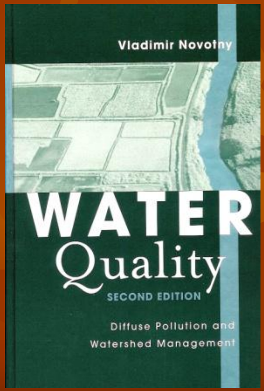
Erosion

Chapter V

WATER QUALITY: Diffuse Pollution and Watershed Management



Types

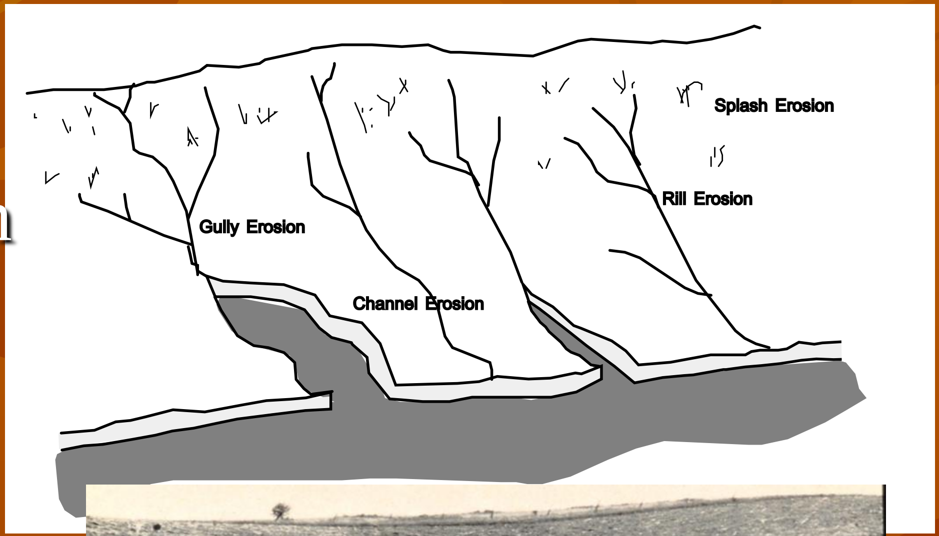
- Natural (not considered as pollution)
  - Grand Canyon, Badlands, Arid regions – natural weathering
- Anthropogenic (caused by humans)
  - Deforestation
  - Agriculture
    - Dust Bowl
  - Overgrazing
  - Construction sites
    - 80 million of tons annual washed from construction sites to receiving water bodies

Others sources of sediments in water bodies

- Urban dust and dirt and other solids (leaves)
  - Accumulation and washoff on impervious surfaces
- Surface mining
- Wind erosion
  - Dust storms
- Waste water solids
- Algae development

Definitions

- Denundation - same as weathering or erosion
- Erosion
  - Upland
    - Sheet and rill
    - Expressed in tons/km^2
  - Channel
    - Stream bank
    - Flood plain scour

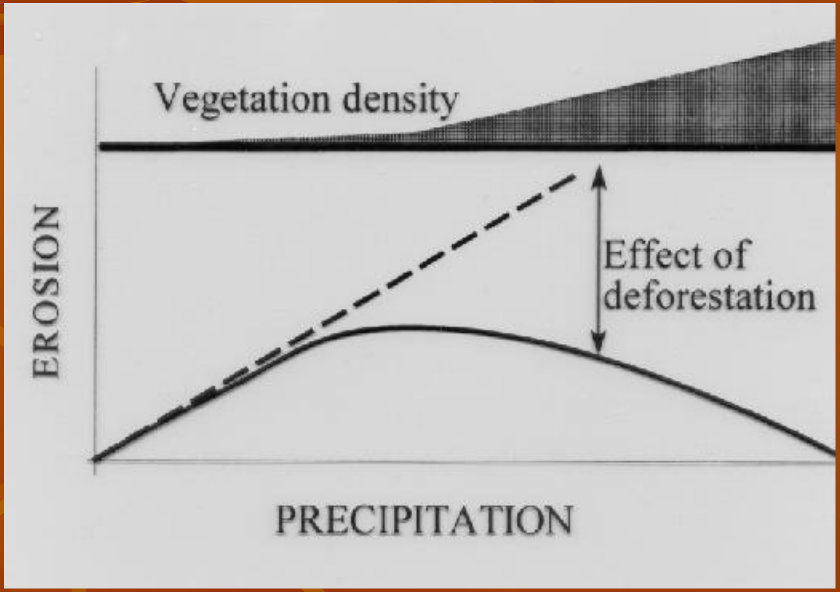


Anthropogenic erosion

- Agricultural erosion
  - Ranges 1000 to 4000 tones/km^2 /year
- Urban erosion
  - Construction sites up to 50,000 tones/km^2 /year
- Highway construction erosion
- Silvicultural
- Streambank, channel and shoreline erosion

Examples

EFFECTS OF DEFORESTATION



DEFORESTATION

Clear cutting is one of the most polluting land use activities. Sediment and pollutant loads in logged watersheds increase by two to four orders of magnitude (10^2 to 10^4). Also soil chemistry changes.

Deforestation is most damaging in humid higher slope water-sheds.

Sediment yield and sediment delivery

- Measured sediment load in streams does not equal the upland erosion emissions

$$Y = DR\ (A)$$

Y = sediment yield

DR = sediment delivery ratio

A = upland watershed and channel gross erosion

Sediment movement in streams

- Suspended sediment (washload)
- Bedload

Cohesive sediments (clays , organic sediments

Noncohesive sediments (sand and gravel)

Estimating erosion

- Sampling and establishing a relationship between sediment concentration C [mg/L] or load [grams/sec = Cx Q] and flow Q [m^3/sec]
  - Note – spurious correlation
- Reservoir sedimentation
- Empirical equations
- Simulation models
  - HSP-F

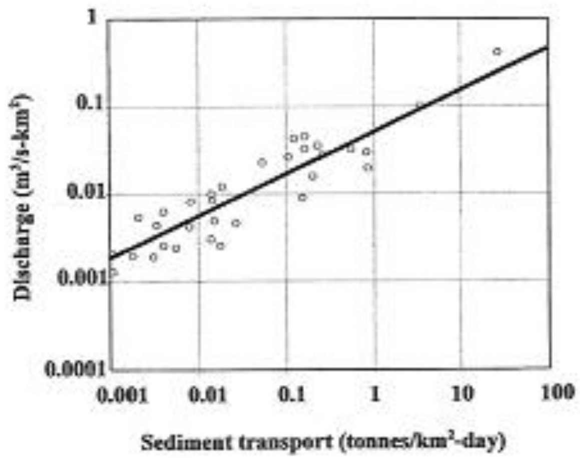


Figure 5.11. Relationship between suspended sediment transport and discharge for the Menomonee River in Wauwatosa, Wisconsin. (Compiled from U.S. Geological Survey, Wisconsin Department of Natural Resources, and Southeatern Wisconsin Regional Planning Commission data.)

Estimating upland erosion
Universal Soil Loss Equation –USLE

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

A = calculated soil loss for a given storm or period

R = rainfall erosivity factor

K = soil erosivity factor

LS = slope length factor

C = cropping management (vegetative cover) factor

P = erosion control practice factor

Example of Experimental Plots for Determining USLE parameters

Field Facility of Agricultural Research Institute in Beijing near Miyun Reservoir

Rainfall erosivity

Expresses rainfall energy that liberates particles from soil

Annual

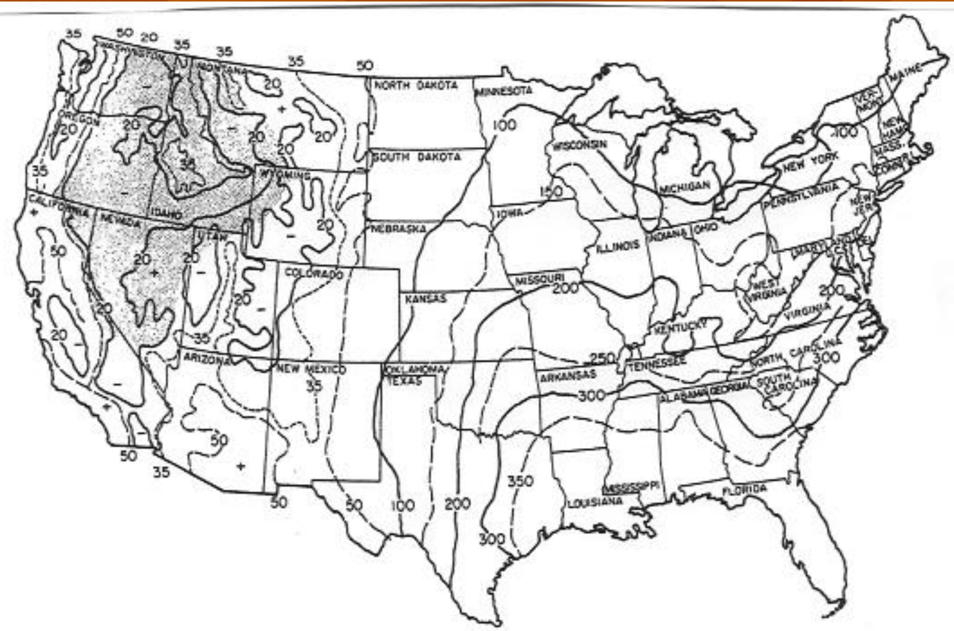


Figure 5.12. Values of the annual rainfall erosivity factor *R* (tons/acre). (To convert to tonnes/ha, multiply by 2.24.) (From Stewart et al., 1975.)

Per storm $R_r = \sum[(2.29+1.15 \ln X_i)D_i)]\ I$

X = rainfall intensity (cm/hr), D = rainfall depth (cm), I=max 30 minutes intensiy of the storm, I – time interval of the storm hyetograph

- Soil Erodibility
  - Expresses detachment of soil particles from soil
  - Unit tons/ha – unit of rainfall erosivity
  - Maximum for fine noncohesive soils (silt)

- Slope/Length Factor   LS
  - Expresses impact of slope on a standard 22 m plot
  - Adjusted for length

$$LS=(L/22.1)^{m}(0.065+0.04579\ S+0.0065\ S^{2})$$

L = length of overland flow m

S = slope %

m= 0.2 for S<1%

m= 0.3 for 1%<S<3%

m= 0.4 for 3.5%<S<4.5%

m= 0.5 for S>4.5%

- Cropping Management or Vegetative Cover Factor C
  - Dimensionless
  - = 1 for bare freshly plowed soils
  - = 0.003to 0.01 for grass and sod
  - =0.06 to 0.2 for mulched soils
  - = 0.1 – 0.3 for corn
  - = 0.001 for woodland
- Erosion Control Factor P
  - = 1 for most application
  - Contouring
  - Crop rotation

Watersheds in Iowa with soil conservation

Contouring, terraces, ponds, wetlands, buffers

Credits NRCS

BOX 5.2: ESTIMATION OF ANNUAL SOIL LOSS BY THE UNIVERSAL SOIL LOSS EQUATION

An erosive 100-ha farm field in southeastern Wisconsin is situated on a silt loam soil with a slope classification B (3 to 6% slope). The farmer is growing corn and plowing up and down slope. Estimate the average annual soil loss per hectare without soil conservation and with contour plowing. The field has a square shape with a drainage ditch located on the side of the field. The overland slope is toward the drainage ditch. Estimate average annual soil loss before and after implementing soil conservation.

Solution: From Figure 5.12 the average annual rainfall erosivity for southeastern Wisconsin is R_r = 125 U.S. tons/acre × 2.24 = 280 tonnes/ha. From Table 5.3 the average soil erodibility factor for silt loam soil is $K = 0.42$. The slope-length factor LS can be calculated from (5.6) (overland flow length L = 1000 m and average slope S = 4.5%) as

$$LS = (1000/22.1)^{0.4}\,[0.065 + 0.04579(4.5) + 0.0065(4.5^2)] = 1.85$$

A plowing practice of continuous fallow tilled up and down the slope has a C factor of $C = 1$ after plowing and 0.1 to 0.3 for corn during the main growing season (Table 5.4), respectively. The average C for no soil conservation planting is assumed to be $C = (1 + 0.3)/2 = 0.65$. Since no erosion control is implemented, $P = 1$. The average annual soil loss without soil conservation is then

$$A = RK(LS)CP = 280(0.42)(1.85)(0.65)(1) = 141.3 \text{ tonnes/ha}$$

Implementing contour plowing will reduce the P factor to 0.5 (Table 5.7). Hence the soil loss will then be

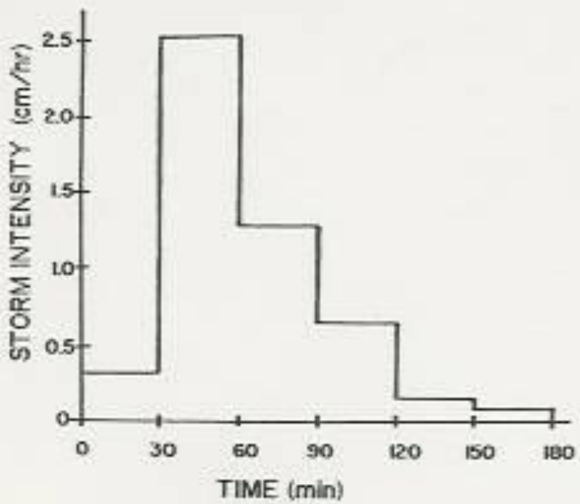
$$A = 280(0.42)(1)(0.65)(0.5) = 70.7 \text{ tonnes/ha}$$

BOX 5.3: SOIL LOSS FROM A CONSTRUCTION AREA FOR A DESIGN STORM

A 50-ha land area is to be developed into a single-family residential area. The soil map indicates that the soil is loam with the following composition:

Clay	20%
Silt	35%
Fine sand	20%
Silt + fine sand	55%
Coarse sand and gravel	25%

The organic content of the soil is 1.5%. The lot is square with a drainage ditch in the center. A future storm sewer is proposed to replace the ditch. The average slope of the lot toward the ditch is 2.4%. Determine the soil loss (potential erosion) for a storm for which the hyetograph is as shown in the accompanying figure. Soil loss should be determined from the pervious areas for the two periods: during construction, when all vegetation is stripped from the soil surface (100% pervious), and subsequent to construction, when 25% of the area is impermeable (streets, roofs, driveways, etc.).



Solution: The rainfall energy factor R_r is determined from the hyetograph. From this information it can be determined that the maximum 30-minute rainfall intensity is 2.5 cm/hr Utilizing (5.3) yields

$$R_r = [(2.29 + 1.15 \ln 0.3)0.15 + (2.29 + 1.15 \ln 2.5)1.25 + (2.29 + 1.15 \ln 1.25)0.6175 + (2.29 + 1.15 \ln 0.7)0.35 + (2.29 + 1.15 \ln 0.2)0.1 + (2.29 + 1.15 \ln 0.1)0.05]2.5 = 16.4$$

The soil erodibility factor is determined from Figure 5.14 assuming soil texture to be fine grained and permeability to be moderate, giving a K value of 0.33. To determine the LS factor for a 50-ha area with a ditch or storm sewer in the middle, the length of the overland flow $= L = 0.5\sqrt{50(100)(100)} = 353.5$ m. With the use of (5.6), the LS factor for $L = 353.5$ and $S = 2.4\%$ becomes

$$LS = (353.5/22.1)^{0.3}[0.065 + 0.04579(2.4) + 0.0065(2.4^2)] = 0.49$$

Factors R_r, K, and LS are the same for both alternatives. The remaining factors, C and P, must be evaluated for each alternative (P only if erosion control practices during construction are implemented). For the period during construction (alternative 1), C is estimated assuming no vegetative protective cover and bulldozed soil. In this case C is approximately the same as for bare fallow ground, that is, $C = 1$. In the absence of erosion control practices, $P = 1$. Thus soil loss for this particulate storm is

$$A = 16.4(0.33)(0.49)(1)(1) = 2.64 \text{ tonnes/ha}$$

Then, for 50 ha, total soil loss for the storm is

$$50(2.64) = 132.3 \text{ tonnes}$$

For the period after construction (alternative 2) and assuming that the pervious areas are covered by lawns, C is reduced to 0.01 and the soil loss per hectare is

$$A = 16.4(0.33)(0.49)(0.01)(1) = 0.026 \text{ tonne/ha}$$

Given the 75% of the area is subject to soil loss, the total sediment generation from pervious areas is

$$0.75(50)(0.026) = 0.97 \text{ tonnes}$$

To complete the analysis, sediment generated from connected impervious areas (street dust and dirt; see Chapters 3 and 8) would have to be added to the amount above. This estimate is also subjected to the condition that the storm will generate appreciable surface runoff.

Sediment delivery

- Number of processes attenuate sediment loads on route from the source area to the receiving water
    - Filtering by grasses
    - Loss of energy after rain terminates
    - Infiltration into soil
    - Small depressions and ponding
    - Change of slope of overland flow

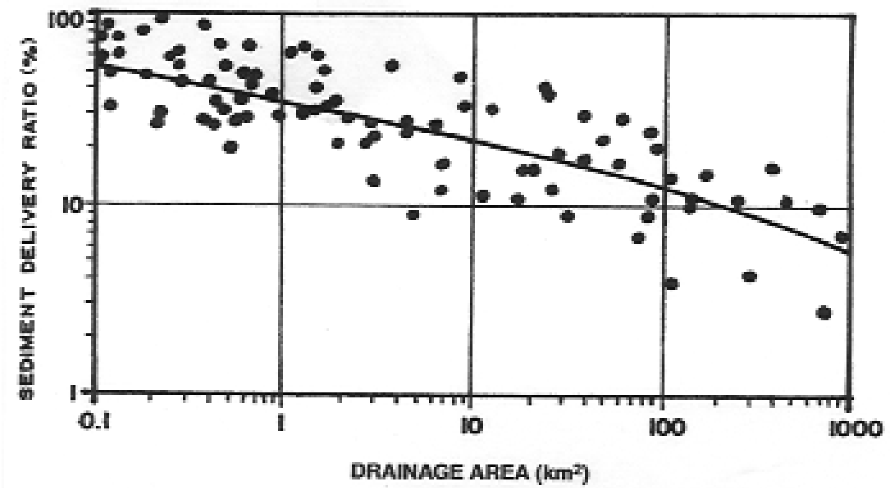


Figure 5.16. Relation of sediment delivery ratio to the watershed area. (Replotted from Roehl, 1962. Published with permission of the Internation Association of Hydrological Sciences.)

Table 5.8 Estimated Sediment Delivery Ratios from Pervious Areas for Various Land Uses in Subbasins of the Menomonee River, Wisconsin

Subbasin Type	Impervious Area (%)	Degree of Storm Sewering (%)	Sediment Delivery Ratio (%)
Agricultural	<5	0	1–30
Developing—construction	<5	20–50	20–50
Low-density residential, unsewered	<20	0	<10
Parks	<10	0	<3
Medium-density residential, partially sewered	30–50	<50	30–70
Medium-density residential, sewered	30–50	>50	70–100
Commercial, high-density residential, sewered	>50	80–100	100

Source: Novotny et al. (1986).

Movement of sediment in streams

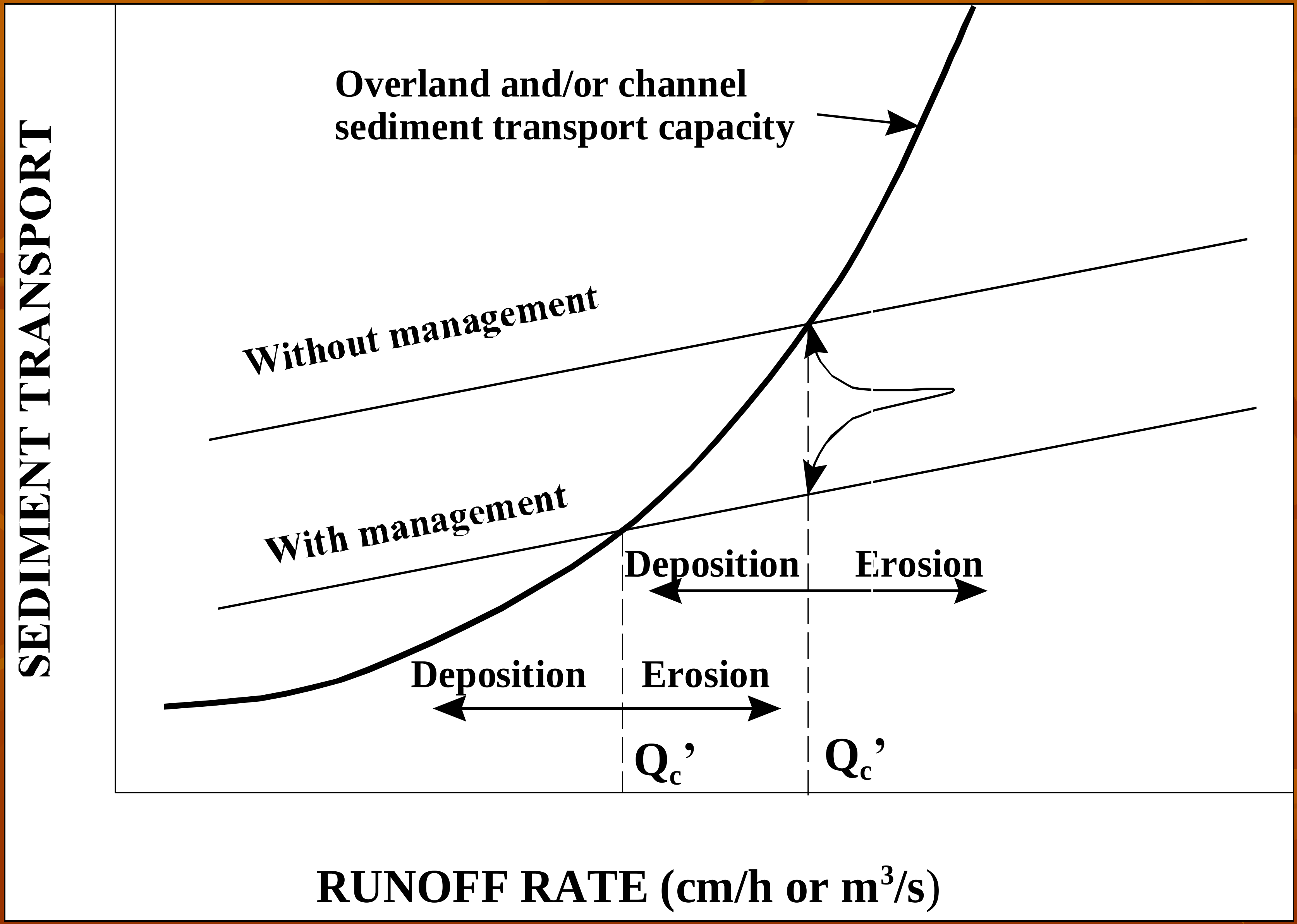
- Erosion and deposition of sediments in channels is related to the bottom shear stress

$$\tau = \gamma R S_e$$

Where τ = shear stress in N/m^2, γ=specific weight of water in N/m^3, R= hydraulic radius in m (for wide channels R is aproximatelly equal to average depth, and S_e is the slope of the energy line

There is a critical shear stress, τ_c, for erosion and scour. For noncohesive sediments, τ_c is the same; however, for cohesive sediments, the critical shear stresss for deosion is smaller than that for erosion.

Shen’s diagram for sediment transport, scour and deposition



Deposition of sediments in floodplain

Erosion Control for Pollution Reduction

- Source controls
- Hydrologic Modification
- Control of delivery
- Capture, storage and treatment

Source Controls

- Soil conservation
  - No-till planting
  - Conservation tillage
  - Contour plowing
  - Stripcropping
  - Terraces
- Vegetative and other surface controls
  - Sod, converting highly erosive lands to pastures and woodlands
  - Crop rotation
  - Mulching
- All of above modify hydrology of the surface (surface storage, roughness, infiltration)

NO-TILL PLANTING

- Improves soils quality by increasing organic matter
- Reduces erosion
- Optimizes soil moisture
- Increases nitrification in the upper soil layer

- Improves nutrient cycling
- Increases both water holding capacity and infiltration
- Speeds up breakdown of pesticides

PROBLEMS

- Requires more pesticides application
- Not applicable to all soils and crops

Terrace

Strip cropping and contour plowing

Terraces in China

Hydroseeding

Mulching

Reduction of Delivery

- Vegetative filter strips
  - Grass filters, buffer strips
- Grassed waterways
- Silt fences and sediment traps

RIPARIAN BUFFERS

In the Food Security Act the US Congress authorized the Conservation Reserve Program that pays farmers for set aside lands on high slope erosive lands and along the receiving water bodies (riparian buffer strips).

Research docummented that when the riparian buffer strips are properly designed they dramatically reduce concentrations of sediment, nutrients and pesticides in runoff and subsurface flow.

REMOVALS

>75% sediment

>50% nutrients and pesticides

>60% pathogens

Grassed Waterways and filter strips

Storage and Treatment

Ponds and wetlands (or combination)

Constructed wetlands

Ca'di Mezzo recreated wetland – Venice Lagoon

Berndoricchio's memorial

- Nitrification of stored organic nitrogen and release of nitrate
- Release of metals stored as metal sulfides
- Loss of pollutant retention capacity "Wetlands are kidneys of nature"
  - BOD and SS removal > 90%
  - Significant removals (immobilization) of toxics
  - pH control
- Wetlands are naturally dystrophic (low dissolved oxygen)