Upland Erosion & Sediment Yield

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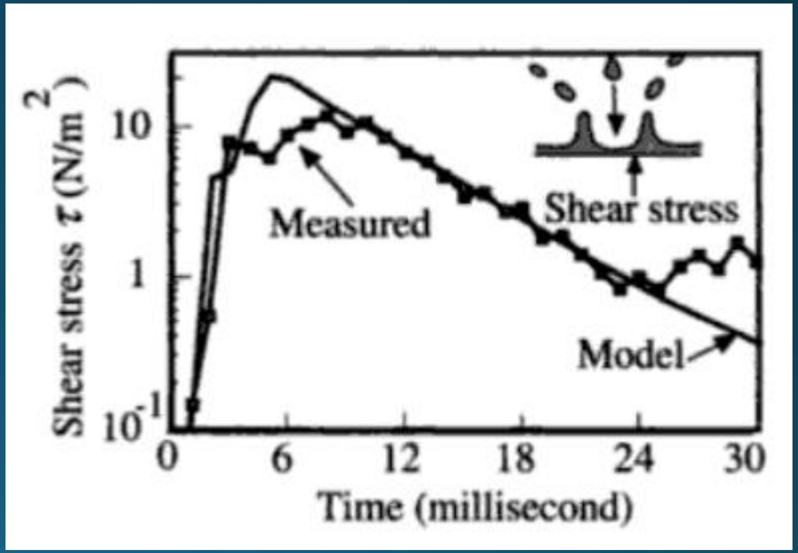
Upland Erosion

- Upland erosion is main source of sediments
- Upland erosion by water could be classified as sheet erosion and rill erosion
- Sheet erosion is the detachment of land surface material by rain drop impact and thawing of frozen grounds and its subsequent removal by sheet flow
- Rill erosion is the removal of soil by concentrated water running through little streamlets, or head-cuts. Detachment in a rill occurs if the sediment in the flow is below the amount the load can transport and if the flow exceeds the soil's resistance to detachment. As detachment continues or flow increases, rills will become wider and deeper.

Upland Erosion

- The surface-erosion process begins when raindrops hit the ground and detach soil particles by splash
- This raindrop splash depends in raindrop size and sheet-flow depth
- The impact of shear stress could be as large as 100 times the base shear stress from shallow sheet flow
- In general, the raindrop impact can be neglected when the sheet-flow depth is larger than three times the raindrop size



Shear-stress under raindrop impact (after Hartley and Julien 1992)

Upland Erosion

- The transport capacity of shallow overland flow, usually called sheet flow
- Sheet flow is increase with filed slope and unit flow discharge
- Soil particles detached by raindrop impact are transported by runoff
- The unit sediment discharge is associated with surface slope,
- **Eventually, Sediment transport estimates can be obtained from an analysis of sediment source and sediment yield**

Sediment Source

- The analysis of sediment source is estimating the total amount of sediment eroded on the watershed on an annual basis
- It depends on the source of sediments in terms of

$$A_T = A_U + A_G + A_B$$

Where, upland erosion A_U is the primary source of sediment

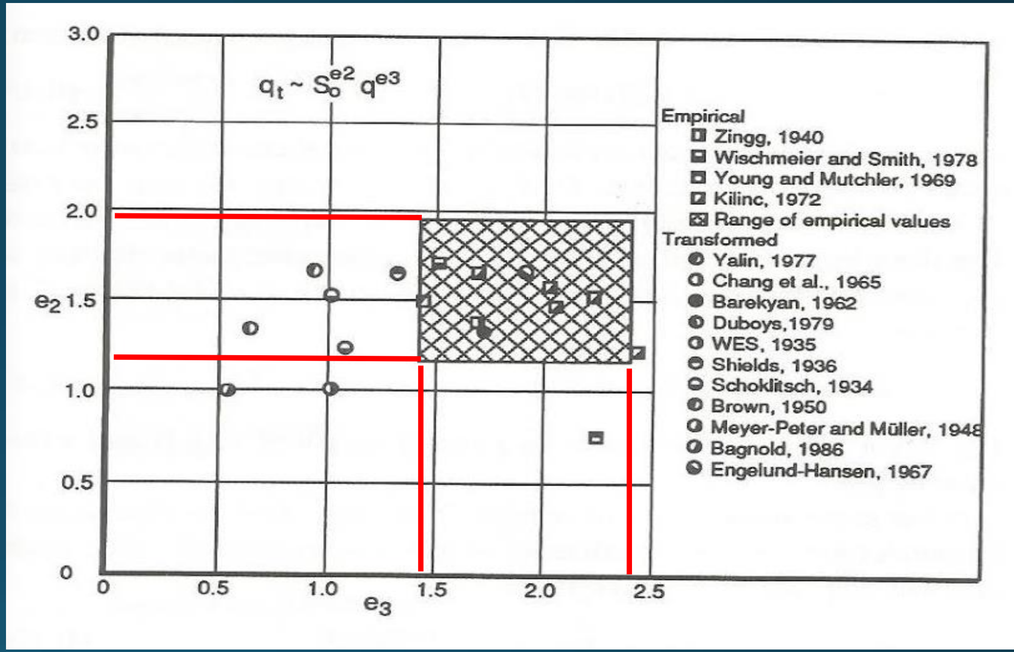
- Gross erosion (A_G) and local bank erosion (A_B) must be estimated separately by calculation of the annual volume of sediment scoured through lateral migration of stream and the upstream migration of head-cuts.

Sediment Source: Upland sediment discharge

- The unit upland sediment discharge from the sheet and rill erosion

$$q_t = e_1 S_0^{e_2} q^{e_3}$$

- q_t is the total unit sediment discharge
- S_o is the bed surface slope
- e_1, e_2, and e_3 are the value of exponents from field observation
- Typically, $1.2 < e_2 < 1.9$ and $1.4 < e_3 < 2.4$



- Equation of Kilinic (1972) for sheet and rill erosion for bare soil

$$q_t(lb/fts) = 1.24 \times 10^5 S_0^{1.66} q^{2.035} \text{ (q in ft}^2\text{/s)}$$

$$q_t(tons/m \times s) = 2.55 \times 10^4 S_0^{1.66} q^{2.035} \text{ (q in m}^2\text{/s)}$$

Sediment Source: The Universal Soil-Loss Equation (USLE)

- The Universal Soil Loss Equation was designed to predict annual average soil erosion loss from field areas with various soil type and vegetation
- The Soil loss ($\hat{E}$) at a given site as a product of six major facotr

$$\hat{E} = \hat{R}\hat{K}\hat{L}\hat{S}\hat{C}\hat{P}$$

- The rainfall erosivity factor $\hat{R}$ is computed from the summation for each storm during the period

$$\hat{R} = 0.01\sum(916 + 331 log I)I$$

Where, I is the rainfall density (in/hr)

Sediment Source: The Universal Soil-Loss Equation (USLE)

- $\widehat{K}$ is the soil erodibility factor
- It describes the inherent erodibility of the soil
- Usually in tons/acre
- Numerous factor control the erodibility of soil such as grain size, distribution, texture, permeability, and organic content

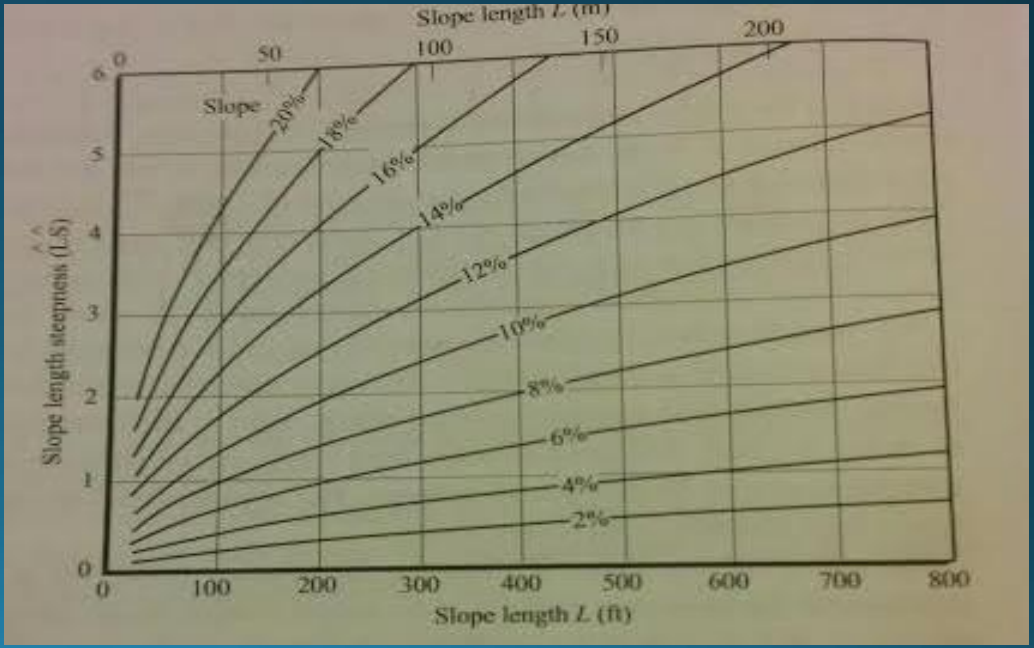
- Source: after schwab et al.(1981)

Textural class	Organic matter content (%) 0.5	2
Fine sand	0.16	0.14
Very fine sand	0.42	0.36
Loamy sand	0.12	0.10
Loamy very fine sand	0.44	0.38
Sandy loam	0.27	0.24
Very fine sandy loam	0.47	0.41
Silt loam	0.48	0.42
Clay loam	0.28	0.25
Silty clay loam	0.37	0.32
Silty clay	0.25	0.23

Sediment Source: The Universal Soil-Loss Equation (USLE)

- $\hat{L}\hat{S}$ is the slope length steepness factor (topographic factor) relating erosion losses from a field of given slope and length
- Could be approximated from
  - $\hat{L}\hat{S} = \sqrt{X_r}(0.0076 + 0.53S_0 + 7.6S_0^2)$
- $\hat{L}$ is the field length factor
- $\hat{S}$ is the field slope factor
- X_r the field runoff length (ft)
- S_0 is the surface slope (ft/ft)
- Also, it could be approximated from

the graph (Wischmeier and Smith, 1978)



Sediment Source: The Universal Soil-Loss Equation (USLE)

- $\hat{C}$ is the cropping-management factor
- It accounts for soil under different cropping and management combination such as different vegetation, canopy during growth stage, before and after harvesting, and etc.
- Various tables for Cropping-management factors.
- For forest , for cropland and for construction slope

(source: after wischmeier and smith 1978)

Percentage of area covered by canopy of trees and undergrowth	Percentage of area covered by duff at least 2 in. deep	Factor $\hat{C}$
100–75	100–90	0.0001–0.001
70–45	85–75	0.002–0.004
40–20	70–40	0.003–0.009

Type of mulch	Mulch rate (tons/acre)	Factor $\hat{C}$
Straw	1.0–2.0	0.06–0.20
Crushed stone, 0.25–1.5 in.	135	0.05
	240	0.02
Wood chips	7	0.08
	12	0.05
	25	0.02

Tilled continuous fallow	1.0
Rough fallow	0.30–0.80
Conventional seed bed	0.50–0.90
No tillage	0.05–0.25
Full canopy	0.10–0.20
Residues left on the field	0.10–0.50

Sediment Source: The Universal Soil-Loss Equation (USLE)

- The cropping-management factor for permanent pasture, range, and idle land

Table 11.4b. *Cropping management factor Ĉ for permanent pasture, range, and idle land*

Vegetative canopy[a]	Type[b]	Percent ground cover					
		0	20	40	60	80	95+
No appreciable canopy	G	0.45	0.20	0.10	0.042	0.013	0.003
	W	0.45	0.24	0.15	0.091	0.043	0.011
Tall weeds or short brush with average drop fall height of 20 in.	G	0.17–0.36	0.10–0.17	0.06–0.09	0.032–0.038	0.011–0.013	0.003
	W	0.17–0.36	0.12–0.20	0.09–0.13	0.068–0.083	0.038–0.042	0.011
Appreciable brush or bushes, with average drop fall height of 6.5 ft	G	0.28–0.40	0.14–0.18	0.08–0.09	0.036–0.040	0.012–0.013	0.003
	W	0.28–0.40	0.17–0.22	0.12–0.14	0.078–0.087	0.040–0.042	0.011
Trees, but not appreciable low brush; average drop fall height of 13 ft	G	0.36–0.42	0.17–0.19	0.09–0.10	0.039–0.041	0.012–0.013	0.003
	W	0.36–0.42	0.20–0.23	0.13–0.14	0.084–0.089	0.041–0.042	0.011

Note: The listed Ĉ values assume that the vegetation and mulch are randomly distributed over the entire area.
[a] Canopy height is measured as the average fall height of water drops falling from the canopy to the ground. The canopy effect is inversely proportional to drop fall height and is negligible if the fall height exceeds 33 ft.
[b] G: cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 in. deep. W: cover at surface is mostly broadleaf herbaceous plants (as weeds with little lateral-root network near the surface) or undecayed residues or both.
Source: Modified from Wischmeier and Smith (1978).

Sediment Source: The Universal Soil-Loss Equation (USLE)

- P is the conservation practice factor
- It equals one for down slope rows and typical values for contouring, strip-cropping, and terracing

(Source: after Wischmeier 1972)

Land slope (%)	Farming on contour	Contour strip crop	Terracing	
			(a)	(b)
2–7	0.50	0.25	0.50	0.10
8–12	0.60	0.30	0.60	0.12
13–18	0.80	0.40	0.80	0.16
19–24	0.90	0.45	0.90	0.18

- In general case of erosion from sheet flow, modifications to unit upland sediment discharge equation reflects the influence of soil type, vegetation, and practice factor.

$$q_t(t/ms) = 1.7 \times 10^4 S_0^{1.66} q^{2.035} \widehat{K} \hat{C} \widehat{P}$$

Upland Erosion & Sediment Yield

- The amount of soils and sediments eroded and transported within a river system has a large impact on the nature and characteristics of the system.
- Upland erosion is defined as the amount of sediment being eroded from the topographical areas upstream of a given point.
- Sediment yield is defined as the quantity of sediment derived within a given drainage area that is transported to the outlet of the system.

Sediment Yield

Definition-*The total amount of sediment delivered to the outlet of a watershed.*

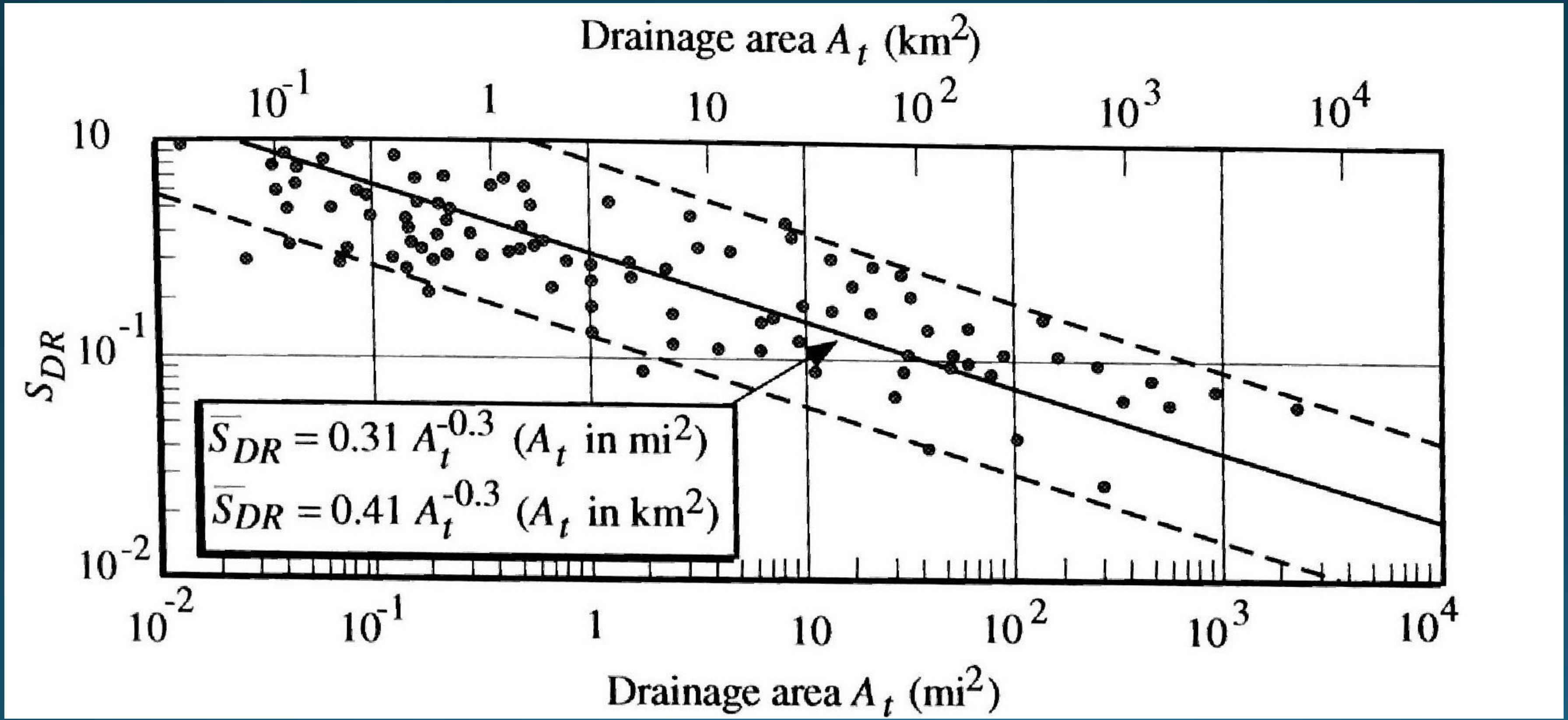
- The total amount of upland and channel erosion is known as the gross erosion of a watershed.
- All of the sediment particles that are mobilized within a drainage do not necessarily reach the outlet and may be deposited at a location within the system, this is the sediment yield.
- The sediment yield is defined by the following equation where the total yield (Y) is the product of the gross erosion of the watershed and the sediment delivery ratio

$$Y = A_T S_{DR}$$

- If re-arranged this equation also shows that the sediment-delivery ratio is the ratio between the sediment yield and the gross erosion in a watershed.

Sediment Yield: Sediment Delivery Ratio

- The sediment delivery ratio is generally determined by empirically derived curves and equations such as those shown below and is found as a function of drainage area.



(Julien, 2012, modified after Boyce, 1975)

Sediment Yield: Grid Size Factor

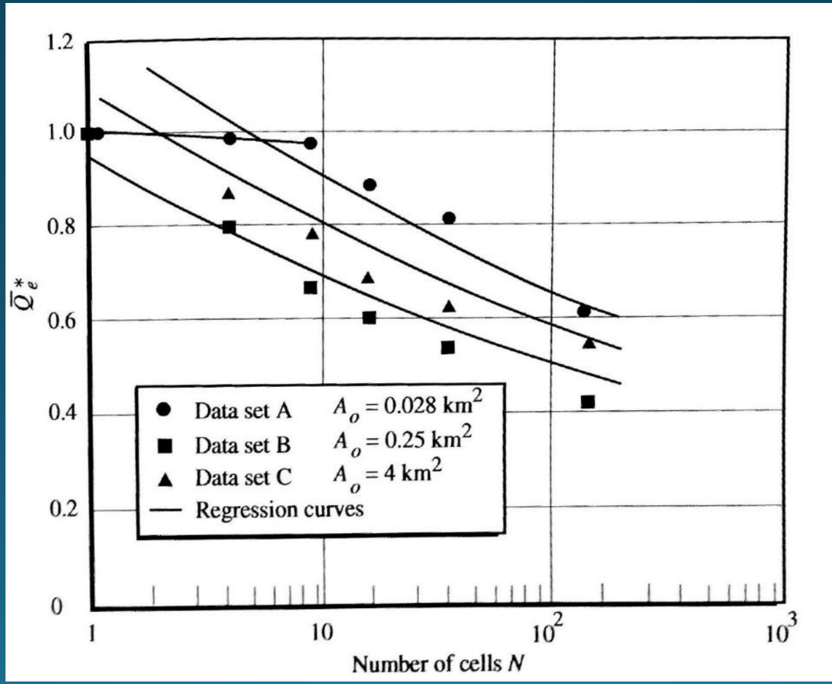
- The influence of grid-cell size used to evaluate a drainage using GIS mapping on soil erosion losses calculations can effect the rates.
- This primarily depends on whether or not the watershed or grid cell average for the USLE parameters is used.
- A relative grid size factor can be defined and used to relate the USLE parameters between grid cells.

$$Q_e^* = \frac{N[\hat{R}\hat{K}\hat{L}\hat{S}\hat{C}\hat{P}]}{\sum_{i=1}^{N} \hat{R}_i\hat{K}_i\hat{L}_i\hat{S}_i\hat{C}_i\hat{P}_i}$$

- i denotes the values for each matrix grid cell of the USLE parameters and the non-subscript values are the watershed average values

Sediment Yield: Average Watershed Correction Factor

- A watershed averaged correction factor can be determined as a function of the number of cells used to evaluate the drainage area.
- The mean value of this correction factor decreases as the number of pixels in the evaluation grid decreases, as shown in the figure below.



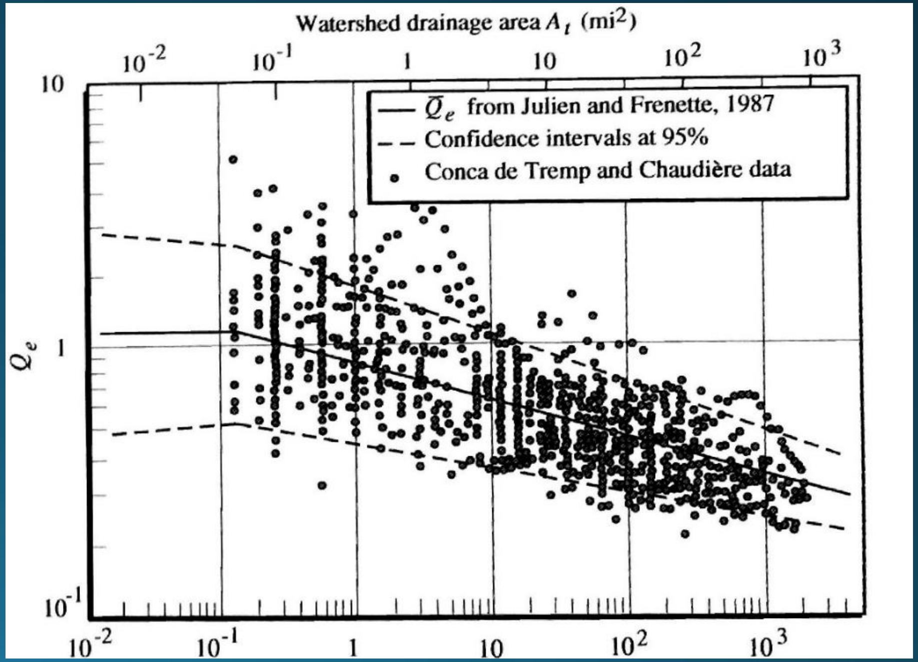
(Julien, 2012, after Julien, 1979)

Sediment Yield: Watershed Correction Factor

- The value of the correction factor has been show to primarily vary with drainage area when applied over a watershed.
- The result is an average value for the watershed-size correction factor that can be determined from the equation or figure below, as a function of drainage area.

$$\overline{Q_e} = 0.84 A_t^{-0.137}$$
$$A_t \geq 0.125\ km^2$$

- The correction factor remains constant when the drainage area is less than 0.125 square-kilometers.



(Julien, 2012, after Julien & del Tanago, 1991)

Sediment Yield: *Annual Erosion Loss (modified)*

- The annual erosion losses in a large watershed can be re – estimated using the USLE erosion value determined by the watershed-averaged coefficients and the correction factor.

$$\hat{E} \cong \frac{\bar{\hat{E}}}{Q_e}$$

- If the mean precipitation during a given time period is considered the annual watershed erosion losses may be approximated by the following equation

$$\hat{E}_{tons} \cong \frac{3.4 \times 10^{11}}{\overline{Q_e}} A_t \overline{L}\overline{S}^{1.66} C_r \overline{h}\overline{\iota}\bar{\hat{K}}\hat{\bar{C}}\bar{\hat{P}}$$

Sediment Yield: Final Modified Yield Equation

https://search.yahoo.com/yhs/searchUTF-8&hspart=mozilla&hsimp=yhs-002

- The final modified sediment yield equation for large watershed is determined by applying the combination of the equations.

$$Y \cong S_{DR} \frac{A_t}{Q_e} 3.4 \times 10^{11} \bar{L}\bar{S}^{1.66} C_r \bar{h}\bar{\imath}\overline{\widehat{K}}\,\overline{\hat{C}}\,\overline{\widehat{P}}$$

- Cr is the runoff coefficient, h the precipitation and i is the rainfall intensity.

Sediment Yield: Estimation & Models

- Models for sediment transport in watershed scales

  1)CASC2D-SED, 2) TREX

- To estimate upland erosion in watershed, the hydrologic processes such as, 1) rainfall precipitation and interception, 2) snowmelt, 3) infiltration and transmission losses, 4) depression storage, and 5) overland and channel flow should be considered.
- Sediment transport processes such as, 1) advection-diffusion, 2) erosion and deposition, 3) bed elevation adjustment also should be considered.

Conclusions

- Besides drainage area the upland erosion and sediment yield will vary greatly depending on the geology, vertical relief and vegetation within a drainage be eroded by river systems as well as on. The factors are estimated by using the ULSE coeeficients.
- For example river systems with high topographical relief and little vegetation is going to have significantly greater amounts of upland erosion and sediment yield then a system with low highlands and large amounts of stable vegetation given a equivalent amount of precipitation and drainage area.
- Knowing the relative amount of upland erosion and sediment yield can be crucial to the development of infrastructure in areas that may be impacted by erosion or dams in areas with large sediment yields.

References

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- *River Mechanics 1st Edition,* Pierre Julien, Cambridge University Press 2002
- Julien, P. Y., Velleux, M. L., Ji, U., & Kim, J. (2014). Upland Erosion Modeling. In Modern Water Resources Engineering (pp. 437-465). Humana Press.