing residue description. The net effective fall height of the standing residue 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 residue descriptions 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.

10.5. List of symbols

A = a reference temperature in temperature function used to compute decomposition (-8 ^{o}C)

b = coefficient that desribes the effectiveness for a particular residue type for reducing erosion (percent^{-1})

B = mass (dry) in a particular residue/dead root pool (mass/area)

B_s = surface residue dry biomass (mass/area)

B_t = standing residue dry biomass (mass/area)

B_{to} = standing residue dry biomass on day when standing residue is created (mass/area)

c = daily cover-management factor

D = time in period over which decomposition is being computed (days)

D_p = period over which N_p precipitation events occur (days)

$D_{1/2}$ = residue half life (time)

f_g = ground (surface) residue cover (fraction)

f_{gm} = ground (surface) cover for crop residue or mulch assuming no other material is present (fraction)

f_{gn} = net ground (surface) cover provided by total surface residue mass (fraction)

f_{gr} = ground (surface) cover provided by the rock surface residue cover assuming no other surface residue is present (fraction)

f_t = canopy cover provided by the standing residue (fraction)

f_{to} = canopy cover provided by standing residue on day that standing residue is created (fraction)

g_c = daily ground cover subfactor

h_{fi} = effective fall height of standing residue (feet)

h_{fo} = effective fall height for the vegetation on day that the standing residue was created (feet)

H_t = effective standing residue ridge height (inches)

H_{to} = effective ridge height of live vegetation on day that the standing residue was created (inches)

n_t = standing residue Manning's n

n_{to} = live vegetation Manning's n on day that the standing residue was created

I = daily amount of water added by irrigation (inches)

N_p = Number of precipitation events in the period D_p

P = daily precipitation (inches)

P_b = base daily precipitation in moisture function used to compute decomposition (inches)

s_b = daily soil biomass subfactor

T = daily air temperature (^oC)

T_f = daily temperature function used to compute decomposition

T_o = optimum temperature for decomposition (^oC)

W_f = daily moisture function used to compute decomposition in RUSLE2

W_{fwe} = RWEQ moisture function used to compute decomposition

W_{fwp} = WEPP moisture function used to compute decomposition

W_{fws} = WEPS moisture function used to compute decomposition

α = coefficient in equation used to compute surface residue cover for a given residue mass [(mass/area^{-1})]

β = coefficient used to compute residue decomposition (day^{-1})

γ_s = portion of the unit stem base mass (dry basis) that remains

γ_t = portion of standing residue mass (dry basis) that remains

θ_f = field capacity moisture content (volume water/volume bulk soil)

θ_o = optimum soil moisture content for residue decomposition (volume water/volume bulk soil)

θ_s = soil moisture content for the surface soil layer (volume water/volume bulk soil)

θ_t = soil moisture content of the tilled soil layer (volume water/volume bulk soil)

μ = coefficient in equation used to compute canopy cover from standing biomass $(mass/area)^{-2/3}$

ϕ = decomposition coefficient that is a function of biomass type (day^{-1})

ϕ_w = weighted decomposition coefficient for residue description composed of two or more distinct residue types (day^{-1})

Indices

i - day

11. SUMMARY

11.1. RUSLE2 overview

The Revised Universal Soil Loss Equation, Version 2, (RUSLE2) is a tool specifically developed to guide erosion control planning at the local field office. RUSLE2 computes estimates of soil erosion caused by rainfall and its associated overland flow. RUSLE2 computes soil erosion estimates based on site-specific conditions for climate, soil, topography, and land use. Typically, RUSLE2 is used to compute soil erosion estimates for alternative erosion control measures that might be applied at a specific site. The erosion control practices that result in erosion estimates less than the erosion control criteria are considered acceptable. Consequently, erosion control can be tailored to site-specific conditions and requirements by using RUSLE2.

RUSLE2 is land-use independent. It applies to all land conditions where mineral soil is exposed to the erosive forces of raindrop impact and surface runoff produced by Hortonian overland flow. This overland flow occurs when rainfall intensity exceeds the infiltration rate of rainwater into the soil. RUSLE2 applies to cropland; permanent pastureland; construction sites; military training grounds; landfills and similar waste disposal sites; rangelands; disturbed forestlands; right-away along highways, pipelines, and electric transmission lines; and other similar lands.

The basic spatial RUSLE2 computational unit is the overland flow path selected to represent the site. Surface runoff follows this path from its origin to where overland flow becomes collected in a channel. The overland flow path can be divided into segments so that RUSLE2 can capture the effects of soil, steepness, and land use conditions varying along the overland flow path. RUSLE2 computes net erosion or deposition (mass/area) for each segment, sediment load (mass/unit flow width) at the end of each segment and at the end of the overland flow path, and sediment characteristics at the detachment point and in the sediment load at the end of each segment.

RUSLE2 also computes deposition in terrace channels assuming uniform conditions along these channels and deposition in small impoundments used on overland flow areas. RUSLE2 does not compute erosion in concentrated flow areas, referred to as ephemeral gully erosion, that terminate the overland flow path.

The basic temporal RUSLE2 computational unit is the long-term average for each day during the computation period used to represent a site's land-use condition. RUSLE2 management descriptions used to represent land-use conditions can be rotations where land use conditions are repeated in cycles or non-rotations where land-use conditions exist only for a single duration. The rotation cycle duration is the computation period. Rotation-type management descriptions are typically used to represent cropland and similar land uses. Also, rotation-type management practices are used to represent permanent land-use conditions that do not change from year to year.

Non-rotation type management descriptions are used to represent one-time land use conditions, such as reclamation of construction sites and surface mines. The computation period for these examples is from final grading through the number of years required for the site to become stabilized.

RUSLE2 sums long-term average daily erosion values to compute average annual values for the computation period used in the management description, for each year, and other sub-periods within the overall computation period. The average annual erosion value for the overall computation period typically is used in erosion control planning. The RUSLE2 computed average annual erosion for the site is compared to the site's erosion control criteria, which is an allowable average annual erosion rate based on the on-site and off-site damages that soil erosion would cause.

RUSLE2 computes how temporal variability of climate, soil, and land-use conditions affects erosion. Soil erosion is greatest when periods of maximum erosivity coincide with periods when the soil is most susceptible to erosion. Climatic erosivity typically varies greatly during the year. Also, land-use conditions vary during the year, ranging from bare soil after a major mechanical disturbance to dense cover provided by mature vegetation. Even erosion susceptibility of a site in permanent vegetation can vary significantly during the year as above ground and below ground biomass grow and subside. Even if vegetative cover and soil biomass do not vary temporally, soil erodibility varies during the year. Soil erodibility is greatest during periods of high soil moisture.

11.2. RUSLE2 mathematical structure

RUSLE2 is hybrid soil erosion prediction (estimation) technology because it is a combination of the empirical, index-based Universal Soil Loss Equation (USLE) and process-based equations for the detachment, transport, and deposition of soil particles. RUSLE2 computes a long-term average daily sediment production value using the USLE factors for erosivity, soil erodibility, slope length, slope steepness, cover-management, and support practice. Each USLE factor, except the one for slope steepness, is modified in RUSLE2 to compute a daily value rather than the standard USLE average annual value.

The USLE mathematical structure is (Wischmeier and Smith, 1978):

$$A = RKLSCP$$

where: A = average annual erosion (mass/area·year), R = average annual erosivity factor (erosivity units/area·year), K = average annual soil erodibility factor (mass/erosivity unit), L = average annual slope length factor (dimensionless), S = average annual slope steepness factor (dimensionless), C = average annual cover-management factor (dimensionless), and P = average annual support practice factor (dimensionless) . Each USLE factor, except the erosivity factor, has the mathematical structure of:

$$F = \left(\sum_{i=1}^{I} f_i \phi_i \right) \Big/ N$$

where: F = average annual factor, f_i = factor value for the *ith* time period, ϕ_i = the fraction of the annual erosivity that occurs during the *ith* period, I = the number of sub-periods in the computationl period for the management description used to represent a site's land use conditions, N = number of years in the computation period. Thus, the USLE has the mathematical structure of:

$$A = R\left[\left(\sum_{i=1}^{I_k} k_i\phi_i\right)\Big/N_k\right]\left[\left(\sum_{i=1}^{I_l} l_i\phi_i\right)\Big/N_l\right]\left[\left(\sum_{i=1}^{I_s} s_i\phi_i\right)\Big/N_s\right]\left[\left(\sum_{i=1}^{I_c} c_i\phi_i\right)\Big/N_c\right]\left[\left(\sum_{i=1}^{I_p} p_i\phi_i\right)\Big/N_p\right]$$

where: k_i = soil erodibility factor for the *ith* period (mass/erosivity unit), I_k = the number of periods in the N_k years used to determine an average annual soil erodibility factor value, l_i = slope length factor for the *ith* period (dimensionless), I_l = the number of periods in the N_l years used to determine an average annual slope length factor value, s_i = slope steepness factor for the *ith* period (dimensionless), I_s = the number of periods in the N_s years used to determine an average annual slope steepness factor value, c_i = cover-management factor for the *ith* period (dimensionless), I_c = the number of periods in the N_c years used to determine an average annual cover-management factor value, p_i = support practice factor for the *ith* period (dimensionless), and, I_p = the number of periods in the N_p years used to determine an average annual support practice factor value. In practice, the USLE mathematical structure is:

$$A = RKLS\left[\left(\sum_{i=1}^{I_c} c_i\phi_i\right)\Big/N_c\right]P$$

where: temporally constant values for K, L, S, and P are used throughout the computation period.

The basic RUSLE1 mathematical structure is the same as the USLE structure except that a temporal soil erodibility factor is used as (Renard et al., 1997):

$$A = R\left[\left(\sum_{i=1}^{24} k_i\phi_i\right)\Big/24\right]LS\left[\left(\sum_{i=1}^{24N_c} c_i\phi_i\right)\Big/24N\right]P$$

where: each year is divided in 24 half month periods and N = years in the overall computation period. Additional sub-periods are added if an operation that disturbs the soil, vegetation, or residue occurs within a half month period.

The RUSLE2 mathematical structure is:

$$A = \left(\sum_{i=1}^{365N} r_i k_i l_i s_i c_i p_i \right) \Big/ N$$

where: r_i = daily erosivity factor (erosivity unit/year), k_i = daily soil erodibility factor (mass/area·erosivity unit), l_i = daily slope length factor (dimensionless), s_i = daily slope steepness factor (dimensionless), c_i = daily cover-management factor (dimensionless), and p_i = daily support practice factor (dimensionless), all long term averages for the *ith* day, and N = number of years in the overall computational period. In practice, a single time-invariant slope steepness S is used instead of a daily s_i slope steepness factor.

The difference in mathematical structure between the USLE, RUSLE1, and RUSLE2 results in the three methods giving different erosion estimates even when each method gives the same average annual values for each USLE factor. Also, RUSLE2 considers much more interdependence between the factors than either the USLE or RUSLE1 considers.

Fundamentally, the USLE applies to a uniform overland flow path where neither soil, steepness, cover-management, nor support practice vary along the flow path. A mathematical procedure is available to apply the USLE to non-uniform overland flow paths where deposition does not occur. The USLE can not be applied to overland flow paths where steepness along the flow path decreases sufficiently to cause deposition.

The same mathematical structure used in process-based erosion prediction technologies to compute deposition along non-uniform overland flow paths is used in RUSLE1 and RUSLE2. Deposition is computed at locations along the flow path where the sediment load exceeds surface runoff's sediment transport capacity. RUSLE2 computes deposition using the equation:

$$D_p = \left(\alpha V_f / q\right)\left(T_c - g\right)$$

where: D_p = deposition rate (mass/area·time), α = an empirically determined deposition coefficient (dimensionless), V_f = the sediment's fall velocity (length/time), q = surface runoff rate (volume/unit overland flow width·time), T_c = surface runoff's sediment transport capacity (mass/unit overflow width·time), and g =sediment load (mass/unit overflow width·time) being transported by surface runoff.

Five sediment classes (primary clay, primary silt, small aggregate, large aggregate, and primary sand) are used in RUSLE2 to represent sediment characteristics. RUSLE2 computes the distribution of the sediment among these classes and the diameters of the aggregate classes at the point of detachment as a function of soil texture. The specific gravity of the aggregate classes is about 65 percent of that for the primary particle classes. RUSLE2 computes how deposition changes sediment characteristics along the overland flow path by applying the deposition equation to each sediment class. RUSLE2 also computes an enrichment ratio based on the specific surface of the sediment load and the specific surface area of the surface soil.

Both the deposition and sediment transport capacity equations are functions of runoff rate. A daily runoff rate index is computed using the NRCS runoff curve number method and the 10 year-24 hour precipitation amount. RUSLE2 computes a daily curve number value as a function of daily cover-management variables.

RUSLE2 computes how soil surface conditions affect runoff's sediment transport capacity. The computation is based on a division of runoff shear stress between that acting on roughness elements, including live vegetation, standing residue, surface residue cover and soil surface roughness, and that acting on the soil grain roughness, which is the part responsible for sediment transport. A daily division of shear stress is computed using daily cover-management variables.

RUSLE2's erosivity and soil erodibility definitions and variables are the same as those used by the USLE, which are based on the unit-plot concept. Also, RUSLE2 can use the standard USLE soil erodibility nomograph to compute soil erodibility factor values for undisturbed soil profiles or a modified nomograph for highly disturbed soil conditions. RUSLE2 computes a daily erodibility factor value that is varied about the base soil erodibility factor values using daily precipitation and temperature values. Daily erosivity is computed as the product of average annual erosivity and the fraction of the annual erosivity that occurs on each day.

The RUSLE2 slope length factor, which is the same as the USLE and RUSLE1 slope length factor, is given by:

$$l_x = (x/\lambda_u)^m$$

where: l_x = slope length factor used to compute erosion at any location x along an overland flow path (dimensionless), λ_u = unit plot length, and m = a slope length factor exponent. Sediment is detached from the soil mass on overland flow area by impacting raindrops (interrill erosion) and surface runoff (rill erosion). Interrill erosion is uniform along a uniform overland flow path, in which case the exponent m = 0. Rill erosion increases along an overland flow path as runoff increases, in which case m = 1. RUSLE2 computes a daily exponent value (between 0 and 1) that depends on the ratio of rill-to-interrill erosion. This ratio is computed as a function of how soil texture, slope steepness, and surface cover affects rill erosion relative to interrill erosion. The rill-to-interrill erosion ratio changes daily as cover-management changes daily.

The RUSLE2 slope steepness factor is the same as the one used in RUSLE1. This factor is time invariant in RUSLE2.

11.3. Land use subfactors

11.3.1. Cover-management subfactors

The use of basic cover-management variables to compute daily cover-management factor and runoff curve number values gives RUSLE2's its land-use independence. Cover-management factor values are computed as the product of several subfactors. These subfactors are canopy, ground (surface) cover, soil surface roughness, soil ridging, soil consolidation, soil biomass, and ponding. An additional soil moisture subfactor is used when RUSLE2 is applied to cropland in certain areas of the northwestern US.

The canopy subfactor describes how above ground canopy (cover that does not touch the soil surface) affects rainfall erosivity. The variables used in this subfactor include fraction of the soil surface covered by canopy and effective fall height of water drops falling from the canopy. RUSLE2 includes equations that estimate effective fall height based on top and bottom canopy heights, canopy shape, and the vertical gradient of canopy mass.

In contrast to canopy cover, ground (surface) cover rests directly on the soil surface. The main component of the equation that computes ground cover subfactor is:

$$c_g = \exp(-bf_g)$$

where: c_g = the subfactor for ground cover. **b** = coefficient for effectiveness of ground cover for reducing erosion (percent^{-1}), and f_g = ground cover (percent). The **b** coefficient, which is a measure of the effectiveness of ground cover for reducing erosion, is a function of the rill-to-interrill erosion ratio. RUSLE2 computed **b** values vary from 0.025 when the erosion is entirely interrill erosion to 0.06 when the erosion is entirely rill erosion. An additional soil surface roughness term is added to this equation in RUSLE2 to account for surface cover having less effect as soil surface roughness increases.

The soil surface roughness subfactor represents how soil surface roughness influences erosion by reducing runoff's erosivity, by causing deposition in local depressions, and by ponding water that protects a portion of the soil surface from direct raindrop impact. Daily soil surface roughness subfactor values are computed as a function of the daily soil surface roughness index. Soil surface roughness decreases daily from the initial soil surface roughness left by a mechanical soil disturbance. RUSLE2 computes the daily decrease in the soil surface roughness index using values for daily precipitation and daily interrill erosion. The soil surface roughness index value left after a mechanical soil disturbance is computed as a function of the soil surface roughness index that exists at the time of the soil disturbance, the soil surface roughness index created by the mechanical soil disturbance applied to a standard soil condition, soil texture, soil biomass, and the degree that the mechanical soil disturbance obliterates existing soil surface roughness.

The soil ridging subfactor represents the effect of ridge side slope on interrill erosion. The soil ridging subfactor is a function of daily ridge height, which is a surrogate for ridge side slope. RUSLE2 decreases daily ridge height from an initial ridge height left by a mechanical soil disturbance as a function of daily precipitation and daily interrill erosion.

The soil consolidation subfactor represents how a bare soil without soil biomass becomes less erodible over time as the soil experiences wetting and drying cycles. Soil consolidation in RUSLE2 refers to the re-bonding of soil particles after a mechanical soil disturbance. The RUSLE2 assumption is that mechanical soil compaction (increase in soil bulk density) does not decrease erosion. RUSLE2 computes soil consolidation subfactor values as a function of the time since the last mechanical soil disturbance. The RUSLE2 time to soil consolidation is seven years but increases to 20 years where average annual precipitation is less than 30 inches.

The soil biomass subfactor represents how soil biomass reduces erosion. RUSLE2 computes daily soil biomass subfactor values as a function of the daily amounts of live roots, dead roots, and buried biomass in the soil and the soil consolidation subfactor. Plant litter, crop residue, manure, and other types of biomass on the soil surface that is incorporated in the soil by mechanical soil disturbance adds to buried soil biomass. Also, injection of manure, sewage sludge, and other organic materials into the soil adds soil biomass. The runoff and erosion reduction computed by the soil biomass subfactor significantly increases as the soil becomes “consolidated” after a mechanical soil disturbance.

The ponding subfactor accounts for how a water layer on the soil surface decreases raindrop impact erosivity in high rainfall regions where land is nearly flat. The variables used to compute ponding subfactor values are land steepness and daily runoff depth, which in turn is a function of the 10 year-24 hour precipitation amount, soil properties, and cover-management.

The antecedent soil moisture subfactor, which is used only on cropland in the northwestern US, accounts for how previous cropping reduces soil moisture that in turn reduces erosion in subsequent cropping periods.

11.3.2. Support practice subfactors

The contouring subfactor computes how contour ridging affects rill erosion and sediment transport by redirecting surface runoff. Contouring subfactor values are computed as a function of daily runoff rate, overland flow path steepness, and ridge-furrow grade

RUSLE2 computes the location along an overland flow path (critical slope length) beyond which contour ridges fail. This computation is a function of the daily runoff rate, daily cover-management conditions, and land steepness.

RUSLE2 computes how profile shape(uniform, convex, concave, and complex) along the overland flow path affects erosion, deposition, and sediment yield from the overland flow path represented in a RUSLE2 computation. RUSLE2 computes the amount of deposition on concave portions of the overland flow path, how this deposition affects sediment characteristics by enriching the sediment in fine and less dense particles.

Strips of dense vegetation placed along overland flow paths can significantly reduce erosion and sediment yield. RUSLE2 computes the reduction in sediment production, the amount of deposition caused by the dense vegetation strips, and the change in sediment characteristics.

Terraces and diversions placed along an overland flow path reduce erosion by decreasing overland flow path length. RUSLE2 also computes deposition and its effect on sediment characteristics in low grade terraces assuming a uniform terrace grade. RUSLE2 does not compute erosion by flow in these channels.

RUSLE2 computes deposition in small impoundments such as small sediment basins used on construction sites and small impoundments created by parallel tile outlet terrace systems. A simple settling-type equation is used to compute deposition by sediment particle class.

The deposition computed by RUSLE2 depends on the characteristics of the sediment reaching the deposition area. Sediment characteristics at the point of detachment are computed as a function of soil texture, but deposition along the overland flow path enriches the sediment in fines and less dense particles that are deposited less readily. Consequently, less deposition is computed in dense grass strips, terrace channels, and in impoundments if upstream deposition has been computed.

RUSLE2 computes how irrigation affects erosion caused by rainfall and its associated overland flow. RUSLE2 takes into account increased yield and increased soil moisture, which increases biomass decomposition and soil erodibility, caused by the irrigation. RUSLE2 does not compute the erosion directly caused by irrigation itself.

The subsurface drainage subfactor represents how subsurface drainage reduces erosion by reducing surface runoff. This subfactor is based on how much subsurface drainage reduces a soil’s runoff potential. The runoff potential (permeability) subfactor in RUSLE2’s computation of unit-plot soil erodibility is used to adjust the soil erodibility value to account for the subsurface drainage effect.

11.4. Biomass accounting

Biomass on and in the soil has a great effect on soil erosion. The input value for production (yield) level provides the starting point for RUSLE2’s biomass accounting. RUSLE2 tracks the conversion of live standing vegetation to dead standing residue by natural and mechanical processes. RUSLE2 accounts for soil surface biomass accumulation from standing residue becoming surface residue caused by standing residue falling by natural processes and mechanical events, by litter fall, and by events that add surface biomass such as straw mulch applications. RUSLE2 estimates the biomass in litter added to the soil surface by senescence based on the decrease in canopy cover.

The RUSLE2 sources of soil biomass are live and dead roots, soil surface biomass that is buried by mechanical soil disturbance, decomposed soil surface biomass that is added to soil, and biomass injected into the soil. RUSLE2 adds the daily decrease in live root biomass to dead root biomass. Live roots decrease annually as a part of the growth cycle of perennial vegetation, and live roots become dead roots when vegetation is killed by a mechanical operation or a natural process such as frost.

RUSLE2 computes the daily decomposition loss of standing residue, surface residue, buried residue, and dead roots as a function of daily precipitation and temperature. The same decomposition coefficient value is used for all plant parts and whether the material is on the soil surface or buried in the soil. However, the decomposition coefficient for standing dead vegetation is assumed to be 30 percent of that for surface and buried material.

RUSLE2 uses a specific set of rules to transfer biomass between standing residue, surface residue, and buried residue pools. For example, live above ground biomass must be converted first to standing residue before live vegetation biomass can become surface residue. Next, standing residue must be converted to soil surface residue. Only surface residue can be buried. That is, standing residue can not be directly buried without first being converted to surface residue. A mechanical soil disturbing operation is required to bury or place residue in the soil, and a mechanical soil disturbing operation is required to resurface previously buried residue.

11.5. Cover-management descriptions

Users provide a cover-management description that RUSLE2 uses to compute how cultural practices affect erosion. A RUSLE2 cover-management description is a list of operations by date, vegetation descriptions and production levels (yields), and residue descriptions and amounts for material added to the soil surface or injected into the soil. A cover-management description is a rotation when the list of operations are repeated in a cycle with a particular duration, which is typical for cropland and permanent vegetation, or a non-rotation when each operation occurs only once over a particular duration, which is typical of construction sites.

11.6. Operation descriptions

Operations are events that affect the soil, vegetation, or residue. The user selects from several processes to describe the effects of an operation. **Begin growth** is the process that tells RUSLE2 to begin using data in a particular vegetation description on a particular date. **Add residue** is used to apply mulch. A residue description that describes the mulch characteristics is assigned in the cover-management description. **Kill vegetation** is the process used to convert live vegetation to standing residue and live roots to dead roots. It is used to describe harvest of an annual crop and to describe frost killing annual vegetation.

The **disturb soil** process describes a mechanical soil disturbance. For example, the operation description for a heavy offset disk includes a **disturb soil** process. The **disturb soil** process includes inputs for burial and resurfacing values for each of the five RUSLE2 residue types, the fraction of the standing residue that is converted to surface residue, the fraction of surface residue that is buried, and the fraction of the buried residue that is resurfaced by the operation. The **disturb soil** process includes a designation for whether the operation buries residue by inverting the soil, by mixing the residue with the soil, by a combination of mixing and inversion, or by pressing the residue into the soil. The **disturb soil** process also includes values for soil disturbance depth, surface roughness left by the operation for a standard condition, and ridge height left by the operation, the degree that the operation obliterates existing soil roughness , and fraction of the soil surface disturbed by the operation.

An operation such as straw baling may include a **remove residue** process to describe reduction in surface residue cover after a small grain harvest, for example.

An operation description can include multiple processes. The sequence of the processes is critically important. For example, having an **add residue** process before a **disturb soil** process gives a very different surface residue cover than if the **add residue** process comes after the **disturb soil** process.

11.7. Vegetation descriptions

Computing the effects of vegetation on erosion is an important RUSLE2 feature. RUSLE2 uses values for vegetation variables including temporal canopy cover, effective fall height, live above ground biomass, and root biomass to compute cover-management subfactor and runoff values. Values for these variables are entered in vegetation descriptions.

RUSLE2 does not model vegetation growth as a function of environmental conditions. Instead RUSLE2 vegetation descriptions apply in particular ecological zones. Each vegetation description is for a particular base production (yield) level. The RUSLE2 user chooses the vegetation description for the site where RUSLE2 is being applied and a appropriate yield for the site is entered in the cover-management description. RUSLE2 adjusts the base vegetation description values according to the input yield value for the site.

11.8. Residue descriptions

A residue description is assigned to each vegetation description to describe the characteristics of residue produced by the vegetation. Also, a residue description is used to describe material added to the soil surface (e.g., straw mulch) and material (e.g., sewage sludge) injected into the soil. The residue description includes a decomposition coefficient value that describes how rapidly the residue decomposes under a standard condition, the fraction of the soil surface covered by a given residue mass, and designation of residue type that denotes the fragility of the residue and how well the residue conforms to the soil surface.

11.9. Climate descriptions

Climate descriptions contain the data on long term average monthly precipitation, temperature, and erosivity values that RUSLE2 uses to compute erosion. Each climate description is for a particular location, county, or rainfall zone.

11.10. Soil descriptions

Soil descriptions contain data on soil properties that RUSLE2 uses to compute erosion and deposition. These properties include soil texture, soil erodibility, runoff potential, rock cover, and time to soil consolidation, all for the reference unit plot condition. RUSLE2 includes soil erodibility nomographs that are used to estimate soil erodibility values from values for basic soil properties.

11.11. RUSLE2 databases

The user runs RUSLE2 by making menu selections from the RUSLE2 database. Each description in the database is stored by an identifier name. In a typical RUSLE2 application, the user selects a climate description by location, soil description by soil mapping unit or some other designator, cultural practice by a cover-management description identifier, and support practices by their identifiers, all appropriate for the site specific conditions. The user enters overland path steepness and length values based on the overland flow path chosen to represent the site.

A wide array of RUSLE2 descriptions, especially for cropland, is available from the USDA-Natural Resources Conservation Service (NRCS). Information can be downloaded and imported into your working RUSLE2 database from the NRCS National RUSLE2 Database and from the database of other RUSLE2 users.

Users can adjust values stored in their working RUSLE2 database to better match site conditions. Also, users can create new database entries. New user chosen values must be consistent with values in the RUSLE2 **Core Database**. RUSLE2 was calibrated using a particular set of **core values**. User input values must be consistent with these **core values** in order to obtain good results with RUSLE2 regardless of how much a user may disagree with the **core values**. If a **core value** were to be changed, other RUSLE2 internal or input values would have to be changed as well, because RUSLE2 has been calibrated to give desired erosion estimates with the **core value**. These core values are contained in the RUSLE2 **Core Database**.

11.12. RUSLE2 validation

The equations for the subfactors were primarily calibrated using data from Agriculture Handbook 537 (Wischmeier and Smith, 1978), which is a summary of more than 10,000 plot-years of data. Additional data from the literature were used to calibrate the equations for conditions not represented by the AH537 data. Erosion values were computed with RUSLE2 for a wide range of conditions, including conditions not represented by existing research data. These values were inspected to ensure that they were consistent with the available research data and consistent with professional judgment.

Ground (surface) cover is perhaps the single most important RUSLE2 variable, at least for cropland conditions. The surface cover left by a cropping system immediately after planting in a key variable used by soil conservationists in judging the effectiveness of a particular cropping system. The adequacy of RUSLE2 for estimating surface cover was very carefully evaluated. An extensive array of literature was reviewed in this evaluation. Scientists have reported differences in RUSLE2 estimates with those made by other comparable erosion models. When RUSLE2 is fitted to the same data used to fit other methods, RUSLE2's estimates of surface cover are almost the same as those estimated by other methods for long term average conditions. The differences were primarily caused by variability in residue data and by differences in techniques used to measure residue mass as it decomposes.

11.13. List of symbols

A = average annual erosion (mass/area·year)

b = coefficient for effectiveness of ground cover for reducing erosion (percent^{-1})

c_g = the subfactor for ground cover (dimensionless)

c_i = cover-management factor for the *ith* period (dimensionless)

C = average annual cover-management factor (dimensionless)

D_p = deposition rate (mass/area·time)

f_g = ground cover (percent)

f_i = factor value for the *ith* time period

F = average annual factor

g =sediment load (mass/unit overflow width·time)

I = the number of sub-periods in the computation period for the management description used to represent a site's land use conditions

I_c = the number of periods in the N_c years used to determine an average annual cover-management factor value

I_k = the number of periods in the N_k years used to determine an average annual soil erodibility factor value

I_l = the number of periods in the N_l years used to determine an average annual slope length factor value

I_p = the number of periods in the N_p years used to determine an average annual support practice factor value

I_s = the number of periods in the N_s years used to determine an average annual slope steepness factor value,

k_i = soil erodibility factor for the *ith* period (mass/erosivity unit)

K = average annual soil erodibility factor (mass/erosivity unit)

l_i = slope length factor for the *ith* period (dimensionless)

l_x = slope length factor used to compute erosion at any location x along an overland flow path (dimensionless)

L = average annual slope length factor (dimensionless)

m = a slope length factor exponent

N = number of years in the computation period

N_c = number of years used to determine an average annual cover-management factor value

N_k = number of years used to determine an average annual soil erodibility factor value

N_l = number of years used to determine an average annual slope length factor value

N_s = number of years used to determine an average annual slope steepness factor value

p_i = support practice factor for the *ith* period (dimensionless)

P = average annual support practice factor (dimensionless)

q = surface runoff rate (volume/unit overland flow width·time)

r_i = erosivity factor for the *ith* period (erosivity unit/area·year)

R = average annual erosivity factor (erosivity unit/area·year)

s_i = slope steepness factor for the *ith* period (dimensionless)

S = average annual slope steepness factor (dimensionless)

T_c = surface runoff's sediment transport capacity (mass/unit overflow width·time)

V_f = the sediment's fall velocity (length/time)

x = distance along overland flow path (length)

α = an empirically determined deposition coefficient (dimensionless)

ϕ_i = the fraction of the annual erosivity that occurs during the *ith* period

λ_u = unit plot length (72.6 ft, 22.1 m)

Indices

i - time period (days)

12. REFERENCES

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