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*30 Años de Excelencia en el Adiestramiento de Oficiales de Transportación
a Nivel Municipal, Estatal, y Federal en Puerto Rico e Islas Vírgenes*



Diseño e Implantación de Medidas para el Control de la Erosión y la Sedimentación

Día 1



Instructor

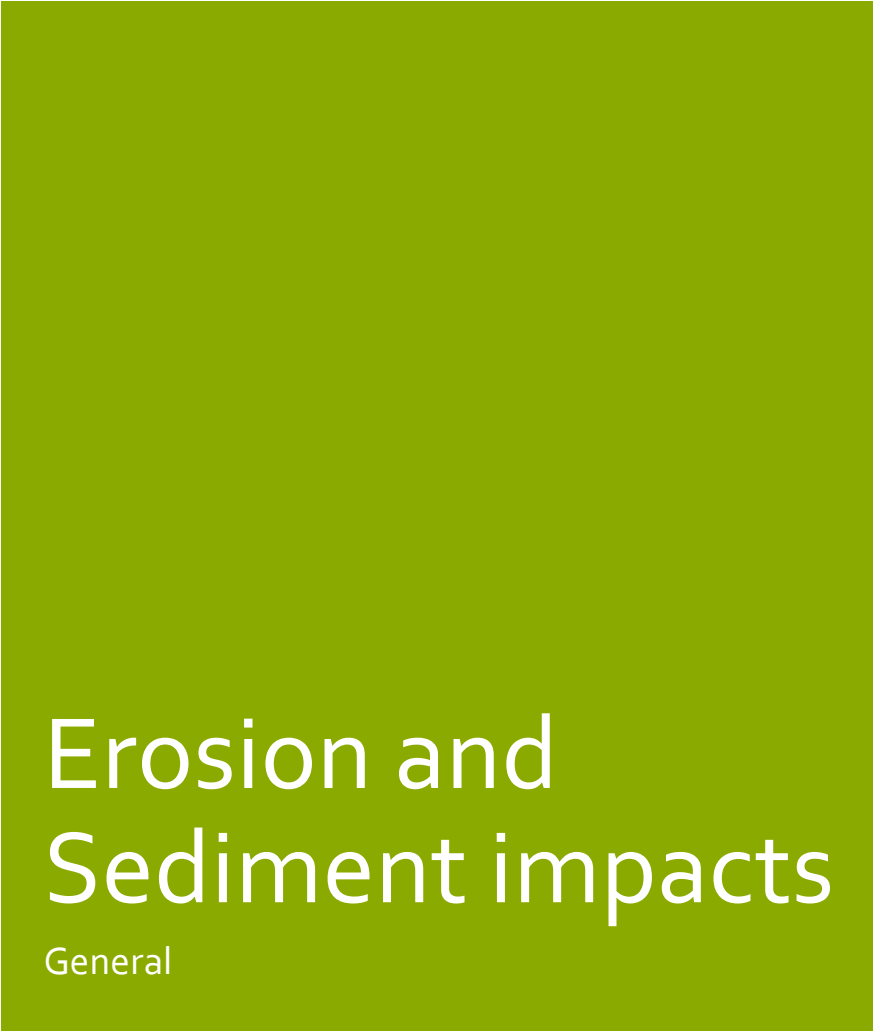
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Catedrático

Departamento de Ingeniería Civil y Agrimensura
UPR – Recinto Universitario de Mayagüez



16 y 17 de junio de 2016



Erosion and Sediment impacts

General



Erosion and sediment impacts

- Pollution
- Ecological impacts
- Hydraulic modifications
- Property damage
- Construction costs and schedule
- Lawsuits

Pollution



Ecological impacts



Hydraulic modifications



Property damage



Construction costs and schedule

- Stop work ordered for noncompliance
- Fines/ penalties for noncompliance
- Repair damage to adjacent properties
- Missed deadlines, litigation, other additional work.



Lawsuits





Types of Erosion

General Erosion Processes



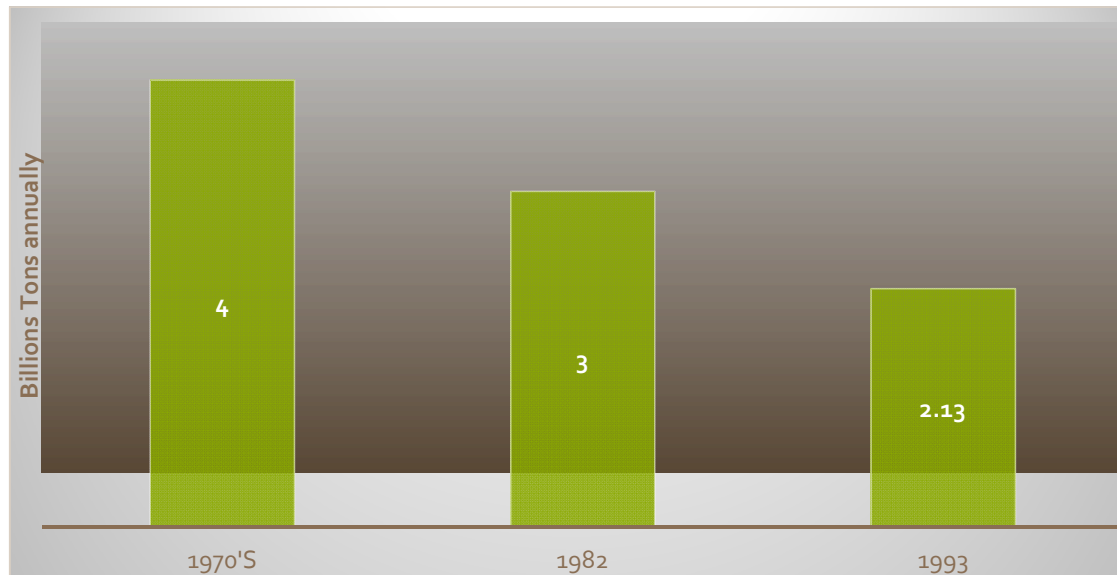
EROSION

- **Erosion** is the process by which the action of wind or water displaces soil particles
- **Water erosion** is the detachment and transport of soil from the land by water , including rainfall and runoff from melted snow and ice.
- **Sediment** is eroded material suspended in air or water
- **Sedimentation** is the deposition of eroded material



Introduction

- Erosion is one of the most important and challenging problems for natural resource manager worldwide.
- It is the main source of sediment that pollutes streams and fill reservoirs.
- Some estimates of erosion rates are presented



This reduction is due to advances in soil erosion control and reduced number of acres under cultivation (NRCS, 1994).

Introduction

- Soil erosion reduces the productivity of soils
- Eroded sediments remove soil organic matter, degrading soil structure and reducing its fertility.
- On shallow soils , the loss of top soil reduce the availability of soil water to the plants resulting in restricted growth because of drought stress.
- Two mayor types of erosion are:
 - a) Geological erosion
 - b) Human or animal activities

Geological erosion

- This type of erosion includes soil-forming as well as soil-eroding processes that maintain the amount of soil in a favorable balance suitable for the growth of most plants.
- The geological erosion has contributed to the formation of our soils and caused many of our present topographic features such as canyons, stream channels and valleys.



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A2



A3
A4

Slide 5

- A1** <http://www.ngenespanol.com/traveler/viajero-ilustrado/594106/gran-canon-atraccion-turistica-cerca-vegas/>
Author, 5/27/2014
- A2** Pagina National Geographic en español
Author, 5/27/2014
- A3** Red Natural de Aragón
Author, 5/27/2014
- A4** <http://www.rednaturaldearagon.com/default.aspx?FolderID=275>
Author, 5/27/2014

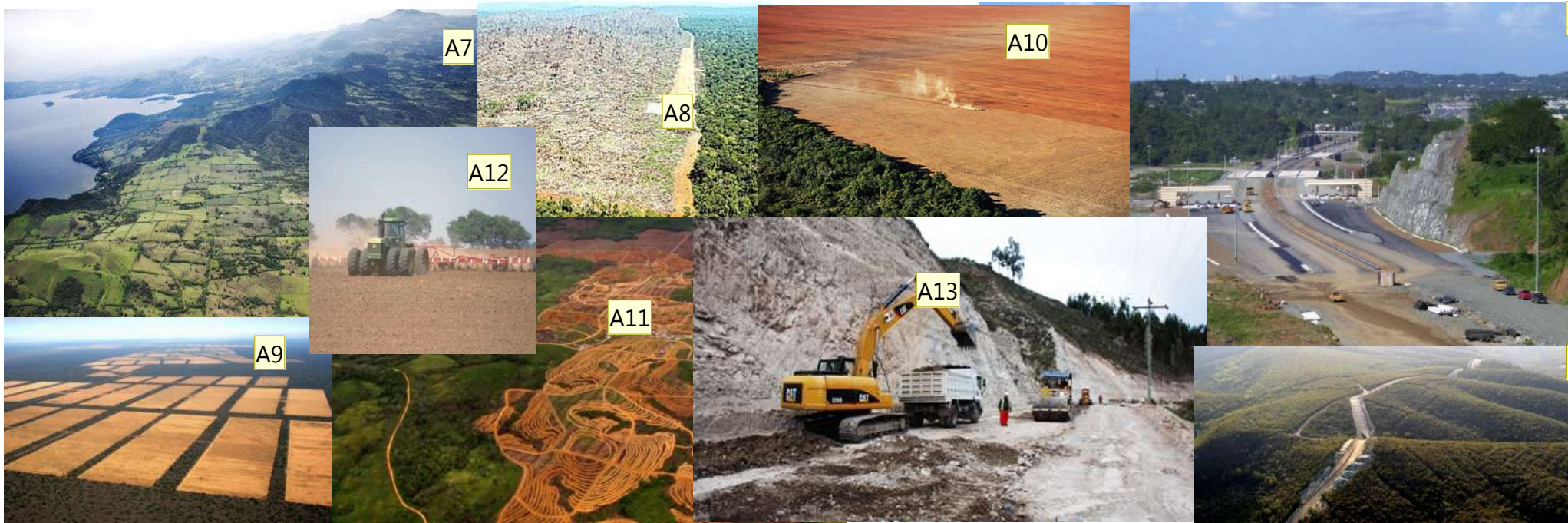
Animal and human erosion

- Animal erosion
 - Caused by grazing animals .



Animal and human erosion

- Human erosion
 - Caused by deforestation and the construction of cities, farming, facilities and roads.



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- A7** <http://www.bionero.org/ecologia/Tuxtlasdeforestacion2.jpg/image>
Author, 5/27/2014
- A8** http://4.bp.blogspot.com/_AaXJKhmEhsY/R5p2mwRUk9I/AAAAAAAAABco/hHqIUtxv7-0/s400/t032dh12.jpg
Author, 5/27/2014
- A9** <http://www.proteger.org.ar/wp-content/uploads/2010/10/DeforestacionGuyraClarín.jpg>
Author, 5/27/2014
- A10** <http://2.bp.blogspot.com/-z6mx1VanFWU/UMuoJTgis4I/AAAAAAAYbM/lrdXmVrSrs/s1600/Deforestaci%C3%B3n.jpg>
Author, 5/27/2014
- A11** <http://www.proyectopv.org/imagen/deforestacion21.jpg>
Author, 5/27/2014
- A12** <http://www.raw-food-health.net/images/TractorErosion.jpg>
Author, 5/27/2014
- A13** <http://mexico.cnn.com/media/2013/10/29/carretera-acapulco-autopista-del-sol.jpg>
Author, 5/27/2014
- A14** <http://static.panoramio.com/photos/large/23351492.jpg>
Author, 5/27/2014
- A15** <http://www.miprv.com/una-ruta-de-mucho-impacto-la-via-verde/>
Author, 5/27/2014

Water erosion

- Types of water erosion include interrill (raindrop and sheet), rill, gully , and stream channel erosion.
- Water erosion is accelerated by farming, forestry, grazing and **construction activities.**



Factors affecting erosion by water

Factors affecting erosion by water:

1. Climate
2. Soil
3. Vegetation
4. Topography



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<http://1.bp.blogspot.com/-SsavrH3clhs/UDFi1s3a25I/AAAAAAAAACI/E6kTwEqdBYg/s1600/deforestacion-500x333>
Author, 5/28/2014

Climate

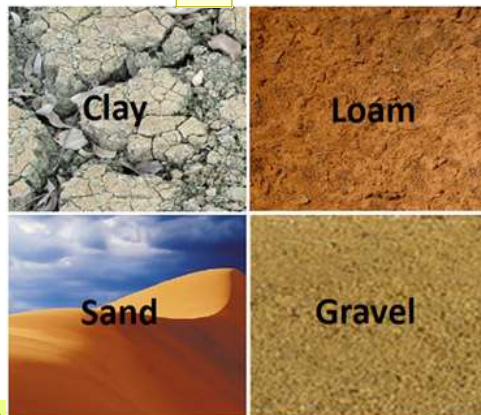
- Climatic factors affecting erosion are:
 - Temperature
 - Humidity
 - Solar radiation
 - Wind
 - Precipitation
- Temperature , humidity , solar radiation, and wind are the most evident through their effects on evaporation and transpiration.
- The wind changes the raindrop velocities and the angle of impact may influence in erosion rates.
- Precipitation promotes separation of soil particles and runoff moves the sediment

Soil

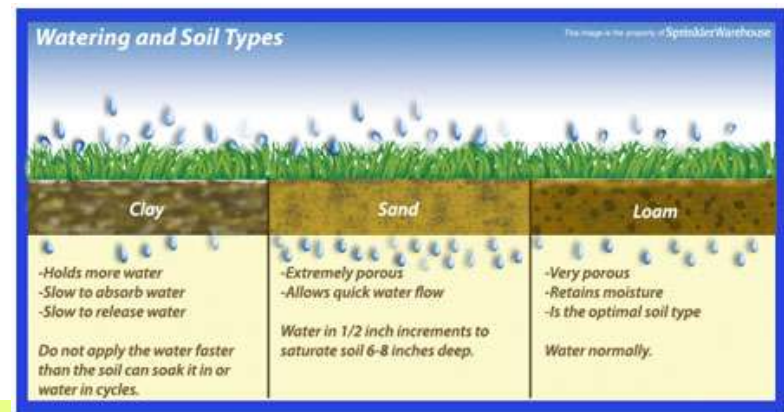
- The soil properties affect the infiltration capacity and the extent that soil particles can be detached and transported.
- For example:
 - Clay particles are more difficult to detach than sand, but clay is more easily transported
 - Texture is the dominant property determining erodibility, but soil structure, organic matter, water content and density or compactness as well as chemical and biological characteristics of the soil, also influence erodibility.

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A18 http://www.beyondgardens.com.au/waterwise/soil_1_1.php?uid=1783-2170-8580-0211
Author, 5/28/2014

A19 <http://www.sprinklerwarehouse.com/DIY-Determine-your-soil-type-s/6561.htm>
Author, 5/28/2014

Vegetation

- Plays a major role in reducing erosion
 1. Protecting the soil from raindrop impact
 2. Reducing surface runoff velocity
 3. Holding soil in place
 4. Improving soil structure with roots, plants residue and increased biological activity in the soil
 5. Increasing transpiration rates.
- The effect of vegetation varies with the species, climate, season, soil type and degree of maturity of the vegetation.



Vegetation

- A particular global concern is the deforestation, this occurs in areas with very high precipitation rates.
- Once trees are removed there is little to stabilize the soil, and these areas rapidly become degraded and unsuitable for plant growth.
- Erosion rates are high in steep sloping



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A20 <http://www.pinterest.com/pin/132996995216636241/>
Author, 5/28/2014

A21 https://www.google.com.pr/search?q=deforestacion&rlz=1C1AVNA_enPR587PR587&es_sm=122&source=lnms&t
Author, 5/28/2014

Topography

- Topographic features that influence erosion are:
 - Slope steepness
 - Length
 - Shape
- Steep slopes implies that runoff water is more erosive and can more easily transport detached sediment downslope
- On longer slopes, increased accumulation of overland flow results in increased rill erosion.
- Concave slopes with less-steep slopes at the foot of the hill, are less erosive than convex slopes .



Types of Water Erosion

Water Erosion Processes



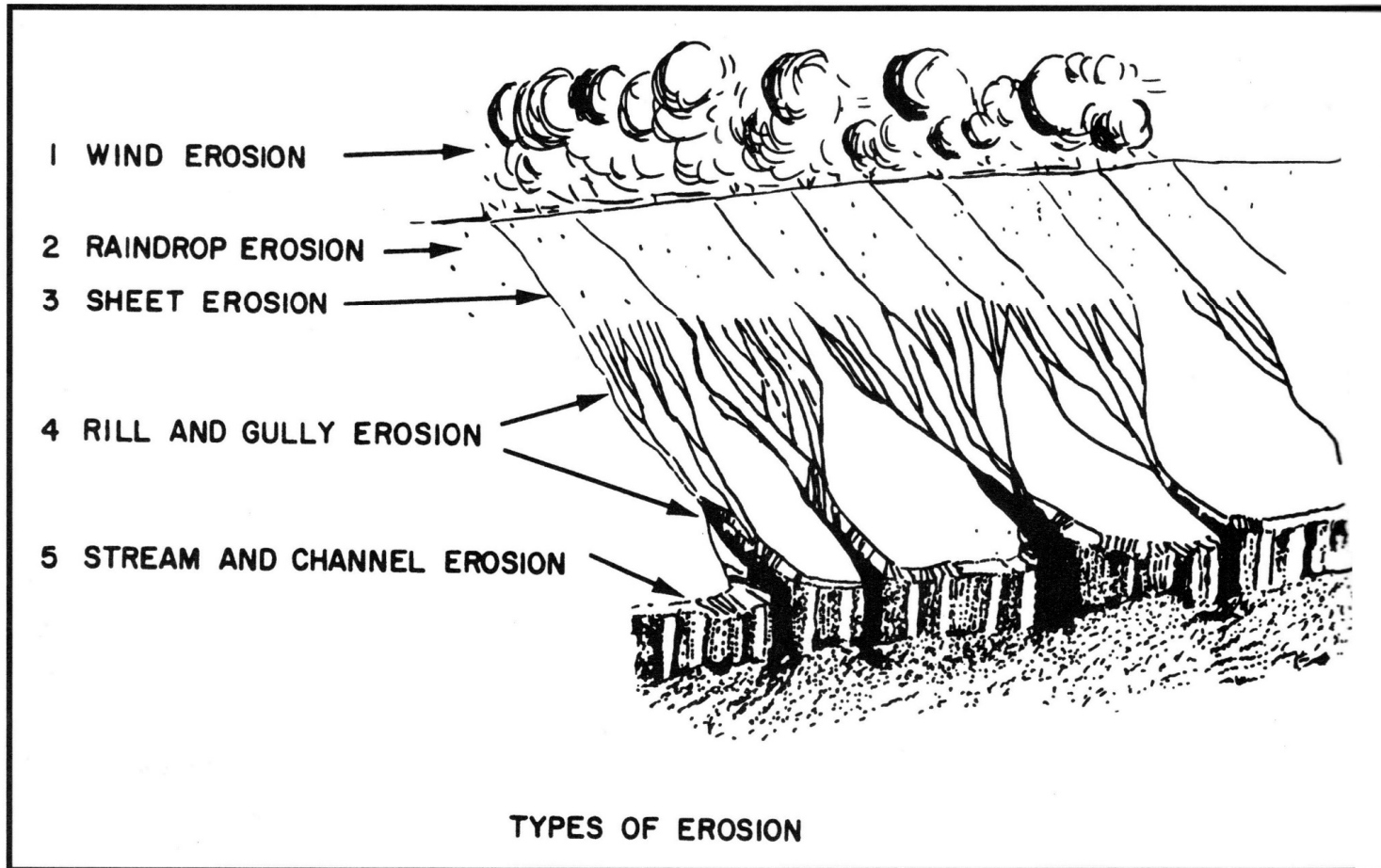


Illustration of Types of Erosion (SCS, 1978)



Splash Erosion

- **Splash erosion** results from the impact of raindrops directly on soil particles or on thin water surfaces.
- Increase turbulence, providing greater sediment-carrying capacity.
- If rain drops fall on crop residue or growing plants the raindrop energy is absorbed, and soil splash is reduced.
- Raindrop impact on bare soil not only causes splash, but also leads to increased runoff.



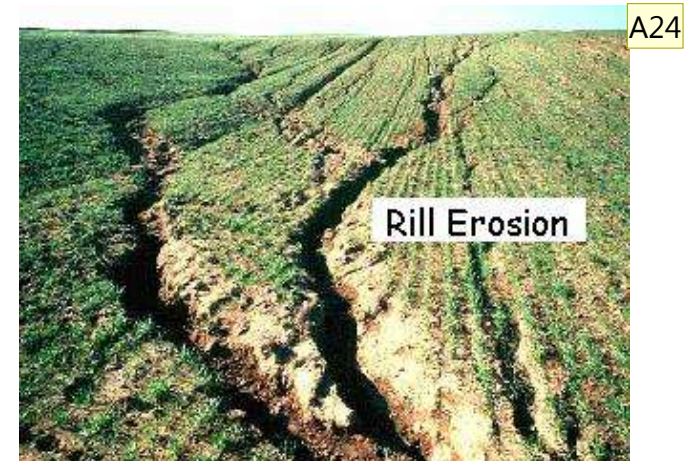
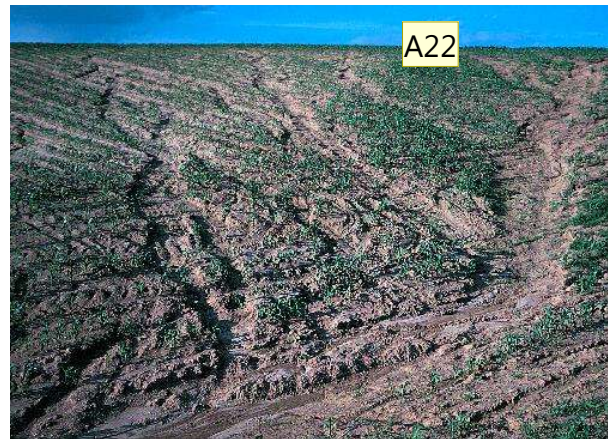
Sheet Erosion

- Is the uniform removal of saturated soil particles conveyed in runoff waters



Rill Erosion

- Is the detachment and transport of soil by a **concentrated** flow of water.
- **Rills** are small channels down an embankment that are about 75 mm (3 inches) or less in depth
- Once the rill exceeds this depth, the formation of **gullies** start
- Rills are small enough to be removed by normal tillage operations.



Slide 19

- A22** http://www.cms.fu-berlin.de/geo/fb/e-learning/geolearning/en/soil_erosion/media_folder/rill_and_gully.jpg
Author, 5/28/2014
- A23** <http://www.fs.fed.us/GRAIP/gallery/Cutslope%20rilling.JPG>
Author, 5/28/2014
- A24** <http://www.swac.umn.edu/classes/soil2125/img/10riller.jpg>
Author, 5/28/2014

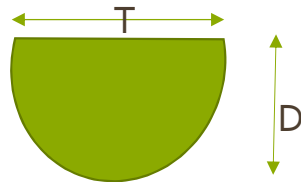
Rill Erosion

- Rill erosion depends of the runoff rate; which is affected by rainfall intensity, soil filtration rates and length of the slope contributing to overland flow.
- **Rill erosion is the most dominant form of erosion on longer and steeper slopes**
- The volume of soil loss in a rill is directly proportional to the width of the rill

How much soil is detached by rill erosion?

- Assume parabolic rill with the width (T) equal to the depth (D)
- Area of parabolic shape:

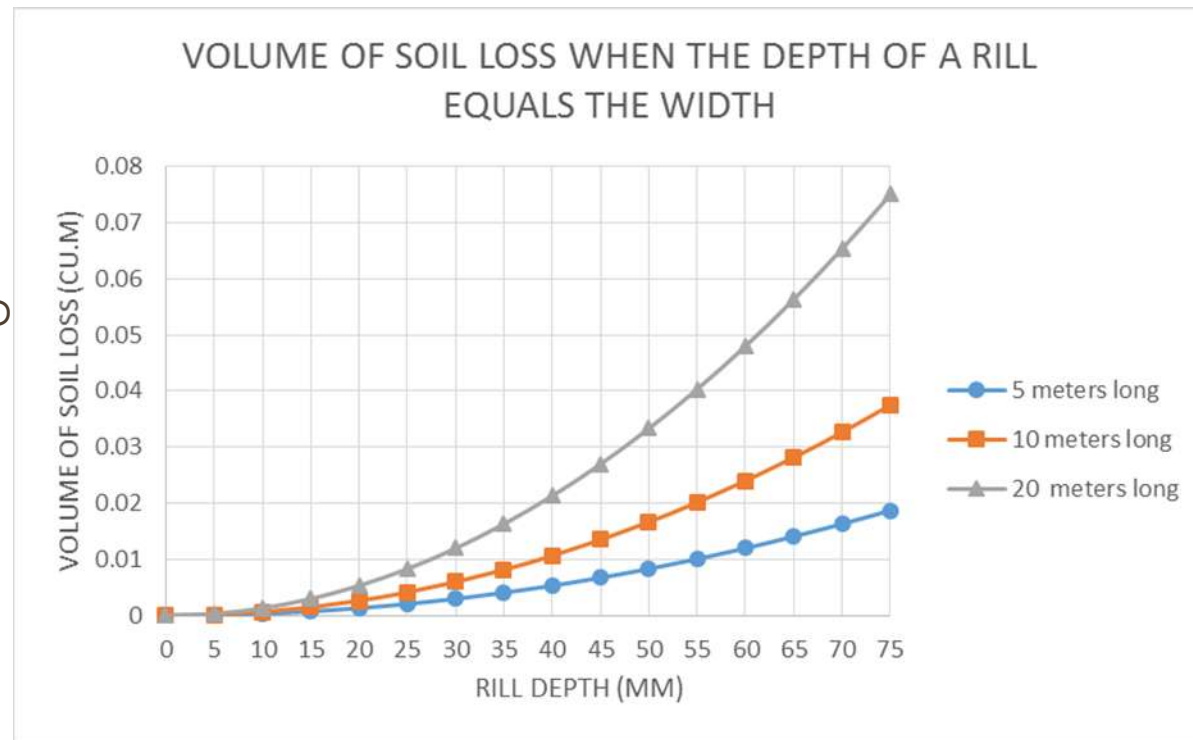
$$A_{rill} = \frac{2}{3} D W$$



- The volume of the rill is:

$$V_{rill} = A_{rill} L = \frac{2}{3} D^2 L$$

- The volume is proportional to the width → rills with twice the depth will loss twice as much soil



A 5 cm wide – 10 m long rill removes 0.017 m³ of soil

If during a rainfall 500 rills are formed the total amount of soil eroded is 8.5 m³ (11.11 y³) !!

A regular truck volume is 7 m³ (9.2 yd.³).

Gully erosion

- Produces channels larger than rills.
- These channels carry water during and immediately after rains.
- The rate of gully erosion depends on runoff, drainage area, soil characteristics, the alignment, size and shape of the gully and, the slope in the channel.
- Gully formation can be reduced or halted by diverting runoff away from the gully or by installing engineering structures at the head of the gully.



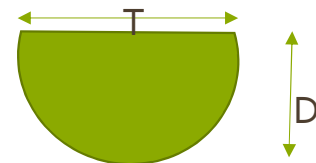
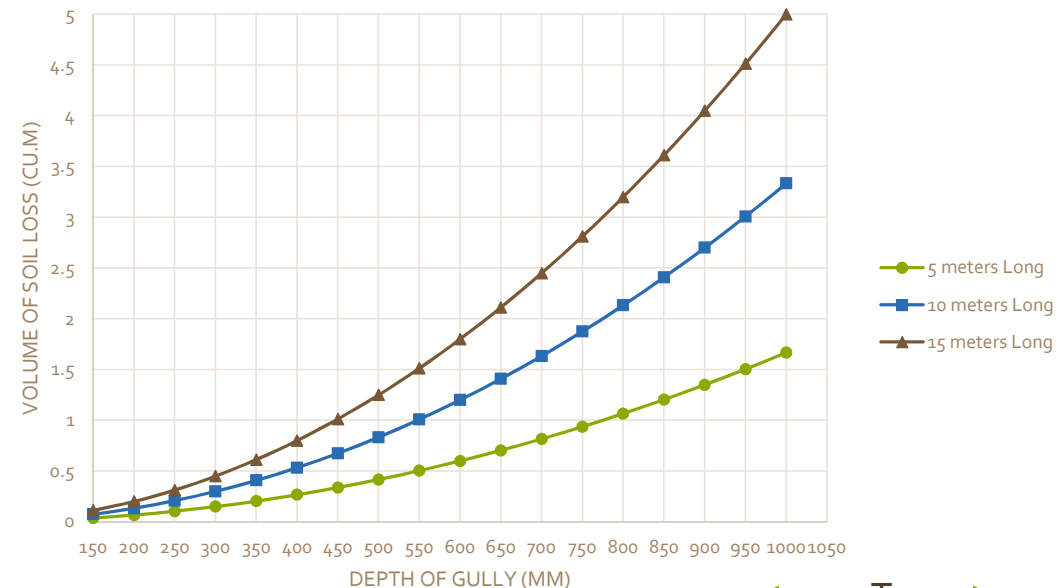
How much soil is detached by rill erosion?

- Once started, the formation of gullies is difficult to stop.
- They are a significant source of sediment
- The amount of sediment from gully erosion is usually less than from rill, but the nuisance from having fields divided by large gullies has been a greater problem.
- Assume parabolic gully with the depth (D) twice the width (T)
- The volume of the gully is:

$$V_{gully} = A_{gully} L = \frac{1}{3} D^2 L$$

A 0.55 m wide – 10 m long – 1 m depth gully removes 1 m³ of soil !

VOLUME OF SOIL LOSS WHEN THE DEPTH OF A GULLY EQUALS TWICE THE WIDTH



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Gully erosion



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- A25** <http://www.google.com.pr/imgres?imgurl=http%3A%2F%2Fpassel.unl.edu%2FImage%2FsiteImages%2FGullyErosi>
Author, 5/28/2014
- A26** [http://www.google.com.pr/imgres?imgurl=http%3A%2F%2Fvro.depi.vic.gov.au%2Fdpi%2Fvro%2Fvroimages.nsf%](http://www.google.com.pr/imgres?imgurl=http%3A%2F%2Fvro.depi.vic.gov.au%2Fdpi%2Fvro%2Fvroimages.nsf%2F)
Author, 5/28/2014
- A27** <http://soer.justice.tas.gov.au/2009/image/1051/lan/id1051-p-GullyErosionPaddock-l.jpg>
Author, 5/28/2014

Stream Channel Erosion

- Consists of soil removal from stream banks or soil movements in the channel.
- Stream banks erode by runoff flowing over the side of the stream bank and mass wasting of the banks.
- Stream bank erosion is often increased by the removal of vegetation, overgrazing, tilling too near the banks, or straightening the channel.
- Scour erosion is influenced by the velocity and direction of flow, depth and width of the channel, and soil texture.

Stream Channel Erosion

- Poor channel alignment and the presence of obstructions such as sandbars increase meandering.
- Meandering is the major cause of erosion along the bank. Straightening channels, however, may increase the rate of scour erosion.





REGULATORY REQUIREMENTS



TOPICS

- Pollutants associated with construction activities
- Regulatory requirements
- National Environmental Policy Act
- Clean Water Act
- National Pollutant Discharge Elimination System
- Storm Water Pollution Prevention Plan
- Federal Enforcement (Section 309 CWA)
- Coastal Zone Management Act (CZMA)
- Resource Conservation and Recovery Act (RCRA) (1976)

Pollutants associated with construction activities

- Runoff from construction sites is regulated and the contractors must comply
- The purpose of regulations is to protect natural resources: lakes, rivers, and air
- Potentially harmful materials addressed:
 - Sediment in runoff from construction sites
 - Wind-borne dust and erosion
 - Industrial, agricultural chemicals concentrations and discharges
 - Hazardous waste discharges



Pollutants associated with construction activities

- Erosion-related pollutants cost the U.S. between \$3.2 billion and \$13 billion each year.
- Pollutants Associated with Construction Activities:
 - Sediment
 - Nutrients, pesticides, and heavy metals
 - Hydrocarbons and other wastes found in runoff waters



Pollutants associated with construction activities

- Sediment loading can be 10 to 20 times greater than soil particles lost where plants grow
- Sediment loads reduces the beneficial uses of water for humans and can harm plants, animals and fish that live in the water



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Pollutants associated with construction activities

- Nutrients (phosphorus and nitrates) come from fertilizers used at construction sites to aid in the establishment of vegetation
- Sediments carry the nutrients and plants use them increasing biomass and robbing water oxygen, killing fish and other organisms
- Pesticides occurs along with nutrients: Herbicides, insecticides and rodenticides



Pollutants associated with construction activities

- Over one half of the trace metals carried in runoff are attached to sediments
- Source of metals are: galvanized metal, paint, and preserved wood
- Nearly all metals are toxic to plants, animals, and fish
- They have the potential to contaminate drinking water



Pollutants associated with construction activities

- Hydrocarbons are the building blocks for many synthetic chemicals used in construction projects
- Soil at the site can become contaminated as a result of leaks from heavy equipment, hydraulic line failures, spills during refueling, and inappropriate disposal of drained fluids.
- Hydrocarbons are washed when runoff occurs, harming plants, and animals.
- Other wastes are:
 - Wash water from concrete mixers.
 - Paints and painting equipment.
 - Wastes from cleaning of vehicles and equipment.
 - Wastes from trees and shrubs removed during land clearing
 - Wood and paper from packaging of building products
 - Food containers: paper, aluminum and metal cans
 - Sanitary wastes



Federal regulatory requirements

- **The National Environmental Policy Act**
- **The Clean Water Act**
- **The Coastal Zone Act Reauthorization Amendments**
- The National Wild and Scenic Rivers Act
- The Endangered Species Act
- The Resource Conservation and Recovery Act
- The Federal Insecticide, Fungicide and Rodenticide Act
- All federally funded projects in the US and its territories must comply with these federal acts.

National Environmental Policy Act (NEPA)

- A method for considering environmental amenities consistent with other national needs.
- The NEPA process mandates the federal government to:
 - administer federal programs in an environmentally safe manner
 - impose environmental responsibilities on all its agencies.
 - identify the environmental impacts of their planned activities
 - determine whether their proposed actions significantly affect the quality of the human environment
 - complete environmental assessment (EA) or environmental impact statements (EIS) on their activities
 - **Projects involving federal funds, oversight, or permits are subject to the NEPA process.**

THE CLEAN WATER ACT PROTECTS MORE THAN WATER.



Walter F. Silva-Ariza

Clean Water Act

- Originally named: the Federal Water Pollution Control Act of 1948 (FWPCA)
 - Limited to state-development ambient water-quality standards applicable to interstate or navigable waters
- Amendments were introduced in 1972 to establish a system of standards, permits, and enforcement for “achieving fishable and swimmable waters” by 1983 and “total elimination of pollutant discharges into navigable water” by 1995.
- In 1977 the FWPCA was amended and renamed as “the Clean Water Act” (CWA).

Clean Water Act

- In 1987 the CWA was amended
- Today is the primary mechanism for protecting and improving water quality
- This law declare unlawful the unregulated discharge of pollutants into all waters of the US
- The CWA provides a comprehensive, nationwide approach to water-quality protection.
- Mandates that states and EPA be jointly responsible for identifying and regulating point and non-point sources of pollution

Clean Water Act

- Unauthorized sediment releases are classified as criminal acts by the Clean Water Act.
- Stormwater runoff from the increase in impervious surfaces in urban areas is a significant threat to water quality.

Clean Water Act

- NON-POINT SOURCE POLLUTION (Sections 208 and 319)
 - Nonpoint source pollution (NPS) represents the most significant source of pollution overall in the country (EPA).
 - Construction activities often lead to an accumulation of pollutants. Pollutants are washed into receiving waters by storm events.
 - Activities associated with construction are subject to state regulations and programs addressing nonpoint-source pollution.
 - The CWA does not provide a detailed definition of nonpoint sources.
 - All nonpoint sources of pollution are caused by runoff of precipitation (rain and/or snow) over or through the ground.
 - Includes stormwater associated with industrial activity, construction-related runoff, and discharges from municipal separated storm sewer systems (MS4s).

Clean Water Act

- NON-POINT SOURCE POLLUTION (Sections 208 and 319)
 - Pollutants commonly associated with NPS include nutrients (phosphorus and nitrogen), pathogens, sediments, oil and grease, and pesticides.
 - States must identify water bodies in which water quality standards cannot be met without control of non-point source pollutants and establish management programs for these water bodies.
 - EPA must approve the plans.
 - The EQB is in charge of NPS regulations in Puerto Rico

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Walter, 5/26/2014

Junta de Calidad Ambiental

- La Junta de Calidad Ambiental es la agencia del Estado Libre Asociado de Puerto Rico que tiene la función principal de proteger y conservar el medioambiente, utilizando sabia y juiciosamente los recursos necesarios para impedir y eliminar daños que puedan afectarlo manteniendo un balance entre el desarrollo económico y el ambiente, a tenor con lo que establece la Ley 416 de septiembre de 2004, mejor conocida como la Ley sobre Política Pública Ambiental.
- La Junta de Calidad Ambiental ha promulgado reglamentos con el propósito principal de establecer las normas que minimicen los daños al ambiente y que establezcan los controles para las actividades que produzcan contaminación.
- En términos generales, la Junta de Calidad Ambiental atiende la contaminación de los terrenos, de los cuerpos de agua y del aire.



National Pollutant Discharge Elimination System (NPDES)

- The CWA makes it illegal to discharge **pollutants** from a **point source**, except in accordance with a **permit**.
- CWA defines a point source as
 - “any discernible, confined and discrete conveyance, including, but not limited to a pipe, ditch, channel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or floating craft from which pollutants are or may be discharged”
- Section 402 of the CWA creates the National Pollutant Discharge Elimination System (NPDES) regulatory and permitting program.
- These permits set limits on the amount of various pollutants that a source can discharge in a given time.
- Point sources must obtain a discharge permit from the proper authority (EPA in the case of Puerto Rico)

National Pollutant Discharge Elimination System (NPDES)

- NPDES permits cover runoff from construction sites disturbing more than one acre.
- All permits state their issuance and expiration date. In accordance with the CWA, permit terms may not exceed five years.
- EPA's regulations require that permit applications be submitted 180 days before discharge (if a new discharger) or before permit expiration (if already an NPDES permit holder).
- Puerto Rico is presently unauthorized to administer the NPDES program
- Therefore, the EPA regional office issues the permits, takes all the enforcement actions, and does the inspections and monitoring visits as necessary.

National Pollutant Discharge Elimination System (NPDES)

- Clean Water Act permit programs are structured to provide permit coverage to point sources in one of two ways:
 - Individual permits
 - General permits
- Individual Permit: developing a unique permit for each discharger
 - An individual facility gets its own unique permit designed for its specific discharge and situation
 - Involve a comprehensive application process
 - Not generally an option for construction activity
- General Permit: developing a single permit that covers a large number of similar dischargers
 - the permitting authority identifies a large number of similar facilities and determines that the permit conditions that would apply to these facilities would be virtually identical

National Pollutant Discharge Elimination System (NPDES)

- General permits required if
 - Disturbing one acre or more
 - Disturbing less than one acre, but activity is part of a larger common development or sale
- AND
 - Stormwater will discharge into a MS₄ or “Waters of the United States”

NPDES Permits Elements

- Effluent limits
- Best management practices
- Compliance Schedule
- Monitoring Requirements
- Reporting Requirements

Storm Water Pollution Prevention Plan



Storm Water Pollution Prevention Plan

- EPA has included the category under “stormwater associated with industrial activity” runoff from construction sites.
- Construction activities disturbing one or more acres need NPDES permits.
- At a minimum, these permits require development of a site-specific Stormwater Pollution Prevention Plan, covering the construction and the post-construction phases of the project.



Storm Water Pollution Prevention Plan

- A Stormwater Pollution Prevention Plan (SWPPP) must include:
 - Site description, including a map that identifies sources of stormwater discharges.
 - Anticipated drainage patterns after major grading.
 - Areas where major structural and nonstructural measures will be employed to control pollutants.
 - Surface waters: including wetlands, and locations of discharge points to surface waters.
 - The SWPPP also describes measures that will be employed
 - Stabilization of disturbed areas of the site no more than 14 days after construction activity has ceased.

FEDERAL ENFORCEMENT (Section 309 CWA)

- Citizens can institute civil actions against EPA, other government agency, any person or the US that is alleged to be in violation of:
 - An effluent standard or limitation
 - An order issued by EPA or a state with respect to such a standard or limitation
- EPA: if there is allegedly a failure of EPA to perform any act or duty that it is required to complete
- Civil, administrative and judicial penalties are associated with illegal discharges of polluted stormwater

FEDERAL ENFORCEMENT (Section 309 CWA)

- Types of Violations
 - Discharge without a permit
 - **Permit effluent exceedance**
 - Non-effluent permit violations
 - Failure to submit required monitoring reports
 - Falsification of monitoring/other data
 - Failure to meet construction schedule deadlines

FEDERAL ENFORCEMENT (Section 309 CWA)

- CRIMINAL PENALTIES
 - **Negligent violations:** fines of \$2,500 to \$50,000- per day for each violation and/or imprisonment for one to two years
 - **Knowing violations:** fines of \$5,000 to \$100,000 per day for each violation
 - **Knowing endangerment that could cause death or serious bodily injury:** fines of \$250,000 to \$2 million and/or imprison for 30 years
 - **False statements, representations or certifications:** fines of \$10,000 to \$20,000 and/or imprisonment for six months per violation.
 - **Administrative penalties:** \$11,000 to \$177,500 per violation.

Coastal Zone Management Act (CZMA)

- The CZMA of 1972 intent to “preserve, protect, develop and, where possible, restore or enhance the resources of the Nation’s coastal zone for this and succeeding generations”
- Coastal zones includes the territories of the US
- Areas subject to CZMA include wetlands, floodplains, estuaries, beaches, dunes, barrier islands, coral reefs, and fish and wildlife habitats.
- The Coastal Zone Act Reauthorization Amendments of 1990 (CZARA) directed state coastal and nonpoint-source programs to address non-point source pollution issues affecting coastal waters.
- Projects affecting coastal waters, ecology, or land use may require additional permitting and/or compliance with state laws or local zoning regulations.

Resource Conservation and Recovery Act (RCRA) (1976)

- Gives EPA authority to regulate disposal of hazardous wastes
- Requires tracking of hazardous wastes and development of hazardous wastes management plans approved by EPA
- The US Dept. of Transportation has enforcement responsibilities for the transport of hazardous wastes.
- RCRA may have impact on highway construction and maintenance projects; depending on the nature of the activity, proximity to receiving waters and characteristics of the site.

Resource Conservation and Recovery Act (RCRA) (1976)

- Construction activities using the following materials are subject to the RCRA:
 - Storage, use and disposal of solid wastes (Plastics, metals, wood, rubber).
 - Petroleum or petroleum-based products (oils, greases)
 - Other chemicals used in construction (detergents, paints, solvents)



REVIEW



NRCS CN-Method

For estimation of Direct Runoff

Reference: *Urban Hydrology for Small Watersheds (TR-55)*, USDA, 1986.

NRCS CN-Method

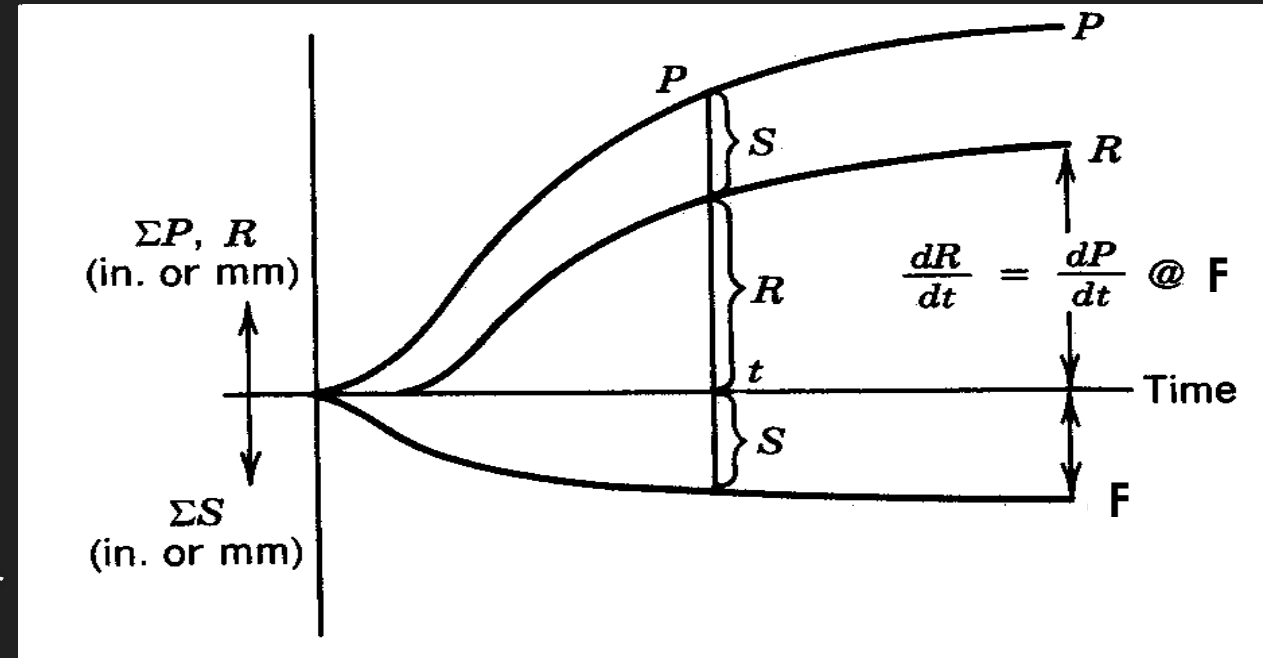
- Rainfall excess (R) and watershed storage (F) are derived from precipitation and soil type.
- A conservation of mass relationship would be: **$R = P - F$**
 - R = rainfall excess (runoff)
 - P = rainfall volume
 - F = storage volume on and within the soil (initial abstractions plus infiltration)

The Curve Number Method

- A proportional relationship was proposed by Mockus:

$$\frac{F}{S} = \frac{R}{P}$$

- S = potential maximum retention after runoff begins (in)



The Curve Number Method

○ Since $F = P - R$ then

$$\frac{(P - R)}{S} = \frac{R}{P} \quad \Rightarrow \quad R = \frac{P^2}{P + S}$$

○ This is the rainfall-runoff relationship in which the initial abstraction is zero

The Curve Number Method

- When the initial abstraction is not zero, the amount of rainfall available for runoff is :

$$(P - I_a)$$

- Substituting in the previous equation results in:
$$R = \frac{(P - I_a)^2}{(P - I_a) + S}$$

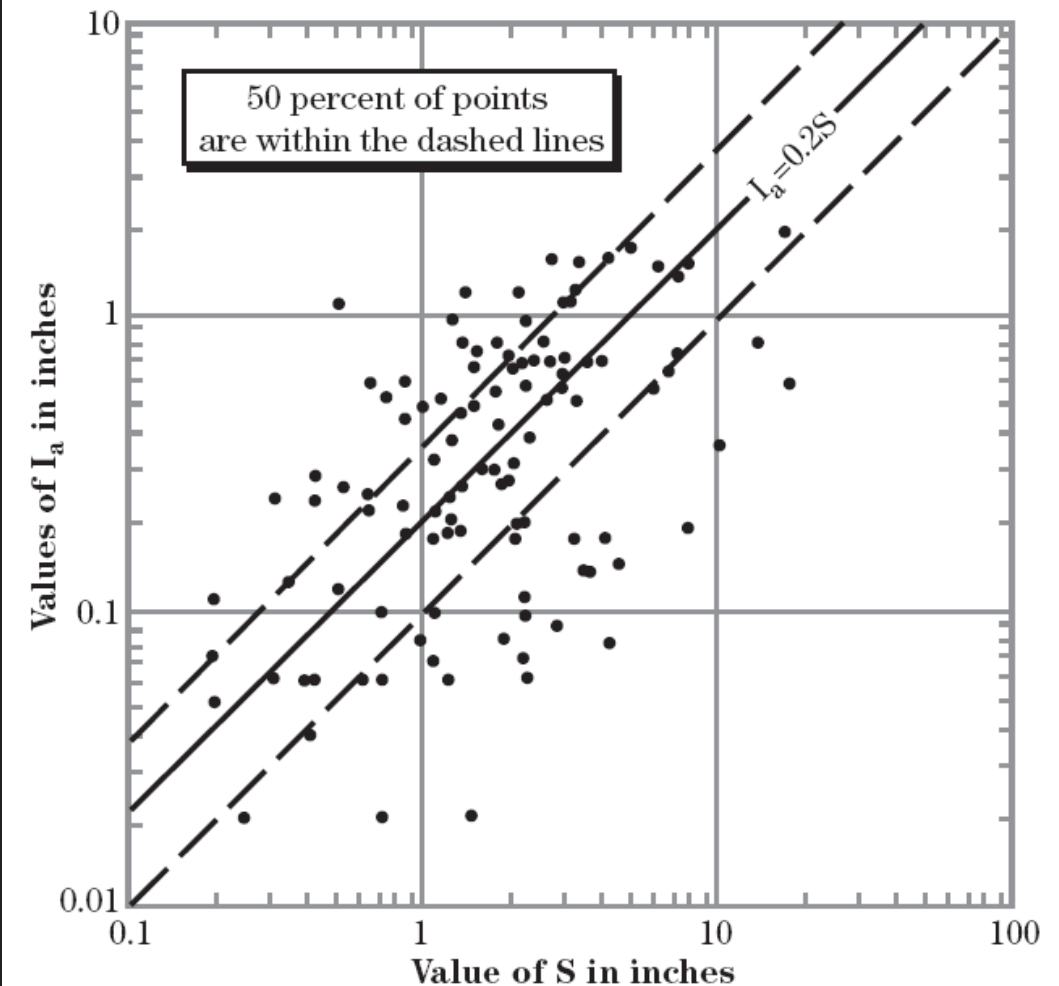
- This is the rainfall-runoff relationship with the initial abstraction explicitly taken into account.
- An empirical relationship between Initial Abstractions (I_a) and S was expressed as

$$I_a = 0.2 S$$

The Curve Number Method

- This figure illustrates the variability for this relationship.
- The points plotted in the figure are derived from experimental watershed data.

Figure 10-1 Relationship between I_a and S



The Curve Number Method

- S is related to soil and cover conditions of the watershed.
- Using more than 3000 soil types divided into four hydrologic groups the NRCS developed curve numbers (CN) to estimate S
- CN is a transformation of S given as:

- For S in inches:
$$CN = \frac{1000}{10 + S}$$

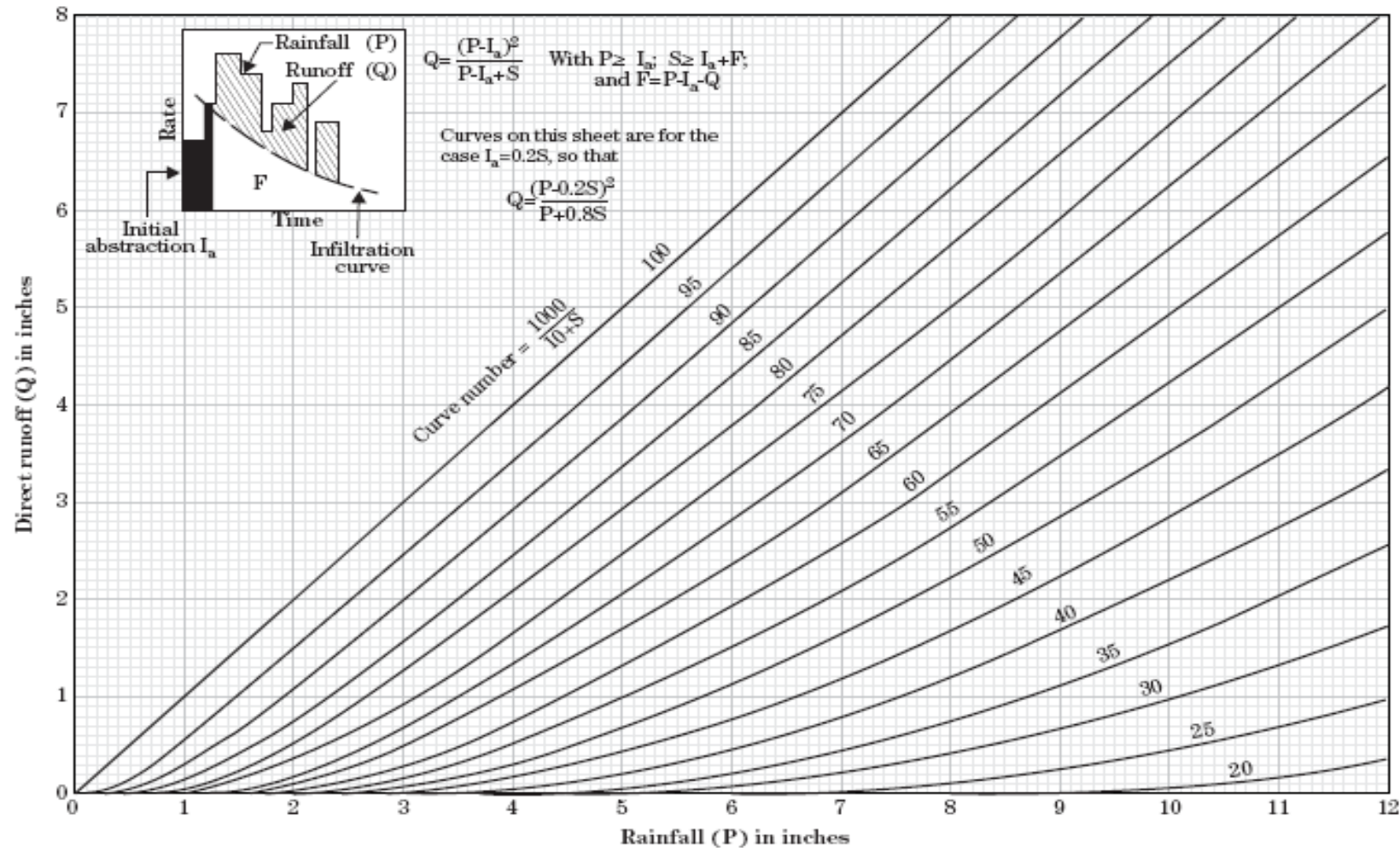
- For S in mm
$$CN = \frac{1000}{10 + \frac{S}{25.4}}$$

- Finally the rainfall excess for $P > 0.2S$ is:
$$R = \frac{(P - 0.2S)^2}{P + 0.8S}$$

- $R = 0$ if $P < 0.2S$

The Curve Number Method

Figure 10-2 ES-1001 graphical solution of the equation $Q = \frac{(P - 0.2S)^2}{P + 0.8S}$



Factors considered in determining runoff curve numbers

○ The major factors that determine CN are

1. the hydrologic soil group (HSG)

2. cover type

3. treatment

4. hydrologic condition

5. antecedent moisture condition (AMC)

Factors considered in determining runoff curve numbers: **Hydrologic soil groups**

- Infiltration rates of soils vary widely and are affected by subsurface permeability as well as surface intake rates.
- Soils are classified into hydrologic soil groups (HSG's) to indicate the minimum rate of infiltration obtained for bare soil after prolonged wetting.
- The HSG's are A, B, C, and D
- TR-55 lists the HSG classification
- The infiltration rate is the rate at which water enters the soil at the soil surface. It is controlled by surface conditions.
- HSG also indicates the transmission rate—the rate at which the water moves within the soil. This rate is controlled by the soil profile

Factors considered in determining runoff curve numbers: **Hydrologic soil groups**

○

The four groups are defined by SCS soil scientists as follows:

- **Group A** soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).
- **Group B** soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15- 0.30 in/hr).
- **Group C** soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).
- **Group D** soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

Factors considered in determining runoff curve numbers: **Cover type**

- Cover types could be vegetation, bare soil, and impervious surfaces.
- There are a number of methods for determining cover type.
- The most common are field reconnaissance, aerial photographs, and land use maps.

Factors considered in determining runoff curve numbers: **Treatment**

- *Treatment* is a cover type modifier to describe the management of cultivated agricultural lands.
- It includes mechanical practices, such as contouring and terracing, and management practices, such as crop rotations and reduced or no tillage..

Factors considered in determining runoff curve numbers: **Hydrologic condition**

- **Hydrologic condition** indicates the effects of cover type and treatment on infiltration and runoff and is generally estimated from density of plant and residue cover on sample areas.
- **Good** hydrologic condition indicates that the soil usually has a low runoff potential for that specific hydrologic soil group, cover type, and treatment.
- Some factors to consider in estimating the effect of cover on infiltration and runoff are
 - canopy or density of lawns, crops, or other vegetative areas
 - amount of year-round cover
 - amount of grass or close-seeded legumes in rotations
 - percent of residue cover
 - degree of surface roughness.

Factors considered in determining runoff curve numbers: **Antecedent moisture conditions**

- The index of runoff potential before a storm event is the antecedent moisture condition (AMC).
- AMC is an attempt to account for the variation in CN at a site from storm to storm.
- CN for the average AMC at a site is the median value as taken from sample rainfall and runoff data.
 - **Condition I:** Soils are dry but not to wilting point; satisfactory cultivation has taken place
 - **Condition II:** Average Conditions
 - **Condition III:** Heavy rainfall, or light rainfall with low temperatures have occurred within the last five days; saturated soil

Curve numbers

Table 10-1 Curve numbers (CN) and constants for the case $I_a = 0.2S$

1	2	3	4	5	1	2	3	4	5
CN for ARC II	-- CN for ARC -- I	III	S values* (in)	Curve* starts where P = (in)	CN for ARC II	-- CN for ARC -- I	III	S values* (in)	Curve* starts where P = (in)
100	100	100	0	0	60	40	78	6.67	1.33
99	97	100	.101	.02	59	39	77	6.95	1.39
98	94	99	.204	.04	58	38	76	7.24	1.45
97	91	99	.309	.06	57	37	75	7.54	1.51
96	89	99	.417	.08	56	36	75	7.86	1.57
95	87	98	.526	.11	55	35	74	8.18	1.64
94	85	98	.638	.13	54	34	73	8.52	1.70
93	83	98	.753	.15	53	33	72	8.87	1.77
92	81	97	.870	.17	52	32	71	9.23	1.85
91	80	97	.989	.20	51	31	70	9.61	1.92
90	78	96	1.11	.22	50	31	70	10.0	2.00
89	76	96	1.24	.25	49	30	69	10.4	2.08
88	75	95	1.36	.27	48	29	68	10.8	2.16
87	73	95	1.49	.30	47	28	67	11.3	2.26
86	72	94	1.63	.33	46	27	66	11.7	2.34
85	70	94	1.76	.35	45	26	65	12.2	2.44
84	68	93	1.90	.38	44	25	64	12.7	2.54
83	67	93	2.05	.41	43	25	63	13.2	2.64
82	66	92	2.20	.44	42	24	62	13.8	2.76
81	64	92	2.34	.47	41	23	61	14.4	2.88
80	63	91	2.50	.50	40	22	60	15.0	3.00
79	62	91	2.66	.53	39	21	59	15.6	3.12
78	60	90	2.82	.56	38	21	58	16.3	3.26
77	59	89	2.99	.60	37	20	57	17.0	3.40
76	58	89	3.16	.63	36	19	56	17.8	3.56
75	57	88	3.33	.67	35	18	55	18.6	3.72
74	55	88	3.51	.70	34	18	54	19.4	3.88
73	54	87	3.70	.74	33	17	53	20.3	4.06
72	53	86	3.89	.78	32	16	52	21.2	4.24
71	52	86	4.08	.82	31	16	51	22.2	4.44
70	51	85	4.28	.86	30	15	50	23.3	4.66
69	50	84	4.49	.90	25	12	43	30.0	6.00
68	48	84	4.70	.94	20	9	37	40.0	8.00
67	47	83	4.92	.98	15	6	30	56.7	11.34
66	46	82	5.15	1.03	10	4	22	90.0	18.00
65	45	82	5.38	1.08	5	2	13	190.0	38.00
64	44	81	5.62	1.12	0	0	0	infinity	infinity
63	43	80	5.87	1.17					
62	42	79	6.13	1.23					
61	41	78	6.39	1.28					

* For CN in column 1.

Curve Numbers tables

Runoff curve numbers for urban areas ^{1/}

Cover description		Curve numbers for hydrologic soil group			
Cover type and hydrologic condition	Average percent impervious area ^{2/}	A	B	C	D
<i>Fully developed urban areas (vegetation established)</i>					
Open space (lawns, parks, golf courses, meteries, etc.) ^{3/} :					
Poor condition (grass cover < 50%)		68	79	86	89
Fair condition (grass cover 50% to 75%)		49	69	79	84
Good condition (grass cover > 75%)		39	61	74	80
Impervious areas:					
Paved parking lots, roofs, driveways, etc. (excluding right-of-way)		98	98	98	98
Streets and roads:					
Paved; curbs and storm sewers (excluding right-of-way)		98	98	98	98
Paved; open ditches (including right-of-way)		83	89	92	93
Gravel (including right-of-way)		76	85	89	91
Dirt (including right-of-way)		72	82	87	89
Western desert urban areas:					
Natural desert landscaping (pervious areas only) ^{4/}		63	77	85	88
Artificial desert landscaping (impervious weed barrier, desert shrub with 1- to 2-inch sand or gravel mulch and basin borders)		96	96	96	96
Urban districts:					
Commercial and business	85	89	92	94	95
Industrial	72	81	88	91	93
Residential districts by average lot size:					
1/8 acre or less (town houses)	65	77	85	90	92
1/4 acre	38	61	75	83	87
1/3 acre	30	57	72	81	86
1/2 acre	25	54	70	80	85
1 acre	20	51	68	79	84
2 acres	12	46	65	77	82
<i>Developing urban areas</i>					
Newly graded areas					
(pervious areas only, no vegetation) ^{5/}		77	86	91	94
Idle lands (CN's are determined using cover types similar to those in table 2-2c).					

^{1/} Average runoff condition, and $I_a = 0.2S$.

^{2/} The average percent impervious area shown was used to develop the composite CN's. Other assumptions are as follows: impervious areas are directly connected to the drainage system, impervious areas have a CN of 98, and pervious areas are considered equivalent to open space in good hydrologic condition. CN's for other combinations of conditions may be computed using figure 2-3 or 2-4.

^{3/} CN's shown are equivalent to those of pasture. Composite CN's may be computed for other combinations of open space cover type.

^{4/} Composite CN's for natural desert landscaping should be computed using figures 2-3 or 2-4 based on the impervious area percentage (CN = 98) and the pervious area CN. The pervious area CN's are assumed equivalent to desert shrub in poor hydrologic condition.

^{5/} Composite CN's to use for the design of temporary measures during grading and construction should be computed using figure 2-3 or 2-4 based on the degree of development (impervious area percentage) and the CN's for the newly graded pervious areas.

Curve Numbers tables

Runoff curve numbers for cultivated agricultural lands ^{1/}

----- Cover description -----			Curve numbers for hydrologic soil group -----			
Cover type	Treatment ^{2/}	Hydrologic condition ^{3/}	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

¹ Average runoff condition, and $I_a=0.2S$

² Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.

³ Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good $\geq 20\%$), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Curve Numbers tables

Runoff curve numbers for other agricultural lands ^{1/}

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. ^{2/}	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. ^{3/}	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 ^{4/}	48	65	73
Woods—grass combination (orchard or tree farm). ^{5/}	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. ^{6/}	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 ^{4/}	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

^{1/} Average runoff condition, and $I_a = 0.2S$.

^{2/} *Poor:* <50% ground cover or heavily grazed with no mulch.

Fair: 50 to 75% ground cover and not heavily grazed.

Good: >75% ground cover and lightly or only occasionally grazed.

^{3/} *Poor:* <50% ground cover.

Fair: 50 to 75% ground cover.

Good: >75% ground cover.

^{4/} Actual curve number is less than 30; use CN = 30 for runoff computations.

^{5/} CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.

^{6/} *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.

Fair: Woods are grazed but not burned, and some forest litter covers the soil.

Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Composite curve number

- Watersheds contain subareas with different infiltration characteristics.
- These watersheds can be routed separately or combined by the use of a *composite curve number*
- A *composite CN* is defined as an areal weighted average of the curve numbers for the watershed subregions

$$\overline{CN} = \frac{\sum CN_i A_i}{\sum A_i}$$

$\overline{CN}$ = Composite Curve Number

A_i = watershed area for region i

CN_i = Curve Number for region i

Limitations

1. Curve numbers describe average conditions that are useful for design purposes. If the rainfall event used is a historical storm, the modeling accuracy decreases.
2. Use the runoff curve number equation with caution when re-creating specific features of an actual storm. The equation does not contain an expression for time and, therefore, does not account for rainfall duration or intensity.
3. The user should understand the assumption reflected in the initial abstraction term (I_a) and should ascertain that the assumption applies to the situation. I_a , which consists of interception, initial infiltration, surface depression storage, evapotranspiration, and other factors, was generalized as $0.2S$ based on data from agricultural watersheds (S is the potential maximum retention after runoff begins).
4. This approximation can be especially important in an urban application because the combination of impervious areas with pervious areas can imply a significant initial loss that may not take place. The opposite effect, a greater initial loss, can occur if the impervious areas have surface depressions that store some runoff.
5. To use a relationship other than $I_a = 0.2S$, one must redevelop the procedure by using the original rainfall-runoff data to establish new S or CN relationships for each cover and hydrologic soil group.
6. Runoff from snowmelt or rain on frozen ground cannot be estimated using these procedures.
7. The CN procedure is less accurate when runoff is less than 0.5 inch. As a check, use another procedure to determine runoff.
8. The SCS runoff procedures apply only to direct surface runoff: do not overlook large sources of subsurface flow or high ground water levels that contribute to runoff. These conditions are often related to HSG A soils and forest areas that have been assigned relatively low CN 's.
9. Good judgment and experience based on stream gage records are needed to adjust CN 's as conditions warrant.
10. When the weighted CN is less than 40, use another procedure to determine runoff.

NRCS Time of concentration formulas

- Time of concentration (T_c) is approximated as the time for runoff to travel from the hydraulically most distant point of the watershed to a point of interest within the watershed.
- The NRCS provided an equation for estimating the watershed time of concentration.
- This parameter is necessary to estimate the peak flow produced by a rainfall event

$$T_c = \frac{l^{0.8} \left(\frac{1000}{CN} - 9 \right)^{0.7}}{1,140 Y^{0.5}}$$

T_c = Time of concentration in hours

l = hydraulic length of watershed in feet

CN= Curve Number

Y = average watershed land slope in percent (%)

NRCS Time of concentration formula

- This equation is for use on watersheds where overland flow dominates and was developed for non-urban watersheds. The NRCS recommended the formula for homogeneous watersheds 2000 acres and less. The method primarily reflects concentrated flow.
- While the 1986 TR-55 does not include this formula, McCuen et al (1984) demonstrated to accurate for areas up to 4000 acres.
- Another version of the equation is:

$$T_c = 0.00526 L^{0.8} \left(\frac{1000}{CN} - 9 \right)^{0.7} S^{-0.5}$$

T_c time of concentration in minutes

S = average watershed land slope in ft/ft

L = hydraulic length of watershed in feet

Estimating Urban Time of Concentration

by **Richard H. McCuen**, Member, ASCE, (Prof., Dept. of Civ. Engrg., Univ. of Maryland, College Park, Md. 20972),
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Walter J. Rawls, Member, ASCE, (Hydro., USDA-ARS, Hydrology Laboratory, Beltsville, Md. 20705)
Journal of Hydraulic Engineering, Vol. 110, No. 7, July 1984, pp. 887-904

Estimation of Peak Runoff Rate

- Graphical Method from NRCS
- Developed from hydrograph analysis
- Depends on the CN method
- The peak discharge equation is: $Q_p = q_u A Q F$

Q_p = Peak discharge (ft³/s)

q_u = Unit peak discharge (ft³/s per mile per inch of runoff)

A = drainage area (mi²)

F = adjustment factor for ponds and swamps

Q = runoff depth (in)

Estimation of Peak Runoff Rate

1. Select the 24 hr rainfall for the project site from NOAA Atlas 14 (P)
2. Compute CN and total runoff (Q) are previously explained. Use AMC II
3. Use CN to determine the initial abstractions (I_a)
Could use the next table to obtain I_a
4. Compute I_a/P
5. Obtain the Unit Peak Discharge (q_u) from the figures provided (only Type II storms are included here)
6. Adjust for ponds or swamps according to percentage of pond and swamp areas using provided table
7. Substitute in equation for Q_p

Table 4-1 I_a values for runoff curve numbers

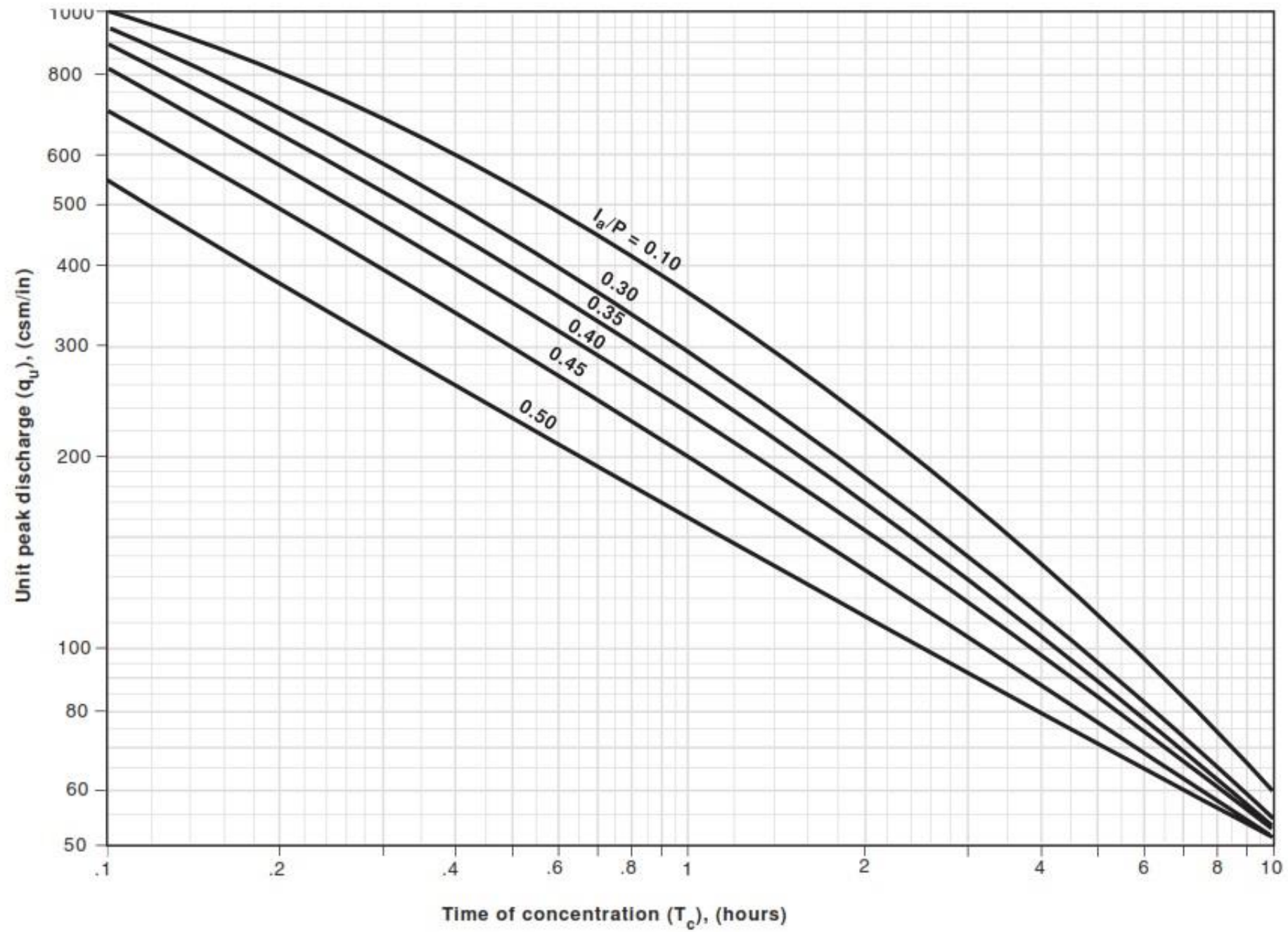
Curve number	I_a (in)	Curve number	I_a (in)
40	3.000	70	0.857
41	2.878	71	0.817
42	2.762	72	0.778
43	2.651	73	0.740
44	2.545	74	0.703
45	2.444	75	0.667
46	2.348	76	0.632
47	2.255	77	0.597
48	2.167	78	0.564
49	2.082	79	0.532
50	2.000	80	0.500
51	1.922	81	0.469
52	1.846	82	0.439
53	1.774	83	0.410
54	1.704	84	0.381
55	1.636	85	0.353
56	1.571	86	0.326
57	1.509	87	0.299
58	1.448	88	0.273
59	1.390	89	0.247
60	1.333	90	0.222
61	1.279	91	0.198
62	1.226	92	0.174
63	1.175	93	0.151
64	1.125	94	0.128
65	1.077	95	0.105
66	1.030	96	0.083
67	0.985	97	0.062
68	0.941	98	0.041
69	0.899		

Estimation of Peak Runoff Rate

Table 4-2 Adjustment factor (F_p) for pond and swamp areas that are spread throughout the watershed

Percentage of pond and swamp areas	F_p
0	1.00
0.2	0.97
1.0	0.87
3.0	0.75
5.0	0.72

Unit peak discharge (q_u) for NRCS (SCS) type II rainfall distribution



Example

- Compare the peak flows from Type A and Type C soils generated during a 2.7 in rainfall over 6 ac (6.18 cuerdas) of newly graded ground.
- The slope of the watershed is 4%.
- The time of concentration is 10 minutes
- Solution
 1. Rainfall = 2.7 in
 2. CN = 77 (Type A) , CN = 91 (Type C) (graded ground)
 $Q = 0.87$ in , $Q = 1.79$ in (SCS formula)
 3. $I_a = 0.597$ (Type A), $I_a = 0.198$ (Type C)
 $S = 2.98$ (Type A), $S = 0.99$ (Type C) (From table or formula)

Example (cont)

○ Solution (cont.)

4. $I_a/P = 0.597/2.7 = 0.22$ (Type A), 0.0733 (Type C)

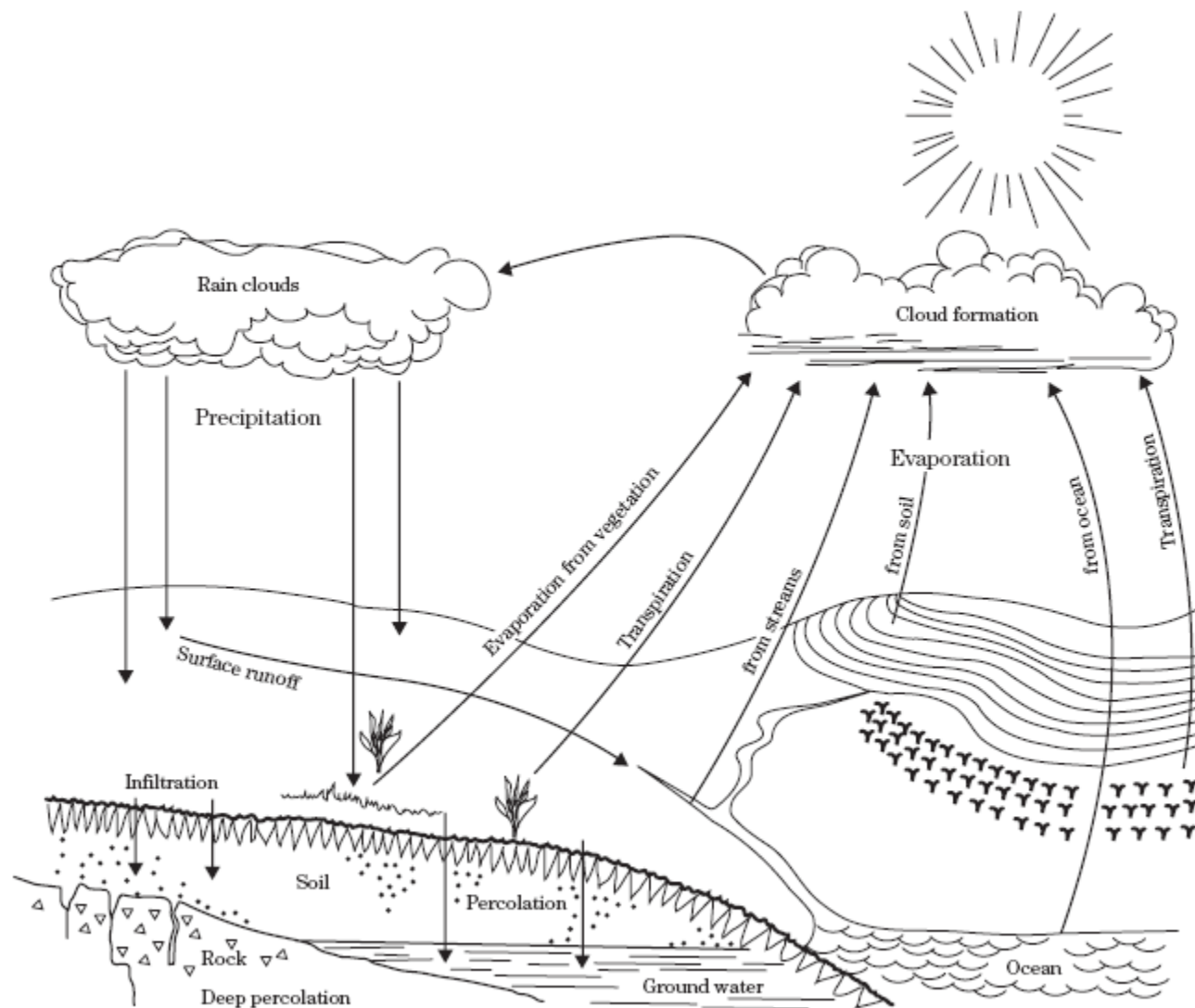
5. Unit Peak Discharge: $q_u = 810$ csm/in (from graph)

6. No ponds

7. $Q_p = 810 \times 6/640 \times 0.87 \times 1 = 6.6$ cfs (Type A)

$$Q_p = 810 \times 6/640 \times 1.79 \times 1 = 13.6 \text{ cfs (Type C)}$$

Careful with units and conversion factors





Estimating Soil Losses



Introduction

- Soil losses or relative erosion rates are estimated to assist contractors, farmers, natural resource managers, and governments agencies in evaluating existing management systems or in future planning to minimize soil losses.
- Between 1945 and 1965 a method of estimating losses was developed that resulted in the universal field soil loss equation (**USLE**).
- A revised version of the USLE (**RUSLE**) has been developed for computer applications.
- A **RUSLE 2** Version with a windows interface is now available and greatly increased the capacities of the RUSLE.
(<http://www.ars.usda.gov/Research/docs.htm?docid=6038>)

The Universal Soil Loss Equation (USLE)

- Widely accepted method for estimating sediment loss.
- Useful for determining the adequacy of conservation measures in resource planning and for predicting nonpoint sediment losses in pollution control programs.
- Has been modified and adapted to different regions of the world and for use at urban or highway construction sites (USDA, USEPA)
- The **average annual soil** loss can be estimated from the equation:

$$A = R K S L C P$$

Average Annual Soil Level (USLE)

$$A = R K SL C P$$

Where:

- A=annual erosion rate or soil loss in tons/acre per year (dry weight)
- R= Rainfall and runoff erosivity factor for a geographic location. (Rainfall Index)
- K= Soil erodibility factor
- LS= the slope steepness and length factor
- C= Cover Factor
- P= Conservation or management practice factor.

Rainfall Erosivity R

- Erosion index for a given storm period.
- Product of rainfall energy times maximum 30-minutes rainfall intensity
- Units: 100 ft-tons in/(ac h) = 17 MJ-mm /(ha h)
- In USLE: R is based on 2yr – 6hr rainfall data
- **How to estimate R for Puerto Rico?**
 - R depends on rainfall
 - ATLAS 14 from NOAA provides Precipitation Frequency-Duration Data for Puerto Rico
 - NOAA Atlas 14: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_pr.html
 - USDA (1972) established relationship between TYPE II, 2 yr frequency – 6 hr duration rainfall and Annual Rainfall Erosion Index (R)
 - Type II distribution rainfall is commonly used for design in Puerto Rico

Rainfall Erosivity R (Annual Index)

- Locate the coordinates of your area of study: Lat. 18,4399 Long -66.2903
- Determine the value of the precipitation corresponding to 2 yr- 6 hr rainfall from Atlas 14

POINT PRECIPITATION FREQUENCY (PF) ESTIMATES
WITH 90% CONFIDENCE INTERVALS AND SUPPLEMENTARY INFORMATION
NOAA Atlas 14, Volume 3, Version 4

PF tabular PF graphical Supplementary information

AMS-based precipitation frequency estimates with 90% confidence intervals

Duration	Annual exceedance probability (1/years)					
	1/2	1/5	1/10	1/25	1/50	1/100
5-min	0.437 (0.406-0.472)	0.571 (0.530-0.615)	0.656 (0.607-0.708)	0.762 (0.702-0.825)	0.839 (0.770-0.913)	0.917 (0.835-1.00)
10-min	0.598 (0.556-0.645)	0.780 (0.724-0.841)	0.897 (0.830-0.967)	1.04 (0.959-1.13)	1.15 (1.05-1.25)	1.25 (1.14-1.37)
15-min	0.767 (0.714-0.827)	1.00 (0.930-1.08)	1.15 (1.06-1.24)	1.34 (1.23-1.45)	1.47 (1.35-1.60)	1.61 (1.47-1.76)
30-min	1.23 (1.14-1.32)	1.60 (1.49-1.73)	1.84 (1.71-1.99)	2.14 (1.97-2.32)	2.36 (2.16-2.56)	2.58 (2.35-2.81)
60-min	1.82 (1.70-1.97)	2.38 (2.21-2.57)	2.73 (2.53-2.95)	3.18 (2.93-3.44)	3.50 (3.21-3.80)	3.82 (3.48-4.17)
2-hr	2.31 (2.12-2.52)	3.16 (2.90-3.45)	3.73 (3.40-4.07)	4.44 (4.03-4.88)	4.99 (4.50-5.49)	5.54 (4.95-6.13)
3-hr	2.54 (2.32-2.80)	3.55 (3.22-3.91)	4.23 (3.83-4.68)	5.13 (4.60-5.70)	5.83 (5.16-6.50)	6.54 (5.75-7.35)
6-hr	3.11 (2.77-3.52)	4.53 (4.02-5.12)	5.54 (4.89-6.27)	6.91 (6.03-7.86)	7.99 (6.91-9.14)	9.11 (7.78-10.5)
12-hr	3.67 (3.20-4.24)	5.53 (4.82-6.39)	6.94 (5.98-8.02)	8.90 (7.58-10.3)	10.5 (8.83-12.2)	12.2 (10.1-14.3)
24-hr	4.23 (3.79-4.77)	6.54 (5.85-7.33)	8.33 (7.43-9.31)	10.9 (9.63-12.1)	12.9 (11.4-14.5)	15.2 (13.3-17.0)

P = 3.11 inches

Assume TYPE II distribution to use:

$$R = 27 P^{2.2} = 27 \times 3.11^{2.2}$$

$$R = 328$$

Rainfall Erosivity R (Monthly Adjustment RUSLE2)

This values are more accurate than other methods

Mayaguez, Puerto Rico

Month	R values, US
Jan	10
Feb	12
Mar	21
Apr	42
May	89
Jun	65
Jul	71
Aug	98
Sep	100
Oct	97
Nov	46
Dec	10
TOTAL	661

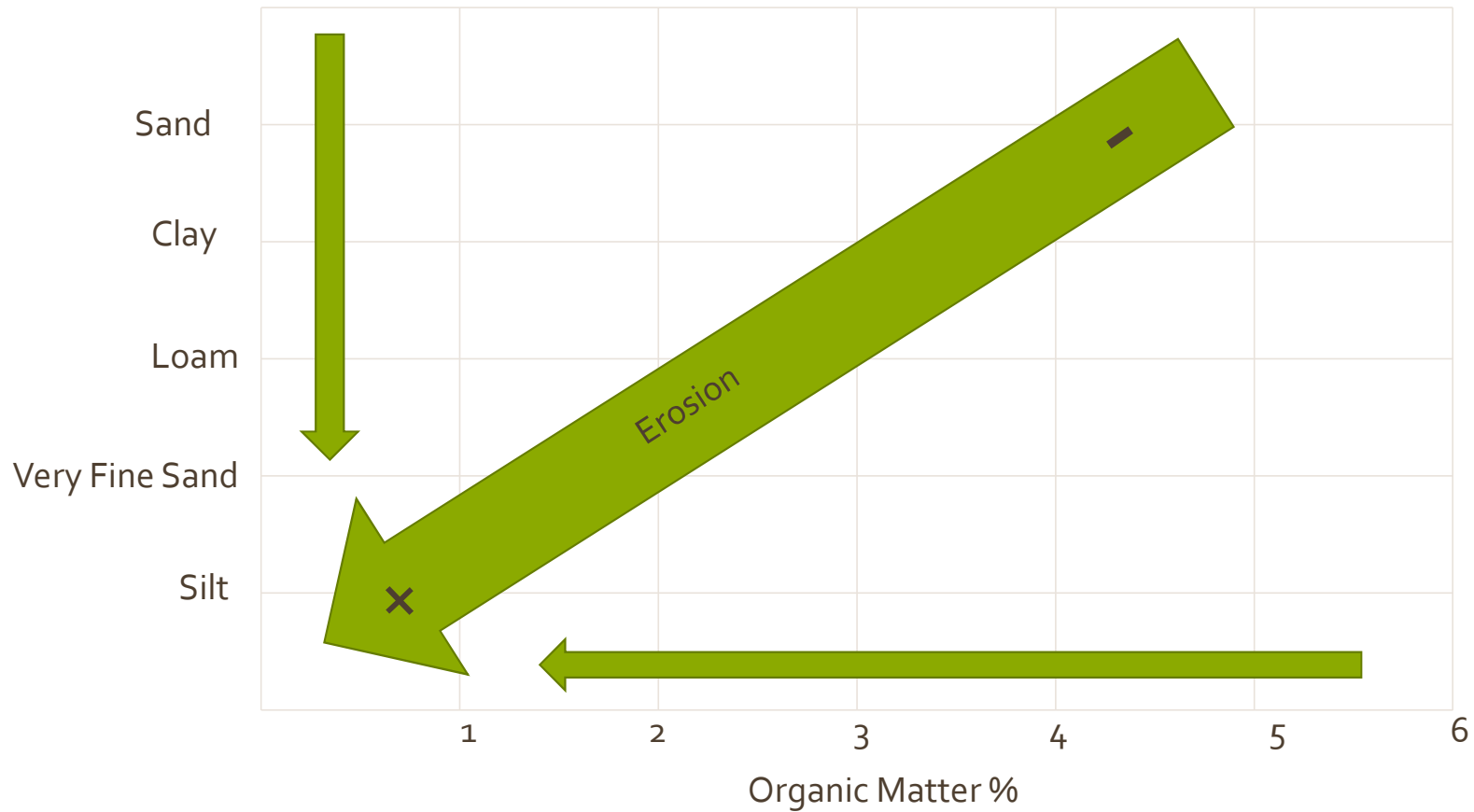
Soil Erodibility (K)

- Erosion rate for specific soil in fallow condition on a 9% slope having a length of 22.1 m
- Obtained by direct soil loss measurements from fallow plots located in many U.S. states .
- Soils that have silt contents tend to be the more erodible.
- The presence of organic matter, stronger subsoil structure, and greater permeabilities generally decrease erodibility.
- Soil erodibility factors for the 10 most common soils in Puerto Rico are presented in the next table.

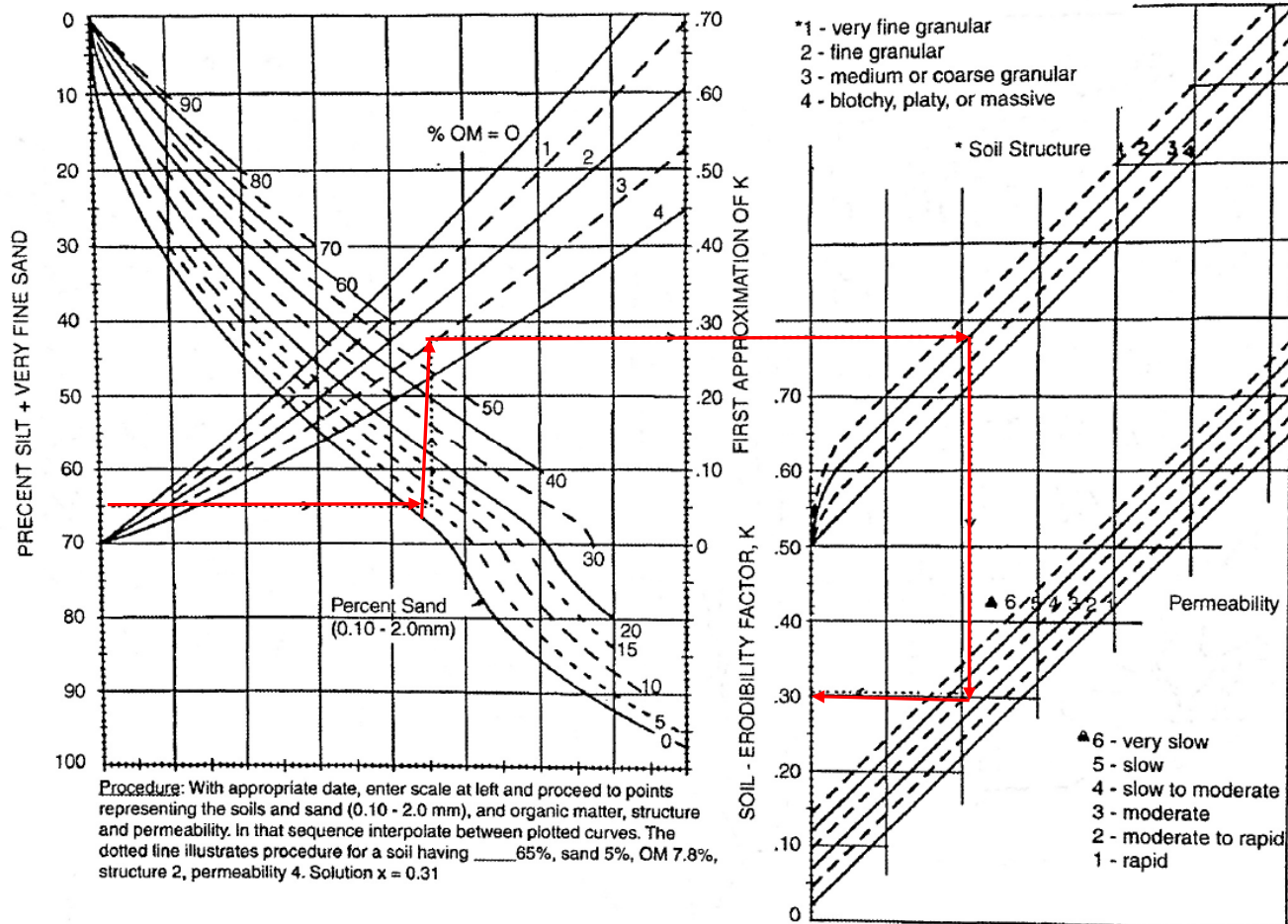
Puerto Rico					
Mucara	D	0.10–0.10	Descalabrado	D	0.24–0.24
Caguabo	D	0.24–0.24	Pandura	D	0.17–0.17
Humatas	C	0.02–0.02	Soller	D	0.17–0.17
Consumo	B	0.10–0.10	Naranjito	C	0.10–0.10
Los Guineos	C	0.10–0.10	Callabo	C	0.10–0.10

Soil Erodibility (K)

Soil Factor



Soil Erodibility (K): NOMOGRAM



Example:
 Determine the soil erodibility K for a soil with the following properties; 65% silt and very fine sand; 5% sand; 2.8% organic matter content (OM); a fine granular soil structure; and a slow to moderate permeability.

Answer:
 $K = 0.31$

Erodibility factors are available at USDA web site

Topographic Factor LS (length and slope steepness)

- The topographic factor LS adjusts the predicted erosion rates to give greater erosion rates in longer and steeper slopes and lower erosion rates on shorter or flatter slopes compared to a USLE “standard” slope of 9% and slope length of 72.6 ft.
- The slope length is measured from the point where surface flow originates (usually the top of the ridge) to the outlet channel or a point downslope where deposition begins.



A28
A29

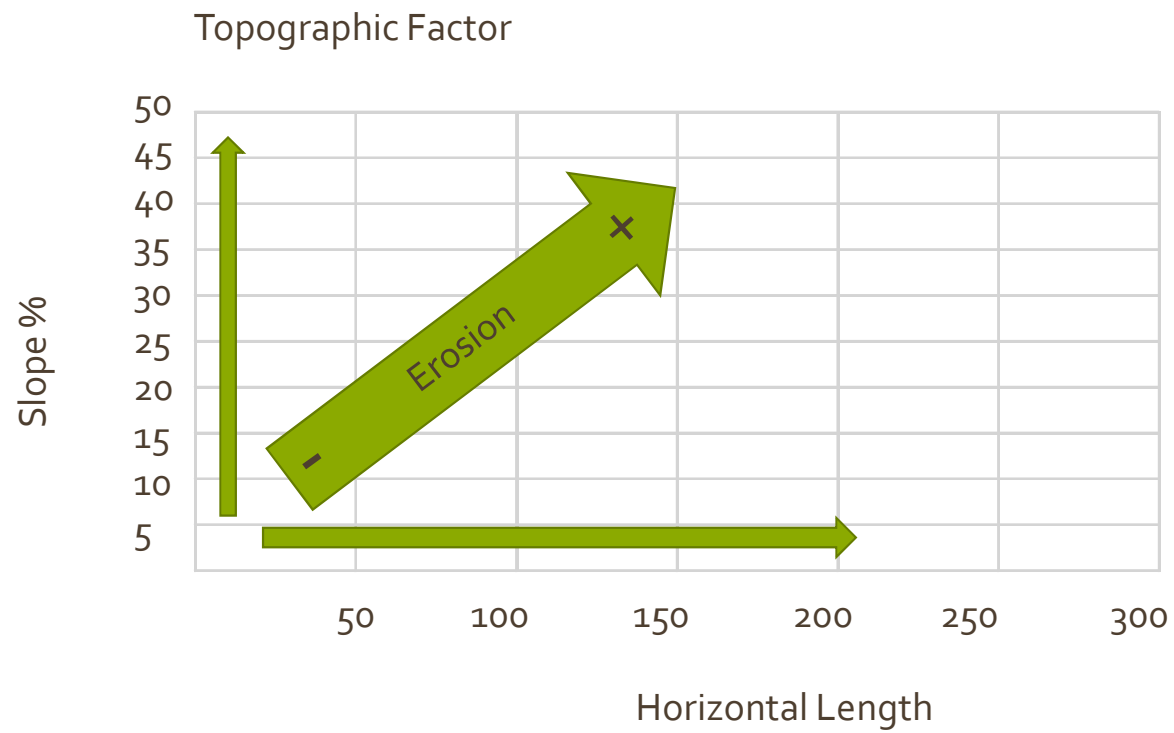


Slide 11

A28 Author, 5/27/2014

A29 <http://www.cesperieni.ro/page3.html>
Author, 5/27/2014

Topographic Factor LS



Topographic Factor LS

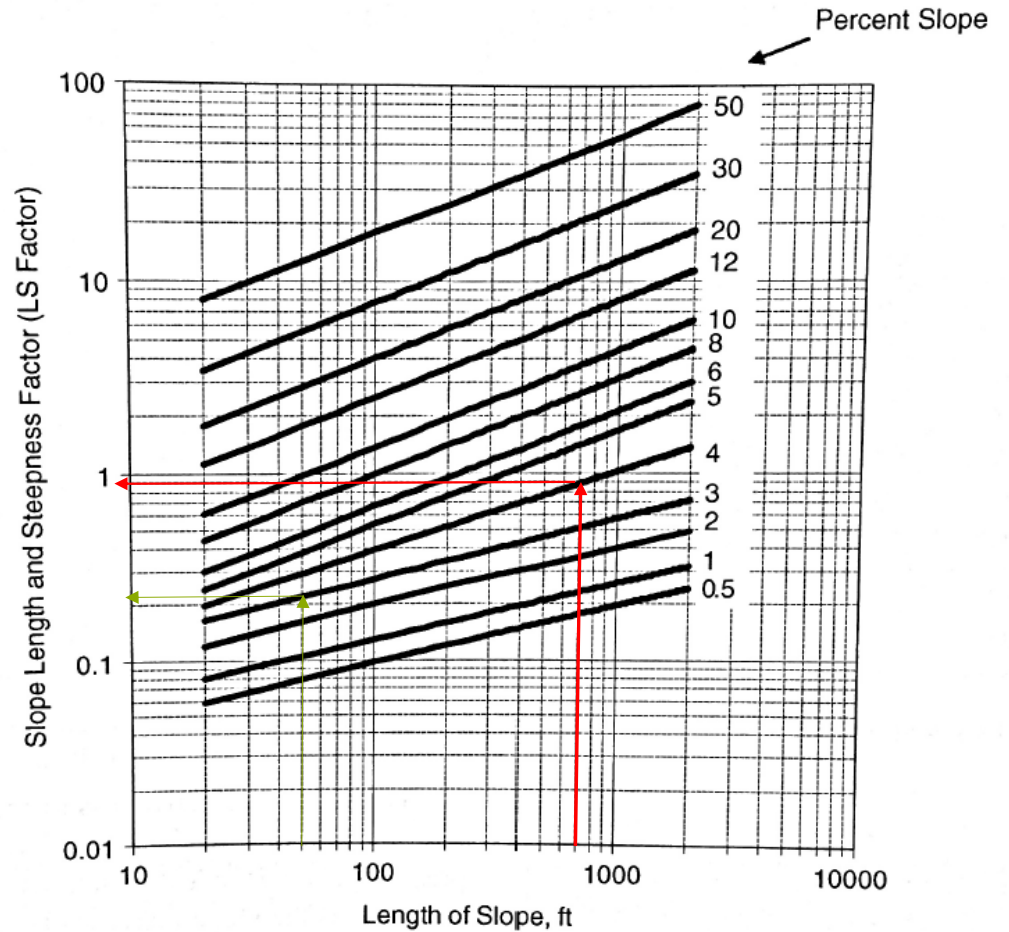
Example:

Determine the LS factor for the field with a slope steepness of 4% and a slope length of 700 ft.

Answer:

LS=0.9

Use this for non-construction sites



LS Values for construction sites

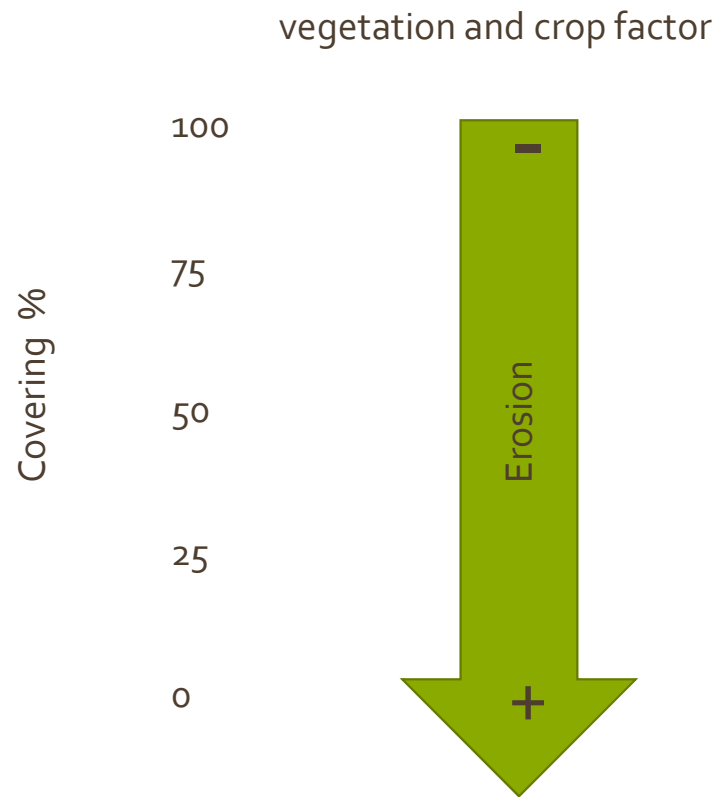
LS Values for Freshly Prepared Construction and other Highly Disturbed Soil, with Little, or No Cover
(Renard, *et al.* 1987).

Slope %	Slope Length in Feet															
	<3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.11	0.12	0.13
1.0	0.09	0.09	0.09	0.09	0.09	0.10	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.22	0.24	0.27
2.0	0.13	0.13	0.13	0.13	0.13	0.16	0.21	0.25	0.28	0.33	0.37	0.40	0.43	0.48	0.56	0.63
3.0	0.17	0.17	0.17	0.17	0.17	0.21	0.30	0.36	0.41	0.50	0.57	0.64	0.69	0.80	0.96	1.10
4.0	0.20	0.20	0.20	0.20	0.20	0.26	0.38	0.47	0.55	0.68	0.79	0.89	0.98	1.14	1.42	1.65
5.0	0.23	0.23	0.23	0.23	0.23	0.31	0.46	0.58	0.68	0.86	1.02	1.16	1.28	1.51	1.91	2.25
6.0	0.26	0.26	0.26	0.26	0.26	0.36	0.54	0.69	0.82	1.05	1.25	1.43	1.60	1.90	2.43	2.89
8.0	0.32	0.32	0.32	0.32	0.32	0.45	0.70	0.91	1.10	1.43	1.72	1.99	2.24	2.70	3.52	4.24
10.0	0.35	0.37	0.38	0.39	0.40	0.57	0.91	1.20	1.46	1.92	2.34	2.72	3.09	3.75	4.95	6.03
12.0	0.36	0.41	0.45	0.47	0.49	0.71	1.15	1.54	1.88	2.51	3.07	3.60	4.09	5.01	6.67	8.17
14.0	0.38	0.45	0.51	0.55	0.58	0.85	1.40	1.87	2.31	3.09	3.81	4.48	5.11	6.30	8.45	10.40
16.0	0.39	0.49	0.56	0.62	0.67	0.98	1.64	2.21	2.73	3.68	4.56	5.37	6.15	7.60	10.26	12.69
20.0	0.41	0.56	0.67	0.76	0.84	1.24	2.10	2.86	3.57	4.85	6.04	7.16	8.23	10.24	13.94	17.35
25.0	0.45	0.64	0.80	0.93	1.04	1.56	2.67	3.67	4.59	6.30	7.88	9.38	10.81	13.53	18.57	23.24
30.0	0.48	0.72	0.91	1.08	1.24	1.86	3.22	4.44	5.58	7.70	9.67	11.55	13.35	16.77	23.14	29.07
40.0	0.53	0.85	1.13	1.37	1.59	2.41	4.24	5.89	7.44	10.35	13.07	15.67	18.17	22.95	31.89	40.29
50.0	0.58	0.97	1.31	1.62	1.91	2.91	5.16	7.20	9.13	12.75	16.16	19.42	22.57	28.60	39.95	50.63
60.0	0.63	1.07	1.47	1.84	2.19	3.36	5.97	8.37	10.63	14.89	18.92	22.78	26.51	33.67	47.18	59.93

Cover Management Factor “C”

- Ratio of soil loss from an area with specified cover to that from the same area but under bare soil conditions
- Includes the effects of vegetative cover, crop sequence, productivity level, length of growing season, tillage practices, residue management, **BMP's for sediment and erosion control at construction sites**
- Values range from 1 for bare soil down to 0.003 for well-established plant cover
- Factors C must be adjusted during construction because ground surface conditions differ from original cover
- Conditions could refer to
 - Before grading
 - During grading
 - During Construction
 - After Construction

Cover Management Factor “C”



Cover index factor C for construction sites.

TYPE OF COVER	FACTOR C	%*
None (fallow ground)	1.0	0.0
Temporary seedings (90% stand):		
Ryegrass (perennial type)	0.05	95
Ryegrass (annuals)	0.1	90
Small grain	0.05	95
Millet or sudan grass	0.05	95
Field brome grass	0.03	97
Permanent seedings (90% stand)	0.01	99
Sod (laid immediately)	0.01	99
Mulch:		
Hay rate of application, tons per acre:		
1½	0.25	75
1	0.13	87
1½	0.07	93
2	0.02	98
Small grain straw	0.02	98
Wood chips	0.06	94
Wood cellulose	0.1	90
Fiberglass	0.05	95
Asphalt emulsion (1250 gals/acre)	0.02	98
Fiber matting, excelsior, gravel, and stone may also be used as protective cover.		

*Percent soil loss reduction as compared with fallow ground.
(From USDA Soil Conservation Service, 1978)

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Ground surface condition factor C for construction sites.

SURFACE CONDITION WITH NO COVER	FACTOR*
Compact and smooth, scraped with bulldozer or scraper up and down hill	1.3
Same condition except raked with bulldozer root rake up and down hill	1.2
Compact and smooth, scraped with bulldozer or scraper across the slope	1.2
Same condition except raked with bulldozer root rake across the slope	0.9
Loose as a disced plow layer	1.0
Rough irregular surface equipment tracks in all directions	0.9
Loose with rough surface greater than 12" depth	0.8
Loose with smooth surface greater than 12" depth	0.9

*Values based on estimates.
(From USDA Soil Conservation Service, 1978)

USLE C-FACTOR AND P-FACTOR VALUES FOR CONSTRUCTION-SITE RAINFALL BMPS
(ISRAELSEN ET AL., 1980; HDI, 1987; SCS, 1978; AND WISCHMEIER AND SMITH, 1978)

TREATMENT	C-FACTOR	P-FACTOR
Bare Soil		
Packed and smooth	1.00	1.00
Freshly disked or rough, irregular surface	1.00	0.90
Sediment Containment Systems (a.k.a. Sediment Trap/Basin)	1.00	0.10-0.90 ^A
Bale or Sandbag Barriers	1.00	0.90
Rock (Diameter = 25-50 mm) Barriers at Sump Location	1.00	0.80
Silt-Fence Barrier	1.00	0.60
Asphalt/Concrete Pavement	0.01	1.00
Gravel (Diameter = 60-400 mm) at 300 tonnes/ha	0.05	1.00
Established Vegetation		1.00
Sod Grass	0.01	1.00
Temporary Vegetation/Cover Crop	0.45 ^B	1.00
Hydraulic Mulch at 4.5 tonnes/ha	0.10 ^C	1.00
Soil Sealant	0.10 - 0.60 ^D	1.00
Rolled Erosion Control Products	0.10 - 0.30 ^D	1.00
Hay or Straw Dry Mulch Applied at 4.5 tonnes/ha and anchored <i>Assumes planting of grass seed has occurred before application, otherwise C-factor = 1.00.</i>		
Slope (%)		
1 to 10	0.06	1.00
11 to 15	0.07	1.00
16 to 20	0.11	1.00
21 to 25	0.14	1.00
26 to 33	0.17	1.00
> 33	0.20	1.00
Contour Furrowed Surface <i>Must be maintained throughout construction activities, otherwise P-factor = 1.00. Maximum length refers to downslope length.</i>		
Slope (%) Max. Length (m)		
1 to 2 120	1.00	0.60
3 to 5 90	1.00	0.50
6 to 8 60	1.00	0.50
9 to 12 40	1.00	0.60
13 to 16 25	1.00	0.70
17 to 20 20	1.00	0.80
> 20 15	1.00	0.80

- ^A Should be constructed as the first step in over-lot grading.
^B Assumes planting occurs within optimal climatic conditions.
^C Some limitation on use in arid and semiarid climates.
^D Value used must be substantiated by documentation.

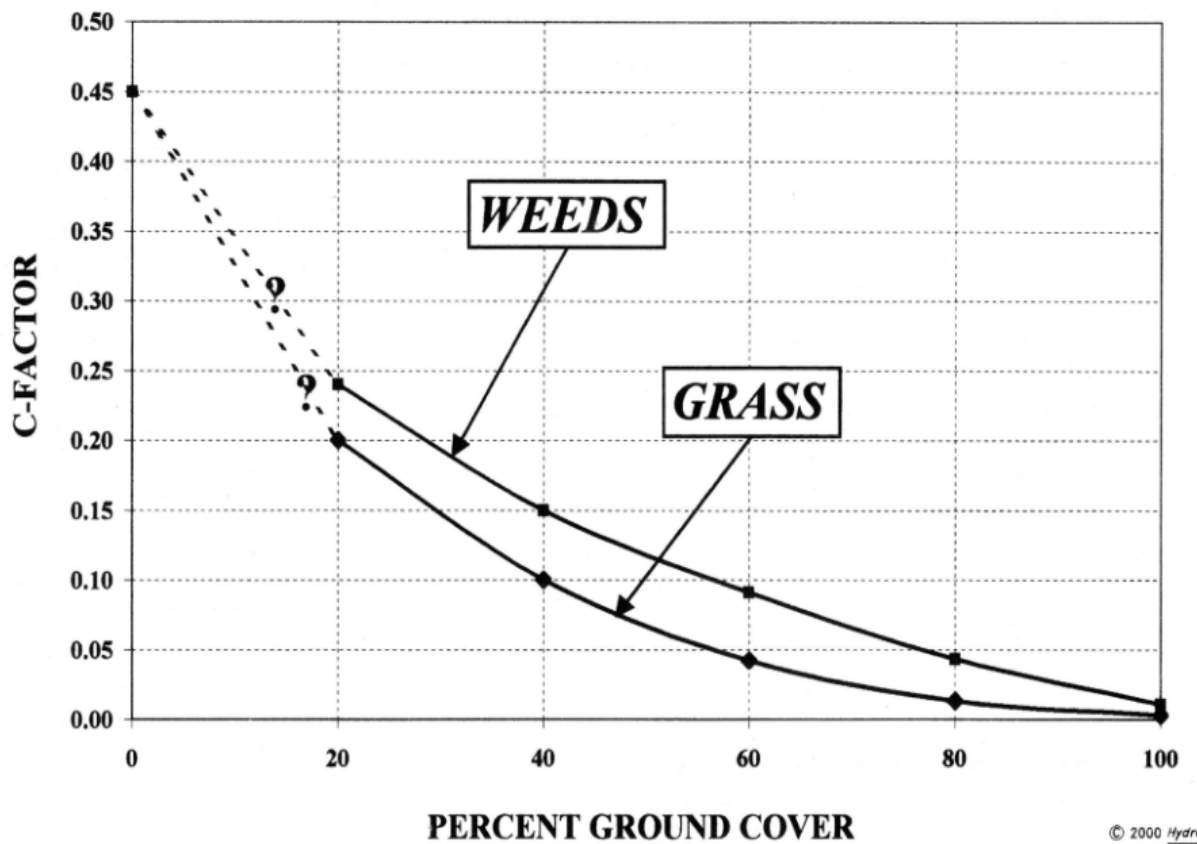
Walter F Silva, Ph.D., PE

TREATMENT	C-FACTOR	P-FACTOR
Terracing <i>Must contain 2-year runoff volumes without overflowing, otherwise P-factor = 1.00</i>		
Slope (%)		
1 to 2	1.00	0.12
3 to 8	1.00	0.10
9 to 12	1.00	0.12
13 to 16	1.00	0.14
17 to 20	1.00	0.16
> 20	1.00	0.18
Grass Buffer Strips to Filter Sediment-Laden Sheet Flows <i>Strips must be at least 15 m (50 ft.) wide and have a ground-cover value of 65% or greater, otherwise P-factor = 1.00.</i>		
Basin Slope		
0% to 10%	1.00	0.60
11% to 24%	1.00	0.80

NOTE: Use of C-factor or P-factor values not in this table must be supported by documentation.

Fifield J., 2011

NO APPRECIABLE CANOPY



C-Factor Values for Established Grass and Weeds (Wischmeier and Smith,

C factors for pasture, rangeland, and idle land.¹

VEGETAL CANOPY		COVER THAT CONTACTS THE SURFACE						
TYPE AND HEIGHT OF RAISED CANOPY ²	CANOPY COVER ³ %	TYPE ⁴	PERCENT GROUND COVER					
			0	20	40	60	80	95-100
COLUMN NO.:	2	3	4	5	6	7	8	9
No appreciable canopy		G	.45	.20	.10	.042	.013	.003
		W	.45	.24	.15	.090	.043	.011
Canopy of tall weeds or short brush (0.5 m fall ht.)	25	G	.36	.17	.09	.038	.012	.003
		W	.36	.20	.13	.082	.041	.011
	50	G	.26	.13	.07	.035	.012	.003
		W	.26	.16	.11	.075	.039	.011
	75	G	.17	.10	.06	.031	.011	.003
		W	.17	.12	.09	.067	.038	.011
Appreciable brush or bushes (2 m fall ht.)	25	G	.40	.18	.09	.040	.013	.003
		W	.40	.22	.14	.085	.042	.011
	50	G	.34	.16	.085	.038	.012	.003
		W	.34	.19	.13	.081	.041	.011
	75	G	.28	.14	.08	.036	.012	.003
		W	.28	.17	.12	.077	.040	.011
Trees but no appreciable low brush (4 m fall ht.)	25	G	.42	.19	.10	.041	.013	.003
		W	.42	.23	.14	.087	.042	.011
	50	G	.39	.18	.09	.040	.013	.003
		W	.39	.21	.14	.085	.042	.011
	75	G	.36	.17	.09	.039	.012	.003
		W	.36	.20	.13	.083	.041	.011

¹All values shown assume: (1) random distribution of mulch or vegetation, and (2) mulch of appreciable depth where it exists.

²Average fall height of waterdrops from canopy to soil surface: m = meters.

³Portion of total-area surface that would be hidden from view by canopy in a vertical projection (a bird's-eye view).

⁴G: Cover at surface is grass, grasslike plants, decaying compacted duff, or litter at least 2 inches deep.

W: Cover at surface is mostly broadleaf herbaceous plants (as weeds) with little lateral-root network near the surface, and/or undecayed residue.

Source: USDA Soil Conservation Service, 1978

Change in soil condition

- Original land was 60% rangeland with brushes and weeds. Small canopy cover.
- Was cleared using bulldozers with scrappers up and down the hill
- Determine the relative erosion increase associated with this land use:
 - Before: Grass and brushes:
 - During clearing:
- Change in land increases soil loss by



Erosion Control Practice P (Management practice factor)

- Ratio of soil lost with a given surface condition to soil loss from a hill where plowing is perpendicular to the contours
- There are practices besides vegetation management that can be employed to control erosion.
- Erosion control practices includes contouring, strip cropping, terracing and stabilized waterways.
- When no erosion control practices are used the P factor is 1.0.
- Values range from 0.80 for contouring on steep slopes (18 to 24%) to 0.10 for terracing on gentle slopes

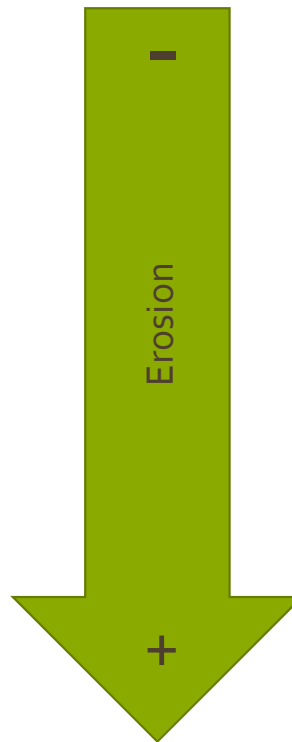
Erosion Control Practice P

Terracing*

Strip cropping

Contour

None



* Must contain the 2-yr runoff volume
Without overflowing, otherwise $P = 1$

USLE C-FACTOR AND P-FACTOR VALUES FOR CONSTRUCTION-SITE RAINFALL BMPS
(ISRAELSEN ET AL., 1980; HDI, 1987; SCS, 1978; AND WISCHMEIER AND SMITH, 1978)

TREATMENT	C-FACTOR	P-FACTOR
Bare Soil		
Packed and smooth	1.00	1.00
Freshly disked or rough, irregular surface	1.00	0.90
Sediment Containment Systems (a.k.a. Sediment Trap/Basin)	1.00	0.10-0.90 ^A
Bale or Sandbag Barriers	1.00	0.90
Rock (Diameter = 25-50 mm) Barriers at Sump Location	1.00	0.80
Silt-Fence Barrier	1.00	0.60
Asphalt/Concrete Pavement	0.01	1.00
Gravel (Diameter = 60-400 mm) at 300 tonnes/ha	0.05	1.00
Established Vegetation	Figs. 3-4 & 3-5	1.00
Sod Grass	0.01	1.00
Temporary Vegetation/Cover Crop	0.45 ^B	1.00
Hydraulic Mulch at 4.5 tonnes/ha	0.10 ^C	1.00
Soil Sealant	0.10 - 0.60 ^D	1.00
Rolled Erosion Control Products	0.10 - 0.30 ^D	1.00
Hay or Straw Dry Mulch Applied at 4.5 tonnes/ha and anchored <i>Assumes planting of grass seed has occurred before application, otherwise C-factor = 1.00.</i>		
Slope (%)		
1 to 10	0.06	1.00
11 to 15	0.07	1.00
16 to 20	0.11	1.00
21 to 25	0.14	1.00
26 to 33	0.17	1.00
> 33	0.20	1.00
Contour Furrowed Surface <i>Must be maintained throughout construction activities, otherwise P-factor = 1.00. Maximum length refers to downslope length.</i>		
Slope (%) Max. Length (m)		
1 to 2 120	1.00	0.60
3 to 5 90	1.00	0.50
6 to 8 60	1.00	0.50
9 to 12 40	1.00	0.60
13 to 16 25	1.00	0.70
17 to 20 20	1.00	0.80
> 20 15	1.00	0.80

- ^A Should be constructed as the first step in over-lot grading.
^B Assumes planting occurs within optimal climatic conditions.
^C Some limitation on use in arid and semiarid climates.
^D Value used must be substantiated by documentation.

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TREATMENT	C-FACTOR	P-FACTOR
Terracing <i>Must contain 2-year runoff volumes without overflowing, otherwise P-factor = 1.00</i>		
Slope (%)		
1 to 2	1.00	0.12
3 to 8	1.00	0.10
9 to 12	1.00	0.12
13 to 16	1.00	0.14
17 to 20	1.00	0.16
> 20	1.00	0.18
Grass Buffer Strips to Filter Sediment-Laden Sheet Flows <i>Strips must be at least 15 m (50 ft.) wide and have a ground-cover value of 65% or greater, otherwise P-factor = 1.00.</i>		
Basin Slope		
0% to 10%	1.00	0.60
11% to 24%	1.00	0.80

NOTE: Use of C-factor or P-factor values not in this table must be supported by documentation.

Fifield J., 2011

Erosion Control Practice P

- Contouring: conducting field operations such as tillage, planting, and harvesting, approximately on the contour.



Slide 24

- A30** http://watershedbmps.com/wp-content/uploads/2012/09/ContourFarming_plantandsoil_unl_edu.jpg
Author, 5/27/2014
- A31** <http://www.airphotona.com/stockimg/images/16803.jpg>
Author, 5/27/2014
- A32** <http://www.airphotona.com/stockimg/images/10650.jpg>
Author, 5/27/2014

Erosion Control Practice P

- **Strip cropping** is the practice of growing alternate strips of different crops in the same field.
- For controlling water erosion , the strips are on the contour.



Slide 25

- A33** http://www.weru.ksu.edu/new_weru/multimedia/control/big/westrip.jpg
Author, 5/27/2014
- A34** <http://nmfarmgirl.umwblogs.org/files/2013/03/strip-cropping-pic.jpg>
Author, 5/27/2014

Erosion Control Practice P

- Terracing

A common erosion control practice is construct terraces in eroding slopes. Terraces reducing the slope length and reduce runoff.



A35



A36



A37

A38

Slide 26

- A35** <http://www.visitourchina.com/images/guide/picture/20081512309242246.jpg>
Author, 5/27/2014
- A36** http://2.bp.blogspot.com/_LcwzdfjiVcl/STQPfIDbtXI/AAAAAAAAAC0/pcZnhR6Eyo/S700/image007.jpg
Author, 5/27/2014
- A37** http://static8.depositphotos.com/1017967/816/i/950/depositphotos_8162607-Terrace-Farming.jpg
Author, 5/27/2014
- A38** <http://resources.touropia.com/gfx/d/incredible-terrace-fields/hani Terraces.jpg>
Author, 5/27/2014

RUSLE, RUSLE₁ and RUSLE₂

- RUSLE is a revised version of USLE. It has the same formula as USLE, but has several improvements in determining factors.
- New and revised isoerodent maps (for continental USA) based on 10yr -24 hr rainfall
- Time-varying approach for soil erodibility factor (K)
- Subfactor approach for evaluating the cover-management factor (C)
- New equation to reflect slope length and steepness; and new conservation-practice values
- Is empirical and estimates average annual soil loss.
- It is not meant to calculate soil loss due to specific storm events
- Only computes sediment from hill slopes profiles and at the outlet of terrace channels
- RUSLE₂ Program: <http://www.ars.usda.gov/Research/docs.htm?docid=6038>