Day 5: Erosion Mechanisms

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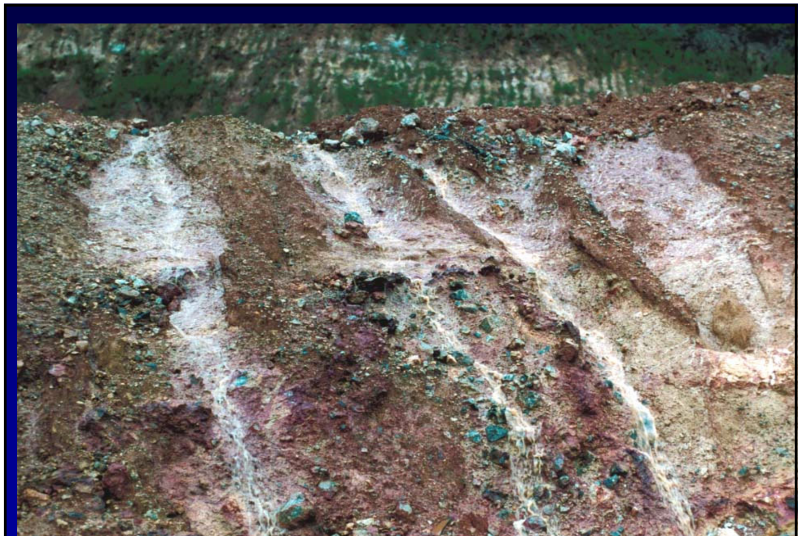

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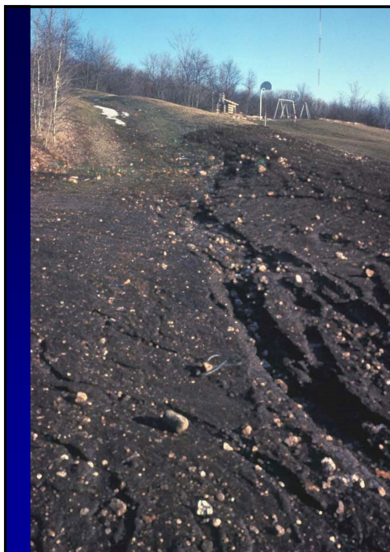

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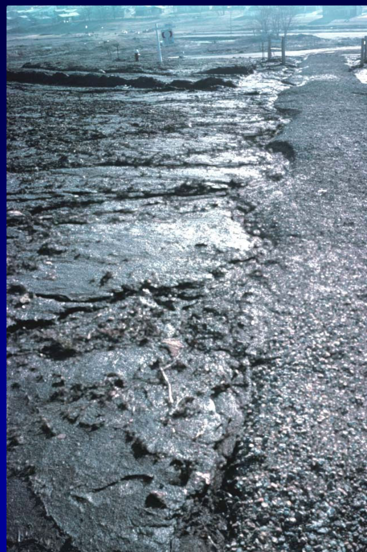

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Soil Mass and Volume Conversions

Soil Texture Class	Conversion Factor to Convert tons to cubic yards
Sands, loamy sands, sand loam	0.70
Sand clay loam, silt loams, loams, and silty clay	0.87
Clay loams, sandy clays, and silty clays	1.02

$$\frac{100 tons}{acre} \times 0.87 = \frac{87 yd^3}{acre}$$

$$\frac{87 yd^3}{acre} \times \frac{acre}{43{,}560 ft^2} \times \frac{27 ft^3}{yd^3} \times \frac{12 in}{ft} = 0.65 inches$$

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Different Approaches for Calculating Erosion Losses from Construction Sites

- Conventional approach is to calculate the annual losses using tools such as the Universal Soil Loss Equation (and derivatives). This does consider the changing site characteristics during the year due to seasonal rain changes and continued modifications on the site during the construction period.
- Event-based can be more useful when designing erosion control practices as they can consider these changing site and rain characteristics.

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The Revised Universal Soil Loss Equation (RUSLE)

(Renard, *et al.* 1987)

- The Revised Universal Soil Loss Equation (RUSLE) is based on many thousands of test plot observations from throughout the US.
- RUSLE was developed in 1987 by the NRCS, and is based on the earlier USLE published by the SCS in 1978.
- Typical uses of RUSLE for construction sites include:
  - predicting the benefits of different management practices,
  - predicting the amounts of sediment that may be trapped in sediment ponds, and
  - determining maintenance schedules for different controls.

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Revised Universal Soil Loss Equation

RUSLE predicts rill and interrill erosion (not channel scour):

$$A = (R)(K)(LS)(C)(P)$$

Where:

A is the total soil loss, in tons per acre for the time period
R is the rain energy factor for the time period
K is the soil erodibility factor
LS is the length-slope factor
C is the degree of soil cover factor
P is the conservation practices factor (for agricultural tillage and crop rotation operations, not generally applicable for construction site calculations)

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Wischmeier (1959) found that the best predictor of R was:

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right]$$

Where:
-E is the total storm kinetic energy in hundreds of ft-tons per acre,
- I30 is the maximum 30-minute rainfall intensity,
- j is the counter for each year used to produce the average,
- k is the counter for the number of storms in a year,
- m is the number of storms n each year, and
- n is the number of years used to obtain the average R.

Wischmeier also found that the rain kinetic energy (E) could be predicted by: E = 916 + (331)log10 (I)
where I is the average rain intensity (in/hr), and the units for E are ft-tons/acre per inch or rain

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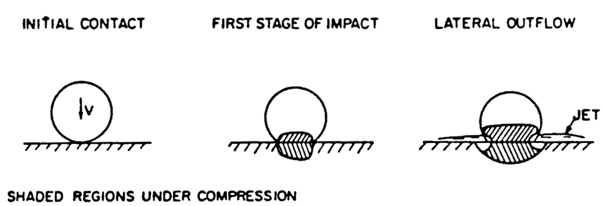
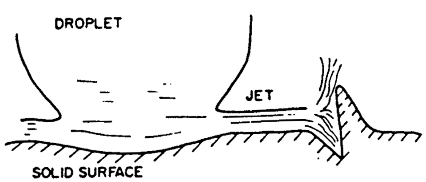
Raindrop Impact with Ground Surface



Impact of a liquid drop on an elastic surface.



Interaction between lateral jets and surface flaws.

Springer 1976

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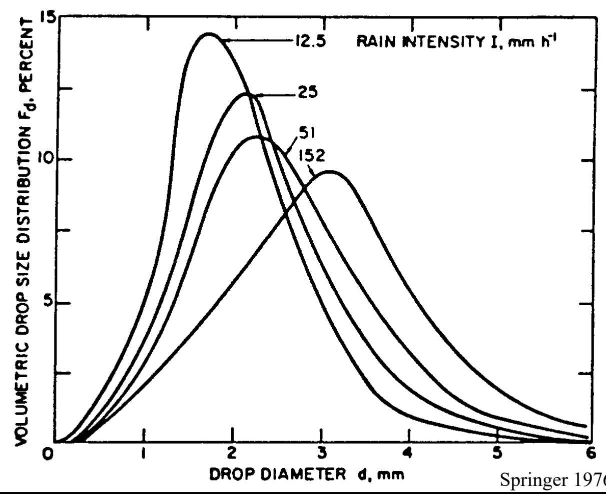
Typical Rain Drop Size Distribution



Springer 1976

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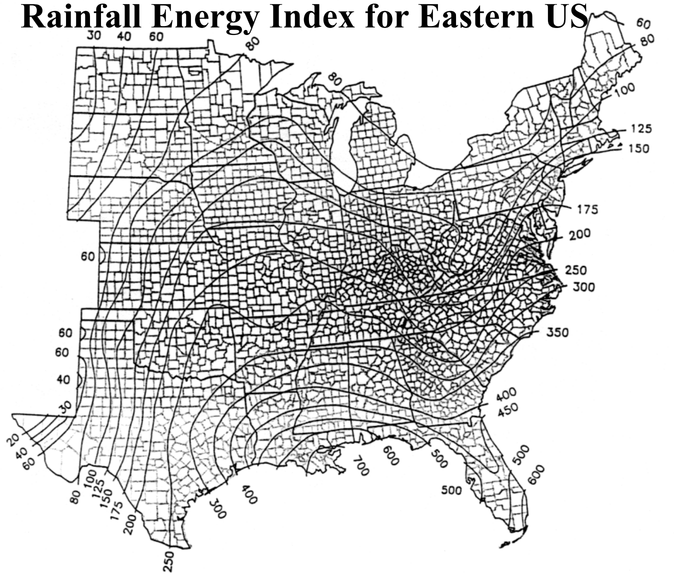
Rainfall Energy Index for Eastern US



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Single Storm Rain Energies (probabilities of single storm values in any one year and % of annual R for single storm)

	100%	50%	5%
Birmingham	54 (15%)	77 (22%)	170 (48%)
Mobile	97 (14%)	122 (21%)	194 (29%)
Montgomery	62 (17%)	86 (24%)	172 (48%)

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Percentage of Annual Rainfall Erosivity Index for Different Time Periods in Alabama

	108 (northeast AL)	107 (central and south AL)
January 1 to 15	3 %	3 %
April 1 to 15	5	4
July 1 to 15	8	9
October 1 to 15	2	3

Not likely to meet the "R of 5" exclusion provision of NPDES in AL (a very short 2 week construction period would likely have an R of at least 10 and as high as 70).

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Percentage of Annual Erosion Yield During Event	Estimated Erosion Yield During Single Event	Probability of Event Occurring at Least Once per: 7 days	14 days	30 days
7%	3,500	3%	6%	12%
5	3,000	8	16	31
3	1,800	17	31	55
2	1,200	29	50	77
1	600	45	70	92
Probable number of events per time period (out of 96):		2	4	8
Probable total erosion yield per time period (lb/acre):		1,200	2,300	5,000

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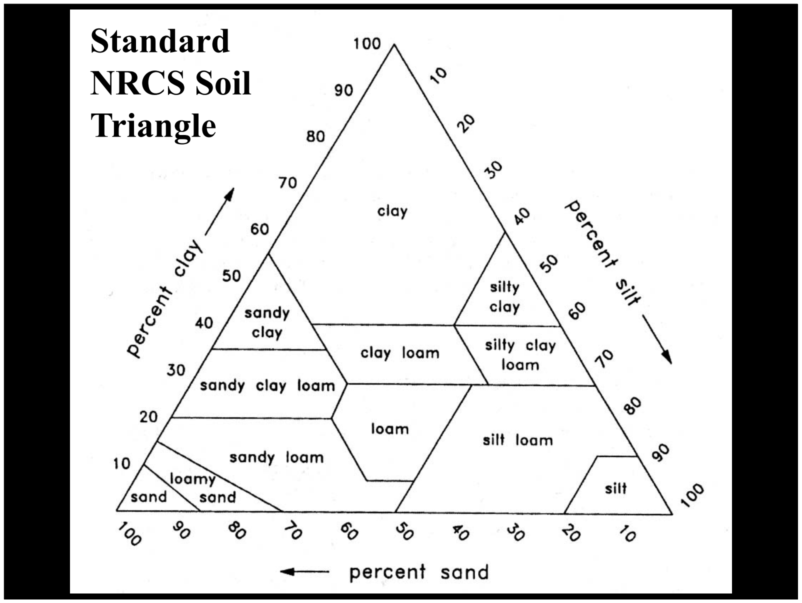

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USDA Particle Size Ranges for Different Soil Texture Categories

	Size Range		
Soil Particle	micrometers	millimeters	inches
Cobble	150,000 to 300,000 µm	150 to 300 mm	6 to 12 in.
Gravel	2,000 to 150,000	2 to 150	0.08 to 6
Sand[1]	50 to 2,000	0.05 to 2.00	0.002 to 0.08
Silt	2 to 50	0.002 to 0.05	0.00008 to 0.002
Clay	<2	<0.002	<0.00008

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Testing Characteristics of Suspended Solids for Erosion Control Design

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Erodibility Factors (k) for Typical Soils (most common soils in Jefferson County)

Soil	Surface k values	Subsurface k values
Birmingham	0 to 5 inches: 0.24	5 to 29 inches: 0.28
Bodine	0 to 72 inches: 0.28	
Fullerton	0 to 6 inches: 0.28	6 to 35 inches: 0.24
Montevallo	0 to 6 inches: 0.37	6 to 16 inches: 0.32
Nauvoo	0 to 12 inches: 0.28	12 to 46 inches: 0.32
Palmerdale	0 to 60 inches: 0.24	
State	0 to 40 inches: 0.28	40 to 60 inches: 0.17
Sullivan	0 to 66 inches: 0.32	
Townley	0 to 4 inches: 0.37	
Urban Land	No specific information	

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General K values for soils having different textures (Dion 2002):

Sandy, fine sand, loamy sand:	0.10
Loamy sand, loamy fine sand, sandy loam, loamy, silty loam:	0.15
Loamy, silty loam, sandy clay loam, fine sandy loam:	0.24
Silty clay loam, silty clay, clay, clay loam, loamy:	0.28

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Length-Slope (LS) Factor

- The erosion of soil from a slope increases as the slope increases and lengthens.
- RUSLE contains a table giving the LS factors for different slopes and slope lengths.
- The slope length is the distance from the ridge to the point where deposition starts to occur near the bottom of the slope.

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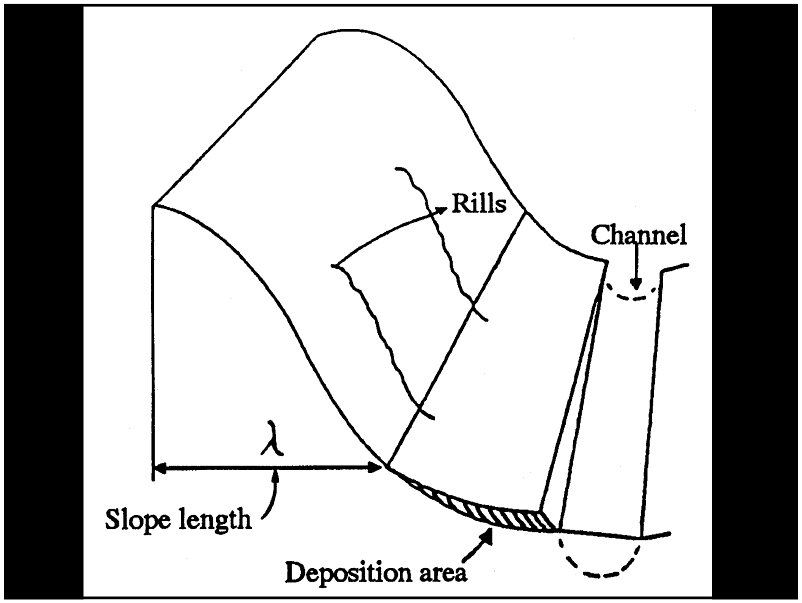

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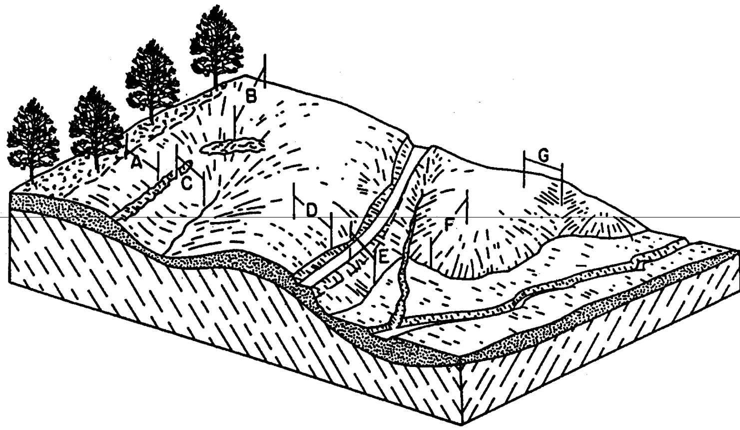

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Length-Slope Factor (cont.)

- A base condition of 1 corresponds to a slope of 9% and a length of 73 ft.
- If the length is 300 ft, or less, the LS factor is less than 0.1 for all slopes of 0.5%, or less.
- Roadway cuts of 1:2 (50% slopes) would have LS factors of >1 for all slope lengths of 6 ft, or longer.
- More than 80% of Jefferson County land has slopes greater than 8%.

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Selected LS Factors for RUSLE

	<3 ft	9 ft	50 ft	300 ft	1,000 ft
0.2%	0.05	0.05	0.05	0.06	0.06
2%	0.13	0.13	0.21	0.43	0.69
6%	0.26	0.26	0.54	1.60	3.30
20%	0.41	0.67	2.10	8.23	20.57
50%	0.58	1.31	5.16	22.57	60.84

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Comparing Different Slope Design Options

Original Slope			Alternative Terrace (1 mid-slope bench)			
Slope	Length	LS factor	New slope	Length (and terrace width)	Approx. new LS factor	Estimated erosion reduction
0.5%	300 ft.	0.10	0.54%	150 (10) ft.	0.095	5%
3.0	300	0.69	3.2	150 (10)	0.51	26
10	300	3.09	10.7	150 (10)	1.9	39
25	300	10.81	26.8	150 (10)	6.0	44
50	300	22.57	53.6	150 (10)	10.6	53

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Terracing to Reduce Slope Length (with slight increases in slope)

Cover Management Factor (C)

- Site preparations that remove all vegetation and root zone material and leaves the soil completely without protection corresponds to the base condition of C = 1.
- Vegetation residue can be an effective erosion control.
- These can be applied as mechanical mulches (such as chopped straw, wood chips, and even crushed stone).
- The lighter mulches needed to be secured with chemical tacking agents or nettings on steep slopes or in areas subject to high winds.
- Erosion control blankets currently available can be used in the most extreme cases, but are much more expensive.
- It is possible to calculate the shear stress for different conditions and select the most cost-effective product.

Example Cover Management C Factors (and % control) for Different Materials

Material	Mulch rate (tons/acre)	Land slope (%)	C factor (% control)	Maximum slope length (ft)
Anchored straw	1.0	1 to 5	0.20 (80%)	200
Anchored straw	2.0	11 to 15	0.07 (93%)	150
Crushed stone	135	34 to 50	0.05 (95%)	75
Wood chips	7	16 to 20	0.08 (92%)	50
Wood chips	25	34 to 50	0.02 (98%)	75

Cover Factor C Values for Different Growth Periods for Planted Cover Crops for Erosion Control at Construction Sites

	SB (seedbed preparation)	Period 1 (establish-ment)	Period 2 (develop-ment)	Period 3a (matur-ing crop)	Period 3b (matur-ing crop)	Period 3c (matur-ing crop)
Crop canopy	0 to 10%	10 to 50%	50 to 75%	75 to 80%	75 to 90%	75 to 96%
Seeding on topsoil, without a mulch	0.79	0.62	0.42	0.17	0.11	0.06
Seeding on an area where residual effects of prior vegetation are no longer significant	1.0	0.75	0.50	0.17	0.11	0.06

Cover Factor C for Established Plants (percent of surface covered by residue)

	Percent cover	Plant type	0 %	40	80	95+
Grass, grasslike plants, or decaying compacted plant litter.	0	Grass	0.45	0.10	0.013	0.003
Tall weeds or short brush with average drop height of ≥20 inches	25	Grass	0.36	0.09	0.013	0.003
		Weeds	0.36	0.13	0.041	0.011
	50	Grass	0.26	0.07	0.012	0.003
		Weeds	0.26	0.11	0.039	0.011
	75	Grass	0.17	0.06	0.011	0.003
		Weeds	0.17	0.09	0.038	0.011

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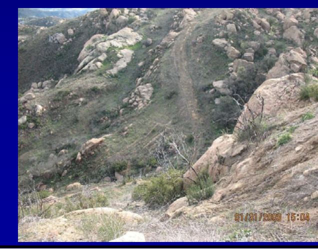
Computerized GIS Application of RUSLE for Rugged Site

- Site area = 62 acres (11% is exposed rock)
- R = 50 (calculated for typical year)
- Soil K values from SSURGO (Soil Survey Geographic Database), NRCS
- LS values calculated from county 10 m LIDAR



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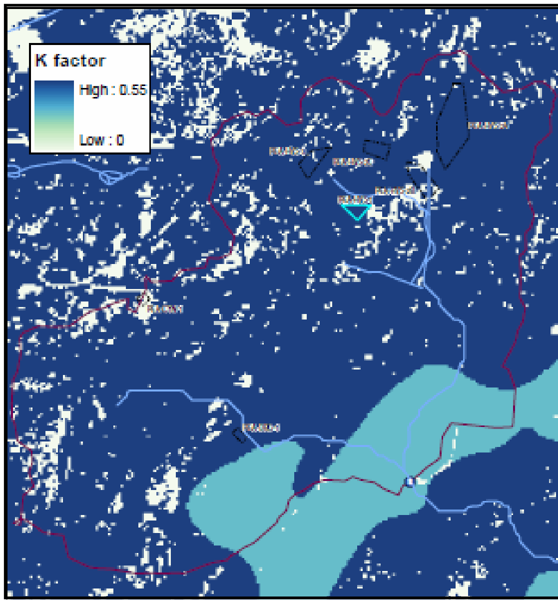

GIS map of soil K factors for site.

K varied from 0.08 to 0.55; site mean of 0.48

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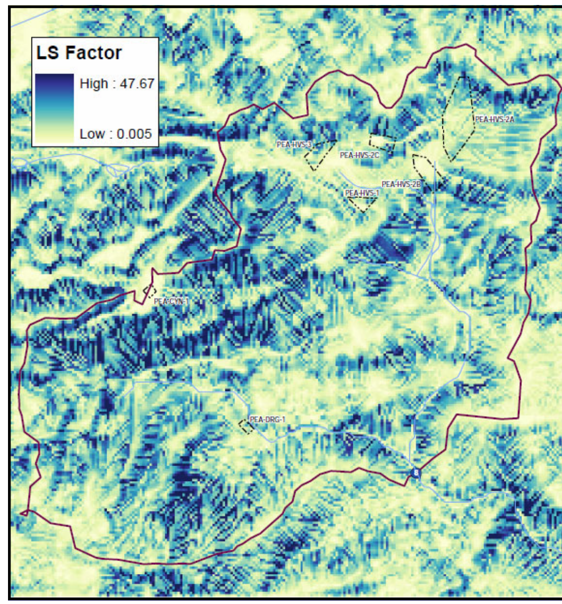

GIS map showing calculated LS factors for site.

Site mean LS factor of 7.2

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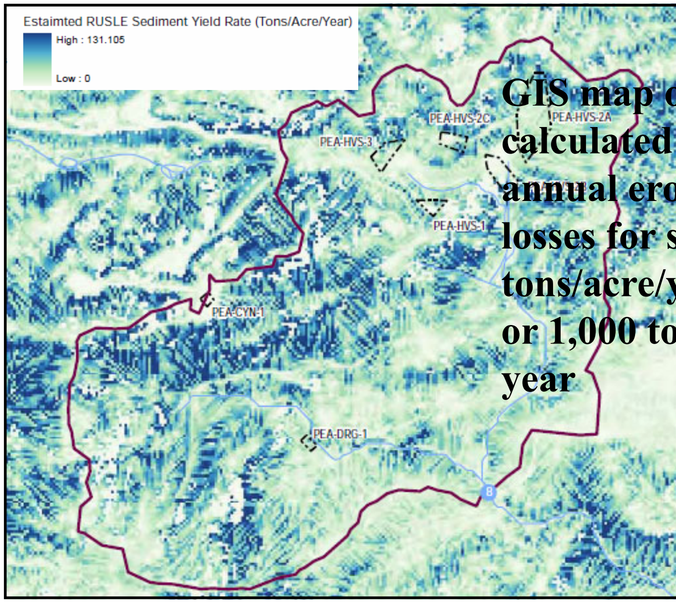

GIS map of calculated annual erosion losses for site. 17 tons/acre/year, or 1,000 tons per year

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Example RUSLE Application

- Start and finish dates for each construction phase is needed (to calculate R for the period).
- The surface soil K values are needed for each area.
- The LS factors need to be calculated for each area, based on typical slopes and lengths
- The mulches or covers are needed. In this example these are:
  - Erosion control mats for road cuts
  - Planted vegetation or tacked mulches on embankment
  - Gravel pads for parking and road surfaces

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The basic time phases of interest for erosion evaluation and control may include the following:

1) install downslope sediment controls (filter fencing and sediment ponds)

2) install upslope diversions and protect on-site channels that will remain (diversion berms and swales, channel lining, establish buffers, and filter fencing)

3) first area clearing and grubbing (minimize area exposed and time to complete phase)

4) first area final contouring (stabilize exposed areas before moving on to next area)

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5) repeat above 2 steps for all other areas, dividing the whole planned disturbed construction site into areas as small as possible (some states restrict the area disturbed to be < 5 acres at any one time)

6) establish roadways and parking areas and install utilities (leaving road bed base, or preliminary pavement, protect inlets, etc.)

7) building erection (provide adequate storage for materials and for construction vehicle parking, practice good housekeeping, etc.)

8) final landscaping (remove temporary controls, replace with permanent stormwater facilities, irrigate vegetation until established)

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Example Simple Application of RUSLE at Construction Site

	Area (acres)	R (Mar 5 to Jul 31)	K	LS	C	Calc soil loss (tons/period)
Undisturbed area	1.51	196	0.15	0.30	0.001	0.01
Road cut	0.54	196	0.28	2.67	0.02	1.58
Embankment	0.84	196	0.28	0.40	0.55	10.14
Parking area	10.5	196	0.28	0.06	0.02	0.69
Road segment	0.95	196	0.28	0.22	0.02	0.23
Total	14.34					12.65

Summary of RUSLE Application

- In this example application, the March 5 to July 31 construction phase for these stabilized areas would produce only about 13 tons of sediment. If there were no ground cover controls, the expected losses would be about 150 tons, for a calculated level of control of about 90%.
- Other construction periods may be less well controlled due to on-going grading operations.
- RUSLE can be used to estimate the level of performance expected for different alternatives, and to calculate the amount of sediment that may be expected to leave the site.

Event-Based Erosion Control Calculations

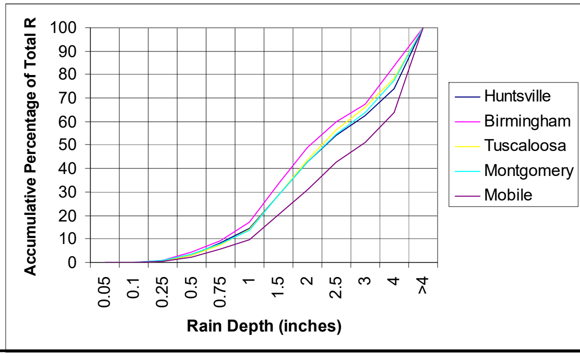
- The statistical-based empirical models used in China that are based on the USLE/RUSLE were found to have limited success in soil loss predictions associated with the steep slopes associated with road construction.
- These problems were thought due to model conceptualization issues and arbitrary selection of model parameters.
- Zhang, *et al.* (2015) concluded that the use of the USLE/RUSLE for construction sites needs further investigations due to the complicated and varied characteristics of soil erosion processes on construction sites, compared to the uniform conditions used to develop the USLE/RUSLE.

Rainfall Energy Calculations for Individual Events

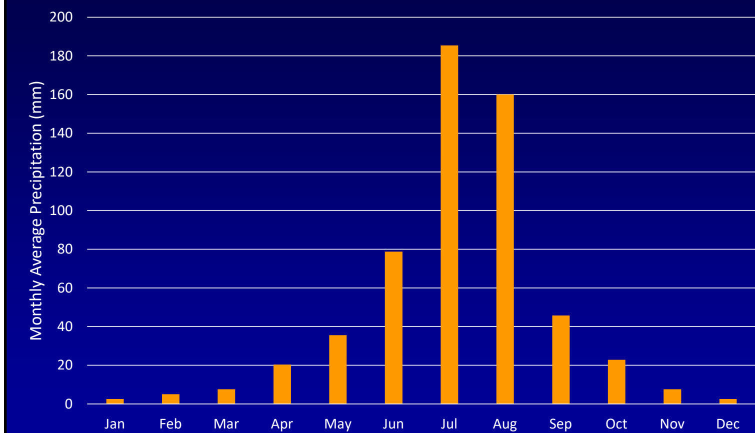
Thronson (1973) presented the following equation to estimate the erosion potential for individual rains:

$$R = \frac{19.25(P)^{2.2}}{(dur)^{0.4672}}$$

P = rain depth in inches and,
dur = rain duration in hours

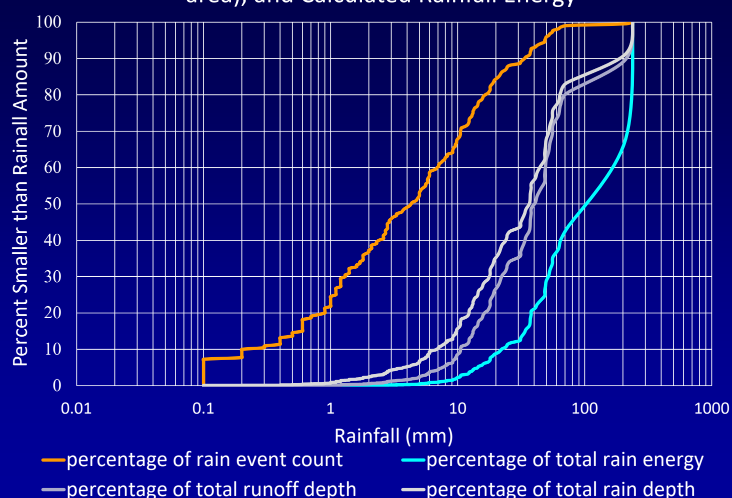


Long-Term Average Beijing Rainfall (China Meteorological Bureau, years not shown)



https://www.weather-atlas.com/en/china/beijing-climate

Beijing 2012 - 2016 Daily Rains, Runoff (high density urban area), and Calculated Rainfall Energy

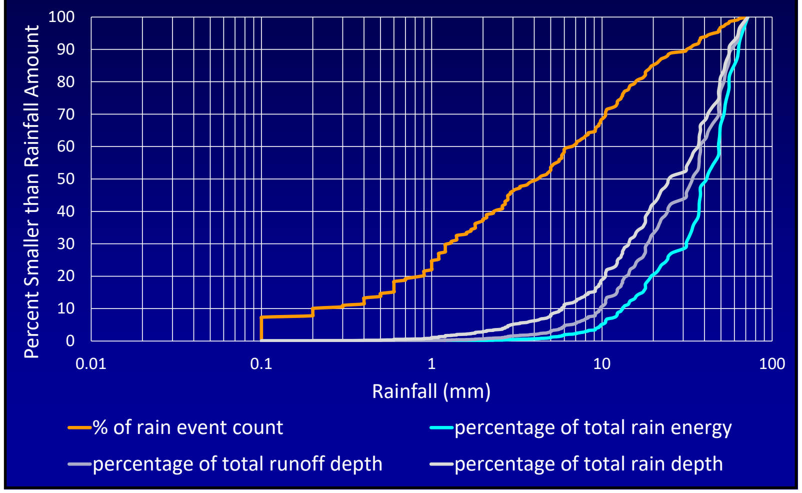


Importance of Large Rains for Rainfall Energy Distributions, Beijing 2012 – 2016 Rains

Precipitation range (mm)	percentage of rain event count	percentage of total rain depth	percentage of total runoff depth	percentage of total rain energy
1 to 10.2	45.0	15.2	8.7	2.3
10.2 to 25.9	20.0	26.5	25.4	9.5
25.9 to 49.7	7.7	25.2	27.9	17.0
49.7 to 72	3.2	15.6	18.3	14.4
72 to 239.6	0.9	16.7	19.6	56.9

71% of the total rain energy associated with 4% of the rains (>50 mm)
57% of the total rain energy associated with <1% of the rains (>70 mm)
Rains >50 mm almost all occurred in July.
Most rains occur in July and August.

Beijing 2012 - 2016 Daily Rains, Runoff (high density urban area) and Calculated Rainfall Energy (w/o 207 and 240 mm large events)



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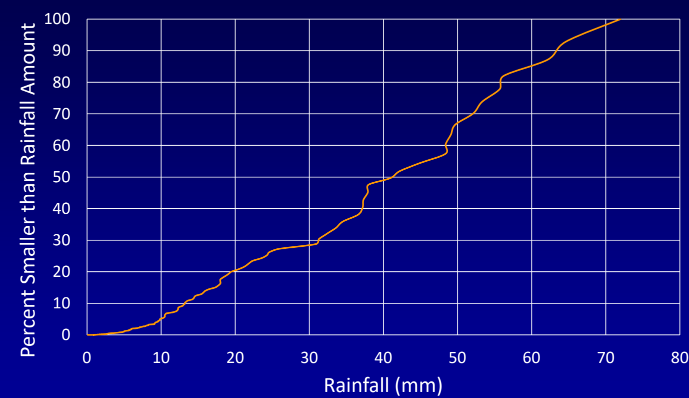
Estimated Accumulative Rain Energy Beijing (2012 - 2016 w/o 207 and 240 mm large events)



Interestingly, without log transformations, rainfall amount is almost directly related to accumulative energy (larger numbers of smaller rains compensate for smaller per rain energy), when remove the two unusually large rains.

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Importance of Large Rains for Rainfall Energy Distributions, Beijing 2012 – 2016 Rains (but without 207 and 240 mm large, rare, events)

Precipitation range (mm)	percentage of rain event count	percentage of total rain depth	percentage of total runoff depth	percentage of total rain energy
1 to 10.2	45.4	18.2	10.9	5.3
10.2 to 25.9	20.2	31.8	31.6	21.9
25.9 to 49.7	7.8	30.3	34.7	39.4
49.7 to 72	3.2	18.7	22.7	33.4

73% of the total rain energy associated with 11% of the rains (>25 mm)
33% of the total rain energy associated with 3.2% of the rains (>50 mm)
Rains >50 mm almost all occurred in July (about once per year).
Most rains occur in July and August.

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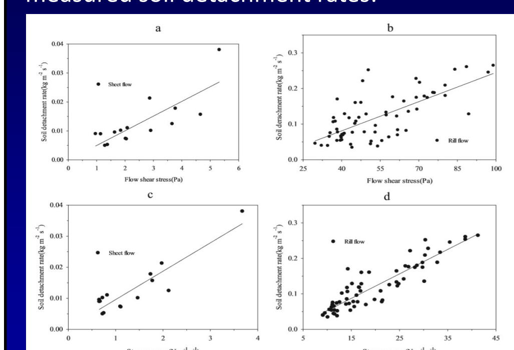
Zhang, *et al.* (2015) conducted pilot-scale tests on steep plots (73%) that are common in China at roadway construction projects to investigate erosion mechanisms. Shear stress and stream power of the sheetflow and rill flow had the best relationships with the measured soil detachment rates:



Tests only for one slope and soil type but for multiple rains. Therefore may not be transferrable to other site conditions, but does show strong relationships with these parameters.

Shear stress:

ρgS

Where ρ = density of water

g = acceleration due to gravity

S = energy gradient

Stream power:

Shear stress * water velocity

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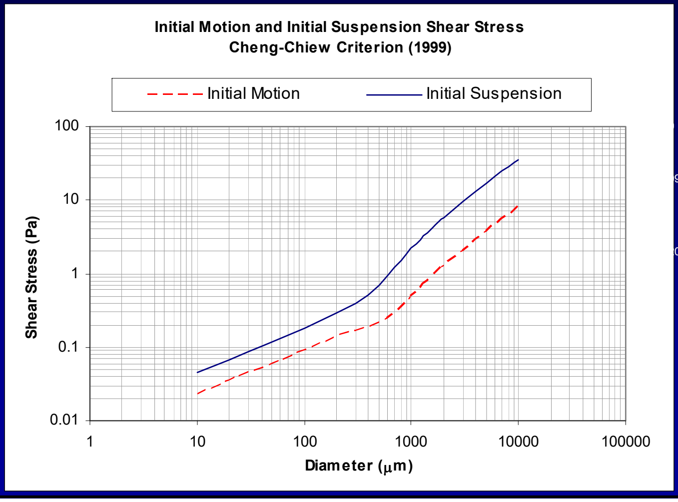
Conventional approach to calculate initial motion (detachment and rill transport) and suspension (sheetflow) for particle size and shear stress (Avila 2008) .



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