

Environmental Water Quality BAE 452/552

Session 14
Erosion and Sediment Transport, Loading
Calculations

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Estimation of Sediment Flux

Methods:

- Stream-flow sampling method using rating curve of sediment and flow (log scale)
- Reservoir sedimentation method (trap)
- For larger sediment fractions: bedload function methods which require particle-size, channel gradient, cross-sections, flow-duration curves

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Estimation of Sediment Flux

Methods:

- Sediment delivery method: estimate watershed upland erosion factored down to account for loss of sedimentation during overland and channel transport
- Empirical equations relating sediment yield to watershed hydrologic or morphologic characteristics
- Watershed sediment load models

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Sediment Load Models

- WEPP (Water Erosion Prediction Project)
- CREAMS
- GWLF
- AGNPS
- ANSWERS

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Estimating Upland Erosion

- Erosion and Sediment
- Variables influencing upland erosion
- The process and associated terminology
- Revised Universal Soil Loss Equation (RUSLE)

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Erosion and Sediment

- Erosion is the removal of soil particles by wind and water
- Sediment is the particulate matter which is carried and eventually deposited by wind and water
- We are concerned with water pollution, and the prediction of sediment loads or yields in stream flow

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Erosion and Sediment

- Upstream erosion of soil surfaces and stream channels is source of streamflow sediment yield
- Watershed sediment yield is substantially less since much of the transported sediment is deposited or filtered from the water

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Erosion and Sediment

- Erosion of land surface by sheet (interrill) and rill erosion is the major source of solid-phase pollutants in surface waters
- We will not consider channel erosion specifically in this class

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Variables Influencing Upland Erosion

- Climate (rainfall, snowmelt, temperature)
- Soil properties (texture, permeability, erodibility)
- Vegetation (dissipation energy)
- Topography (slope, path length)
- Human activities (ag land use, construction)
- Frozen soils

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Erosion Process

Three components:

- Detachment (rainfall splash, water erosivity)
- Transport (stream power)
- Deposition (reduced transport capacity)

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Erosion Terminology

- Interrill (sheet) erosion: raindrop impact on soil, no slope effect
- Rill erosion: flow is concentrated in microrelief channels with sufficient depth and slope to cause incision (random, function of slope steepness and length, and soil cohesion); detachment from shear forces

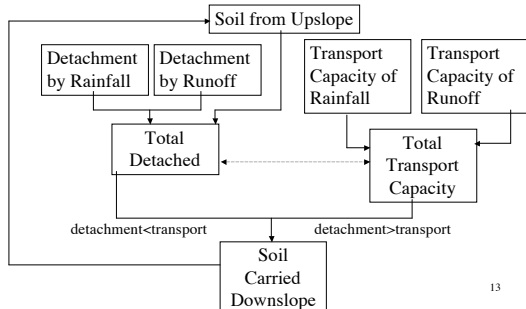
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Erosion Terminology

- Gully erosion: macrorelief channels (re-) occurring in the same location; ephemeral and classic
- Channel erosion: drainage network of watershed where sediment may be stored temporarily and eroded during flow events

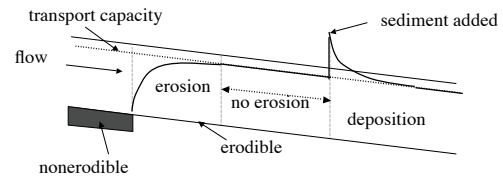
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Detachment, Transport, Deposition



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Transport Capacity



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Revised Universal Soil Loss Equation (RUSLE)

- RUSLE is an index method having factors that represent how climate, soil, topography, and land use affect rill and interrill soil erosion caused by raindrop impact and surface runoff.

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RUSLE

- <http://www.sedlab.olemiss.edu/rusle/>
- Select Documentation for access to Handbook 703
- Select Download RUSLE if you want to check out the RUSLE software

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RUSLE

- $X = R K L S C P$
where:
- X = average annual soil loss (tons ac⁻¹)
- P = rainfall-erosivity factor
- K = soil erodibility factor
- L = slope length factor
- S = slope steepness factor
- C = cover-management factor
- P = supporting practices factor

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Soil Loss Conversions

- If Soil Loss X is determined in tons ac⁻¹ multiply by 2.24 to obtain X in metric tons ha⁻¹
- If Soil Loss X is determined using metric R factor, multiply by 1.29 to obtain X in metric tons ha⁻¹
- 1 ton = 2000 lbs
- 1 metric ton = 1000 kg = 2205 lbs
- 1 ha = 2.47 acres

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Original RUSLE Plots

The product RK in RUSLE is an estimate of soil loss from unit plot conditions. These two factors have dimensions and units, whereas the other RUSLE factor are dimensionless relative to unit plot conditions. A unit plot is 72.6 ft long on a 9 percent steepness, is maintained in continuous fallow, is tilled up and down hill according to a particular sequence of operations much like those used in clean-tilled row crops, and is cultivated periodically to break the crust that forms from rainfall and to control weeds. The soil surface is left relatively smooth and free of ridges after the last tillage operation in the sequence.

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R Factor

The R factor represents the erosivity of the climate at a particular location. An average annual value of R is determined from historical weather records and is the average annual sum of the erosivity of individual storms. Erosivity range from less than 8 (US customary units) in the western US to about 700 for New Orleans.

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R Factor

Rainfall erosivity (EI):

- Rainfall energy per inch x rainfall intensity
- $EI = 916 + 331 \log_{10}(i)$ for $i \leq 3$ in hr^{-1}
- $EI = 1074$ for $i > 3$ in hr^{-1}
- EI unit: ft-tons/acre-in, i = intensity (in hr^{-1})
- EI (metric) = 1.735 EI (english)
- EI_{30} = EI using maximum 30-min intensity

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R Factor

- Then:
$$R = \frac{\sum_{i=1}^j (EI_{30})_i}{N}$$
- where
- $(EI_{30})_i = EI_{30}$ for storm i
- j = number of storms in an N year period

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R Factor (NWRR)

- $R_{eq} = -129.0 + 12.61 P$
- $R_{eq} = 1.602 e^{(0.2418P)}$ for $7.5 < P < 15$
- where P is annual precipitation in inches
- Isoerodent maps were created for most areas in the United States

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K Factor

The K factor is an empirical measure of soil erodibility as affected by intrinsic soil properties. Erosion measurements based on unit plot conditions are used to experimentally determine values for K.

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K Factor

The factor K is a measure of soil erodibility under this standard condition. Land use, such as incorporation of organic material into the soil, affects soil erodibility, but such effects are considered in the C factor. The K factor is influenced by the detachability of the soil, infiltration and runoff, and the transportability of the sediment eroded from the soil.

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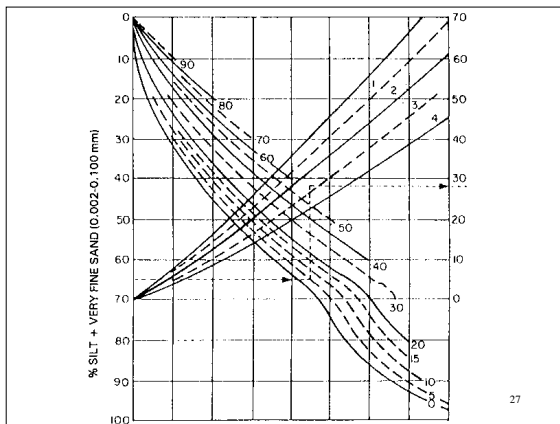
K Factor

- Unit: soil loss per unit rainfall erosion index (ton acre hr (hundreds of acre ft-tonf in)⁻¹)

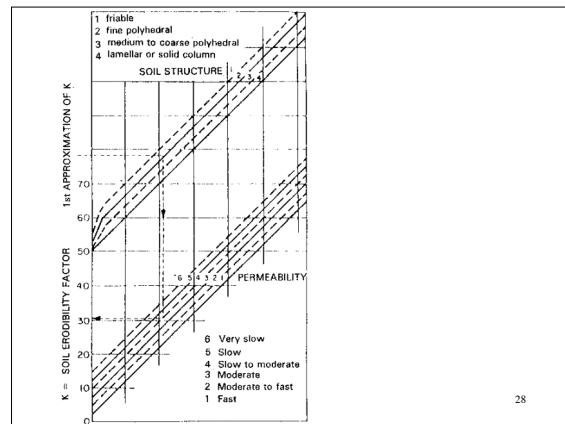
- Experimentally:
$$K = \frac{\text{measured erosion}}{\sum EI_{30}}$$

- Tabulated in Soil Survey
- Use of nomographs makes selection easy

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LS Factor

The L and S factors jointly represent the effect of slope length, steepness, and shape on sediment production. Rill erosion is primarily caused by surface runoff and increases in a downslope direction because runoff increases in a downslope direction. Interrill erosion is caused primarily by raindrop impact and is uniform along a slope. Therefore, the L factor is greater for those conditions where rill erosion tends to be greater than interrill erosion.

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LS Factor

- If λ is length of horizontal slope, and θ is the slope angle (in degrees)

- S is slope steepness factor for $\lambda > 15$ ft:

$$S = 10.8 \sin \theta + 0.03 \text{ for } \sin \theta < 0.09$$

$$S = 16.8 \sin \theta - 0.50 \text{ for } \sin \theta \geq 0.09$$

- For $\lambda < 15$ ft:

$$S = 3.0(\sin \theta)^{0.8} + 0.56 \text{ for } \sin \theta \geq 0.09$$

- When recently tilled soil is thawing

$$S = (\sin(\theta)/0.0896)^{0.6} \text{ for } \sin \theta \geq 0.09$$

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LS Factor

- $L = [\lambda/72.6]^m$
- where m is variable slope length exponent
- $m = \beta/(1 + \beta)$
- where β is ratio of rill to interrill erosion

$$\beta = \frac{11.16 \sin \theta}{3.0(\sin \theta)^{0.8} + 0.56}$$

- for PNW: runoff during thawing $\beta=0.5$

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LS Factor

- When implementing on GIS:

$$L = (m + 1) \left(\frac{A_r}{22.1} \right)^m$$

where

- A_r is upslope contributing area (m^2)
- 22.1 is standard plot length in meters
- For an example using GIS:
<http://www.blm.gov/nstc/ecosysmod/rusle.html>

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C Factor

The C factor for the effects of cover-management, along with the P factor, is one of the most important factors in RUSLE because it represents the effect of land use on erosion. It is the single factor most easily changed and is the factor most often considered in developing a conservation plan. For example, the C factor describes the effects of differences between vegetation communities, tillage systems, and addition of mulches.

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C Factor

- Effects of above ground effects (rainfall interception)
- Surface effects (raindrop impact and shearing forces)
- Below surface effects (tillage related)
- $C=1$ for continuous fallow, tilled up and down slope
- Use tabulated values for other conditions ($C < 1$)
- For ag fields, crop rotation is needed

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C Factor Example Values

Vegetation	Tillage Practice			
	Fall Conv.	Spring Conv.	Spring Cons.	NoTill
C	0.40	0.36	0.27	0.10
C S	0.42	0.37	0.24	0.10
C S O M M	0.13	0.12	0.082	0.052
Pasture (poor/good)				0.04/0.01

*C = corn, S = soybean, O = oats, M = meadow

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P Factor

The supporting practice P factor describes the effects of practices such as contouring, strip cropping, concave slopes, terraces, sediment basins, grass hedges, silt fences, straw bales, and subsurface drainage. These practices are applied to support the basic cultural practices used to control erosion, such as vegetation, management system, and mulch additions that are represented by the C factor.

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P Factor

- Ratio of soil loss from any conservation support practice to that of up and down slope tillage
- Redirecting runoff or reducing transport capacity
- P=1 for continuous fallow, tilled up and down slope
- Use tabulated values for other conditions (P < 1)

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P Factor Example Values

Contour Farming:

Land slope %	Max. slope length (ft)*	P factor
1 - 2	400	0.6
3 - 5	300	0.5
6 - 8	200	0.5
9 - 12	120	0.6
13 - 16	80	0.7
17 - 20	60	0.8

* max slope length for strip cropping twice contouring

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Watershed Sediment Yield

Annual yields due to surface erosion:

$$Y = \text{SDR} \sum_k A_k X_k$$

where

- Y is annual sediment yield (tons/yr)
- X_k = erosion from source k by RUSLE
- A_k = area of source area k (ha or acre)
- SDR = watershed sediment delivery ratio

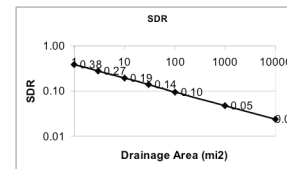
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Sediment Delivery Ratio

- Many relationships exist. Presented here:

$$\text{SDR} = 0.38 A_t^{-0.3}$$

where A_t = watershed area (mi²)



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Dissolved Waste Loads (in runoff)

- Dissolved Pollutant Waste Load (LD):

$$\text{LD} = 0.1 C_d Q$$

where

LD is dissolved chemical load in runoff (kg/ha)

C_d is concentration of dissolved chemical in runoff (mg/L)

Q is runoff from source area (cm)

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Solid Phase Waste Loads (in runoff)

- Solid Phase Pollutant Waste Load (LS):

$$\text{LS} = 0.001 C_{\text{sed}} X$$

where

LS is solid-phase chemical load in runoff (kg/ha)

C_{sed} is concentration of chemical in eroded soil (sediment) (mg/kg)

X = soil loss (t/ha)

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