Runoff Estimation, and Surface Erosion and Control

Runoff Estimation

TR55 CN Method

- The SCS has developed a method of determining excess rain based on precipitation depth (P). The model developed by the SCS separates precipitation into three categories:
- Q - Direct runoff (excess rain) This is the depth (in) of rain that shows up as runoff.
- F - Actual retention. This is the depth (in) of the abstraction
- Ia - Initial abstraction This is the depth (in) of rain that must fall before runoff starts.

SCS Runoff Equation

- Where Q = runoff (in)
- P = rainfall (in)
- S = potential maximum retention after runoff begins (in) and
- Ia = initial abstraction (in)

$$Q = \frac{(P - I_a)^2}{(P - I_a + S)}$$

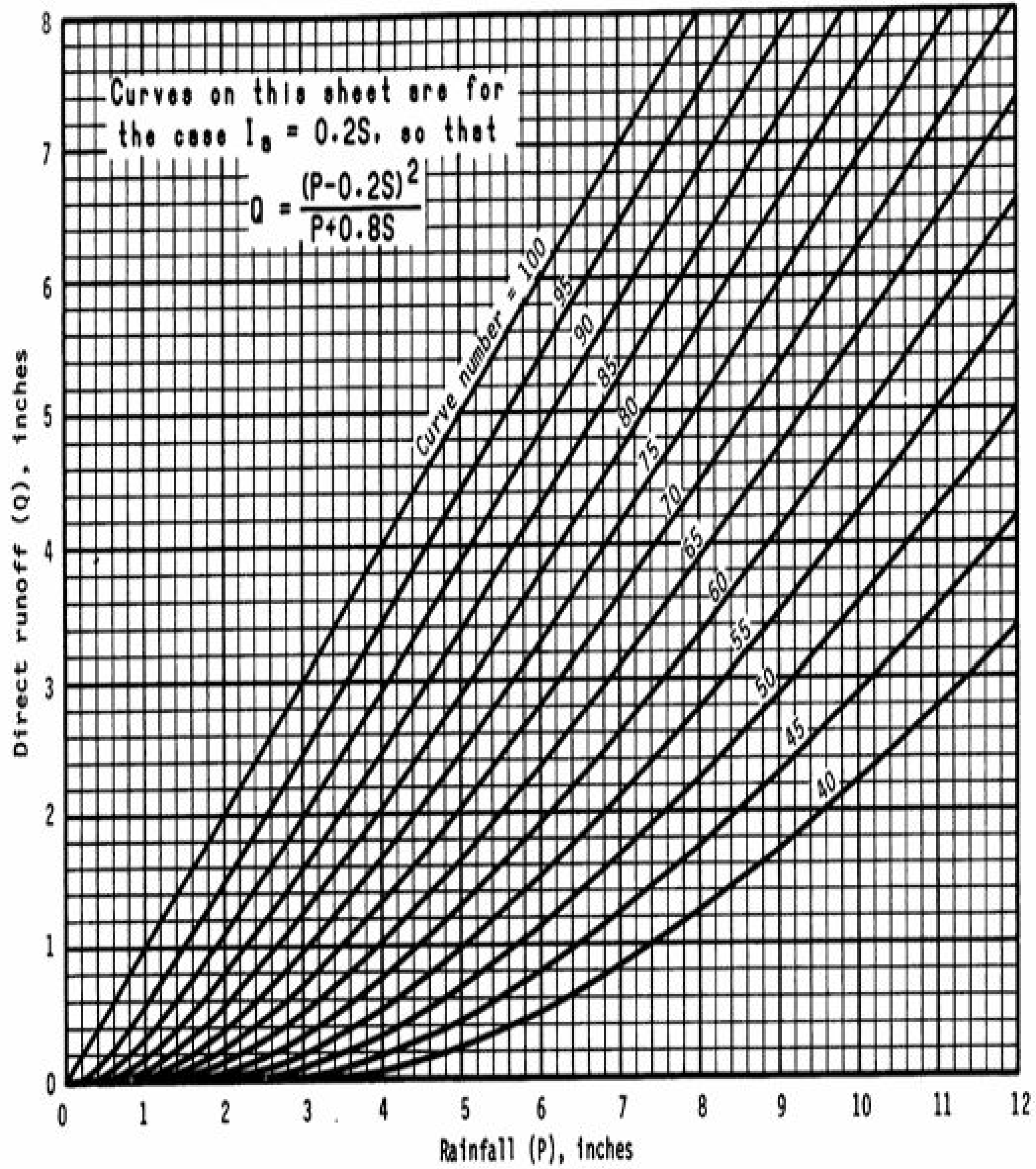
- Ia is all losses before runoff begins it includes:
  - water retained in surface depressions,
  - Water interception by vegetation
  - Evaporation and infiltration.
- Ia was found to follow: Ia = 0.2*S

$$Q = \frac{(P - 0.2 * S)^2}{(P + 0.8 * S)}$$

Potential Maximum Retention

- S is related to the soil cover conditions of the watershed through the CN.
- CN has a range of 0 to 100

$$\mathbf{S = \frac{1000}{CN} - 10}$$



–Solution of runoff equation.

- The ultimate total retention, S, and the initial abstraction, Ia, are assumed to be dependent on the following properties of the drainage basin:
  - Land use
  - Soil Type: A, B, C, D
    - Soil group A – Well drained sand or gravel, high infiltration rate
    - Soil group B – Moderately well drained soil, moderate infiltration rate, with fine to moderately coarse texture
    - Soil group C – Slow infiltration rate, moderate to fine texture
    - Soil group D – Very slow infiltration, mainly clay material, relatively impervious
  - Hydrologic condition – good/fair/poor (rural land use only)
  - Antecedent moisture condition (AMC)
    - AMC I – Dry soil
    - AMC II – Average soil moisture
    - AMC III – Wet soil

Appendix A Hydrologic Soil Groups

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, which are A, B, C, and D, are one element used in determining runoff curve numbers (see chapter 2). For the convenience of TR-55 users, exhibit A-1 lists the HSG classification of United States soils.

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. Approximate numerical ranges for transmission rates shown in the HSG definitions were first published by Musgrave (USDA 1955). The four groups are defined by SCS soil scientists as follows:

Group Asoils 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 Bsoils 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 Csoils 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 Dsoils have high runoff potential. They have very low infiltration rates when thoroughly wetted and

Disturbed soil profiles

As a result of urbanization, the soil profile may be considerably altered and the listed group classification may no longer apply. In these circumstances, use the following to determine HSG according to the texture of the new surface soil, provided that significant compaction has not occurred (Brakensiek and Rawls 1983).

HSG	*Soil textures*
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Drainage and group D soils

Some soils in the list are in group D because of a high water table that creates a drainage problem. Once these soils are effectively drained, they are placed in a different group. For example, Ackerman soil is classified as A/D. This indicates that the drained Ackerman soil is in group A and the undrained soil is in group D.

—Runoff curve numbers for urban areas[1]

Cover type and hydrologic condition	Average percent impervious area[2]	A	B	C	D
Fully developed urban areas (vegetation established)					
Open space (lawns, parks, golf courses, cemeteries, 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
Developing urban areas					
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.

—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
l 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]Hydrologic condition is based on combination of 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 in rotations, (d) percent of residue cover on the land surface (good ≥ 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.

Runoff Curve Numbers[2]

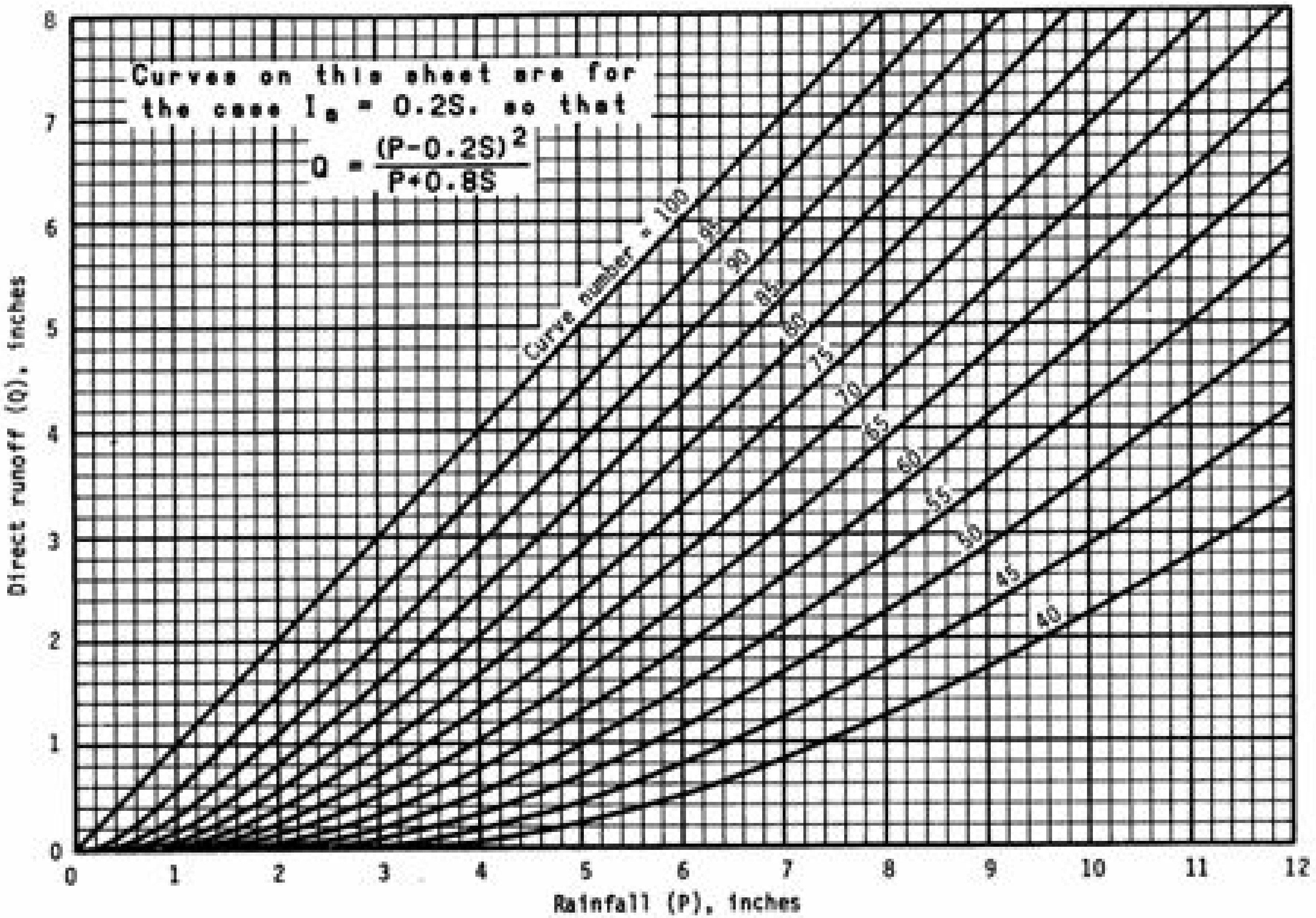
Runoff curve number for selected agricultural suburban and urban land use
(Antecedent moisture condition II and $I_a = 0.2 S$)

Land Use Description		Hydrologic Soil Group			
Cultivated Land[1]:	without conservation treatment	72	81	88	91
	with conservation treatment	62	71	78	81
Pasture or Range Land:	poor condition	68	79	86	89
	good condition	39	61	74	80
Meadow:	good condition	30	58	71	78
Wood or Forest Land:	thin stand, poor cover, no mulch	45	66	77	83
	good cover[2]	25	55	70	77
Open Spaces, Lawns, Parks, Golf Courses, Cemeteries, etc.					
Good Condition:	grass cover on 75% or more of the area	39	61	74	80
Fair Condition:	grass cover on 50% to 75% of the area	49	69	79	84
Commercial and Business Areas (85% impervious)		89	92	94	95
Industrial Districts (72% impervious)		81	88	91	93
Residential[3]:					
Average lot size	Average % Impervious[4]				
1/20 hectare or less (1/8 acre)	65	77	85	90	92
1/10 hectare (1/4 acre)	38	61	75	83	87
3/20 hectare (1/3 acre)	30	57	72	81	86
1/5 hectare (1/2 acre)	25	54	70	80	85
2/5 hectare (1 acre)	20	51	68	79	84
Paved Parking Lots, Roofs, Driveways, etc.[5]		98	98	98	98
Streets and Roads:					
paved with curbs and storm sewers[5]		98	98	98	98
gravel		76	85	89	91
dirt		72	82	87	89

Notes:
1. For a more detailed description of agricultural land use curve numbers, refer to National Engineering Handbook, Section 4, Hydrology, Chapter 9, Aug. 1972[3].
2. Good cover is protected from grazing and litter and brush cover soil.
3. Curve numbers are computed assuming the runoff from the house and driveway is directed toward the street with a minimum of roof water directed to lawns where additional infiltration could occur.
4. The remaining pervious areas (lawn) are considered to be in good pasture condition for these curve numbers.
5. In some warmer climates of the country, a curve number of 95 may be used.

Adjustment of curve numbers for dry (condition I) and wet (condition III) antecedent moisture conditions

CN for Condition II	Corresponding CN for Condition I	Corresponding CN for Condition III
100	100	100
95	87	99
90	78	98
85	70	97
80	63	94
75	57	91
70	51	87
65	45	83
60	40	79
55	35	75
50	31	70
45	27	65
40	23	60
35	19	55
30	15	50
25	12	45
20	9	39
15	7	33
10	4	26
5	2	17
0	0	0



—Solution of runoff equation.

- Example: Use the graphical solution curve to determine the 100-year, 24-hour depth of runoff for a basin with ½-ac lots on a B soil. Use the 100-year, NRC IDF data for the precipitation depth.
- Compute precipitation depth:

$$P_{100,24} = i_{100,24} \text{ x } 24\text{hr} = (0.33 \text{ in/hr})(24 \text{ hr}) = 7.92 \text{ in}$$

- CN = 80.0

Worksheet 2: Runoff curve number and runoff

Project	Heavenly Acres	By	WJR	Date	10/1/85
Location	Dyer County, Tennessee	Checked	NM	Date	10/3/85

Check one: [X] Present [ ] Developed

1. Runoff curve number

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN 1/ Table 2-2	CN 1/ Figure 2-3	CN 1/ Figure 2-4	Area [ ] acres [ ] mi² [X] %	Product of CN x area
Memphis, B	Pasture, good condition	61			30	1830
Loring, C	Pasture, good condition	74			70	5180
				Totals ➡	100	7010

1/ Use only one CN source per line

CN (weighted) = total product / total area = 7010 / 100 = 70.1 ; Use CN ➡ 70

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	6.0		
Runoff, Q (Use P and CN with table 2-1, figure 2-1, or equations 2-3 and 2-4)	in	2.81		

Examples

Four examples illustrate the procedure for computing runoff curve number (CN) and runoff (Q) in inches. Worksheet 2 in appendix D is provided to assist TR-55 users. Figures 2-5 to 2-8 represent the use of worksheet 2 for each example. All four examples are based on the same watershed and the same storm event.

The watershed covers 250 acres in Dyer County, northwestern Tennessee. Seventy percent (175 acres) is a Loring soil, which is in hydrologic soil group C. Thirty percent (75 acres) is a Memphis soil, which is in group B. The event is a 25-year frequency, 24-hour storm with total rainfall of 6 inches.

Cover type and conditions in the watershed are different for each example. The examples, therefore, illustrate how to compute CN and Q for various situations of proposed, planned, or present development.

Example 2-1

The present cover type is pasture in good hydrologic condition. (See figure 2-5 for worksheet 2 information.)

Example 2-2

Seventy percent (175 acres) of the watershed, consisting of all the Memphis soil and 100 acres of the Loring soil, is 1/2-acre residential lots with lawns in good hydrologic condition. The rest of the watershed is scattered open space in good hydrologic condition. (See figure 2-6.)

Worksheet 2: Runoff curve number and runoff

Project Heavenly Acres	By WJR	Date 10/1/85
Location Dyer County, Tennessee	Checked NM	Date 10/3/85

Check one: ☐ Present ☒ Developed

1. Runoff curve number

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1/] Table 2-2	CN Figure 2-3	CN Figure 2-4	Area ☒ acres ☐ mi² ☐ %	Product of CN x area
Memphis, B	35% impervious 1/2 acre lots, good condition		74		75	5550
Loring, C	35% impervious 1/2 acre lots, good condition		82		100	8200
Loring, C	Open space, good condition	74			75	5550
				Totals ➡	250	19,300

1/ Use only one CN source per line

$$CN \text{ (weighted)} = \frac{\text{total product}}{\text{total area}} = \frac{19{,}300}{250} = 77.2$$; Use CN ➡ 77

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	25		
Rainfall, P (24-hour)	in	6.0		
Runoff, Q (Use P and CN with table 2-1, figure 2-1, or equations 2-3 and 2-4)	in	3.48		

Soil Erosion

What’s soil erosion?

Erosion is the process of detachment and transport of soil particles by erosive agents (Ellison, 1944)

Erosion is a natural geologic process

- WATER EROSION
- WIND EROSION
- TILLAGE TRANSLOCATION

SOIL EROSION IS GLOBAL PROBLEM

- 1/3 WORLD’S ARABLE LAND LOST SINCE 1950
- MOST IN ASIA, AFRICA, S. AMERICA
  - 13-18 t/a/yr
- 30% OF US FARMLAND ABANDONED
  - EROSION
  - SALINIZATION
  - WATER-LOGGING
- 90% OF US CROPLAND LOSING SOIL FASTER THAN IT IS REPLACED
  - >1 t/a/yr

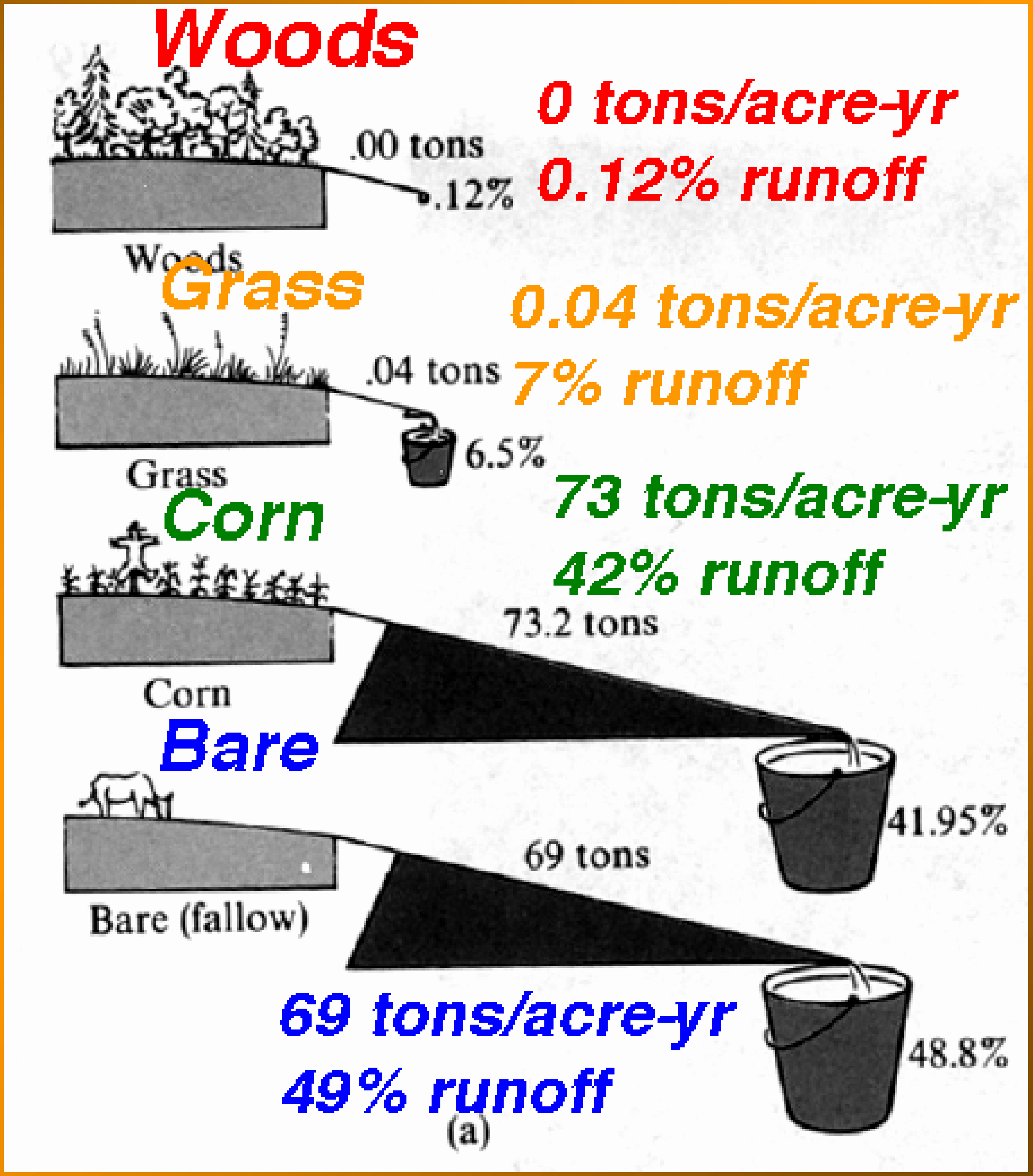
PIMENTEL ET AL., 1995

SIGNIFICANT SOIL LOSS IN THE USA

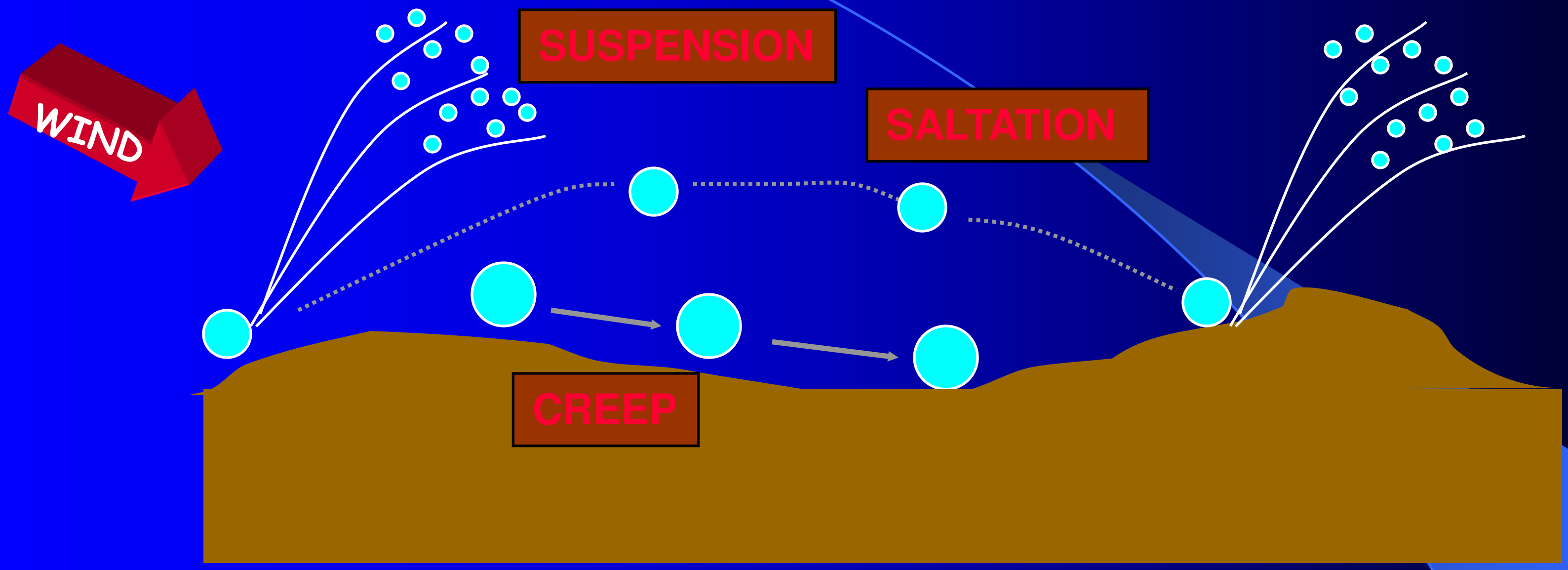
WATER
3.5×10^9 T/yr

WIND
1.5×10^9 T/yr

Soil erosion: Midwest US



WIND EROSION



- SALTATION DETACHES PARTICLES
- SMALLER PARTICLES SUSPENDED
- LARGER PARTICLES CREEP
- SANDY AND SILTY SOILS MOST SUSCEPTIBLE
- SOIL ACCUMULATION IN DITCHES AND FENCE ROWS

WIND EROSION CAN BE SIGNIFICANT

Near Mitchell, SD

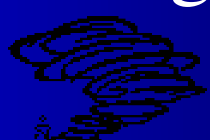
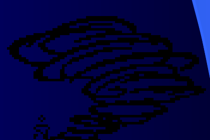
Dust bowl

- 1931-1939 there was a drought called the "dust bowl". It caused huge dust storms to erupt that destructed billions of acres of farm land.

storms

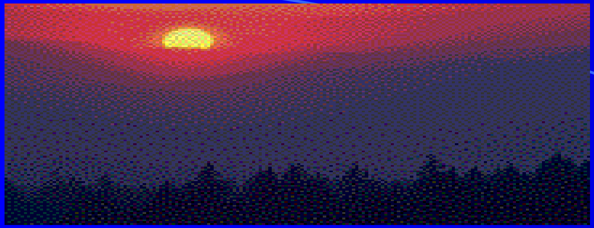
- In the first year of the drought there were 14 storms reported and the second year there were 38 storms. It was getting worse.



Ruined land

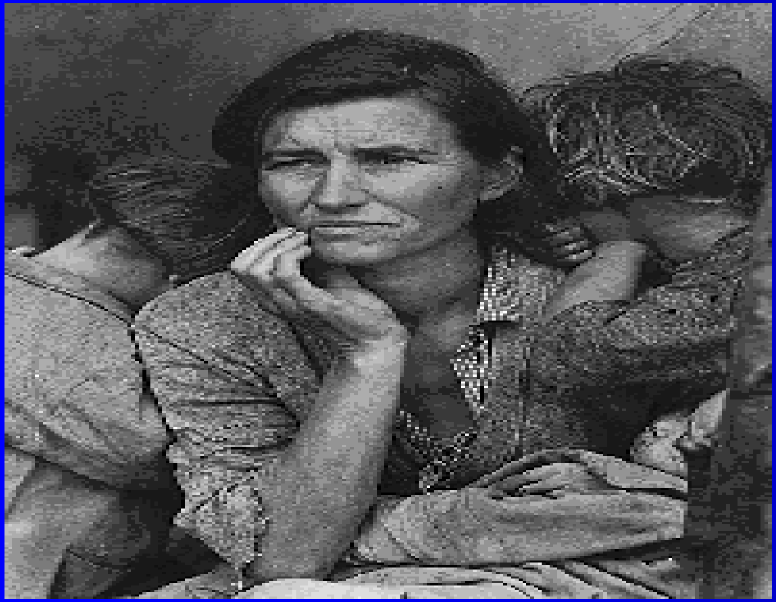
- Tons of damage was done to every ones land and it costs billions of dollars to repair the damages.



Black Sunday

- April 14th,1934 black Sunday was the worst blizzard of the dustbowl which caused the most extensive damage.

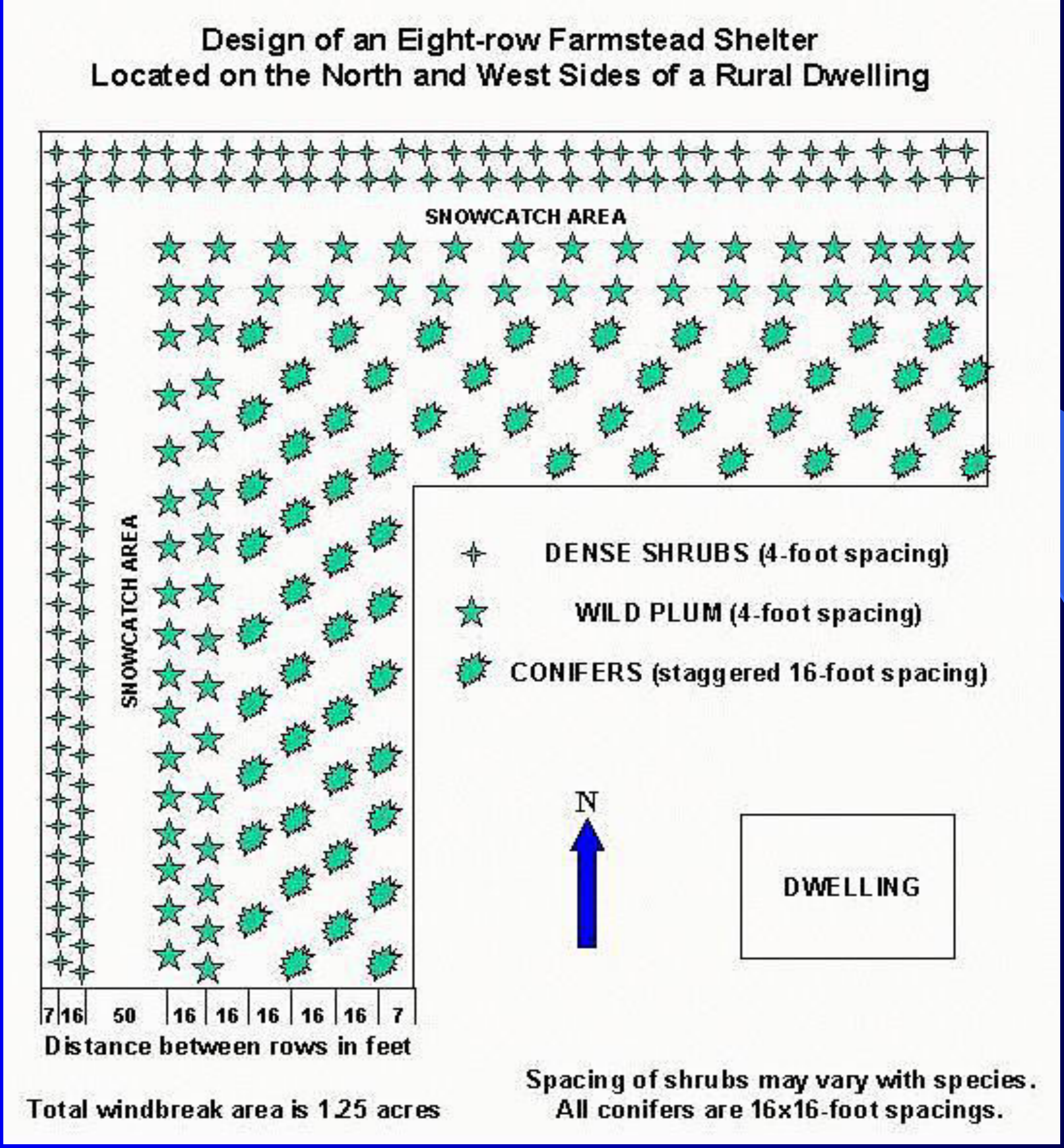





REDUCING WIND EROSION

- MAINTAIN SURFACE COVER
  - CROP RESIDUE
  - COVER CROPS
- INCREASE STUBBLE HEIGHT
- INSTALL WINDBREAKS
  - EFFECTIVE 15x HEIGHT
- IRRIGATE
- STRIP CROPS PERPENDICULAR TO PREVAILING WIND

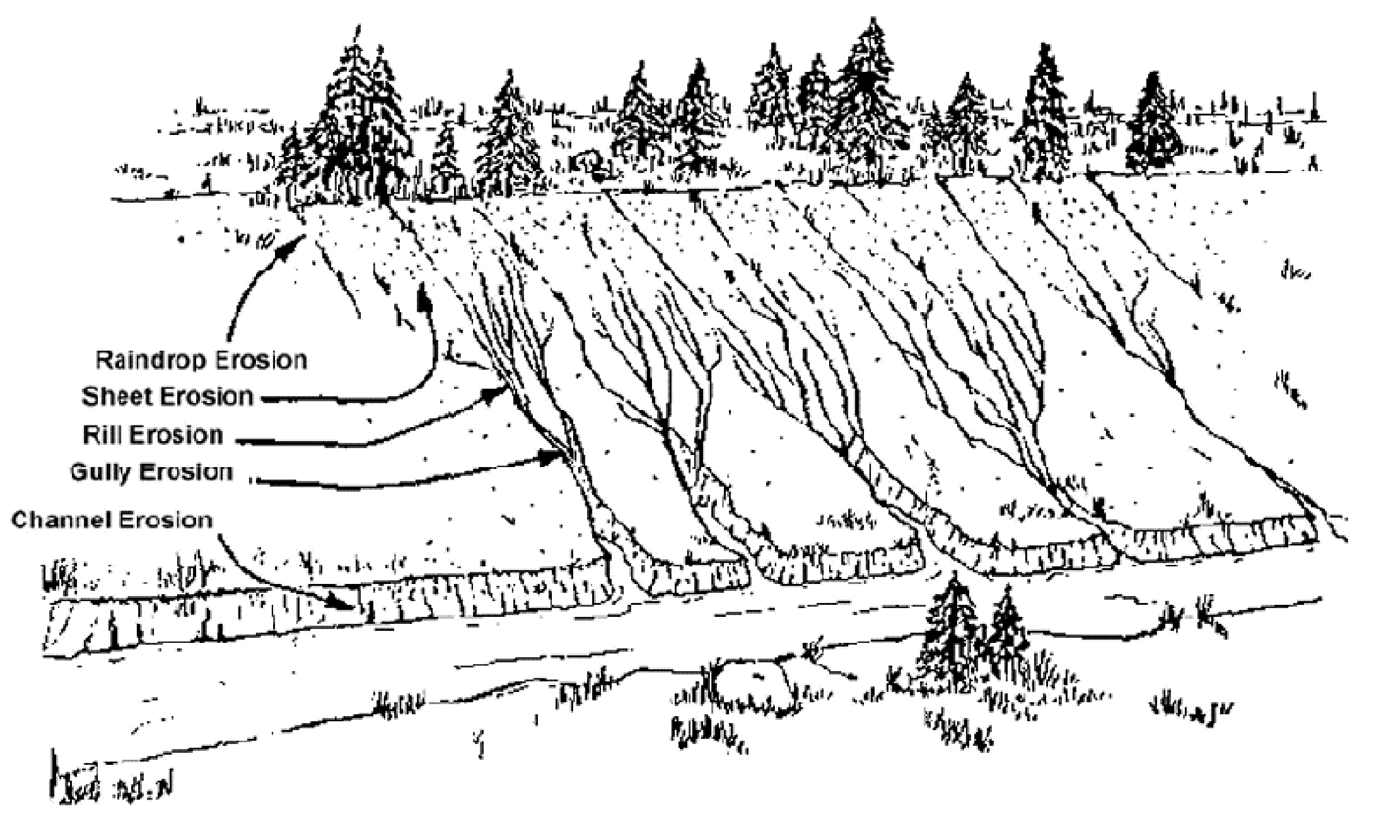
The Shelterbelt Program



WATER EROSION PROCESS

- BEGINS WITH RAINDROPS STRIKING BARE SOIL DISLODGING PARTICLES
- INTENSE RAINS SEAL SURFACE
- WHEN RAINFALL EXCEEDS INFILTRATION WATER IS STORED IN SMALL DEPRESSIONS
- ONCE DEPRESSIONS ARE FILLED, RUNOFF BEGINS

Rainsplash erosion

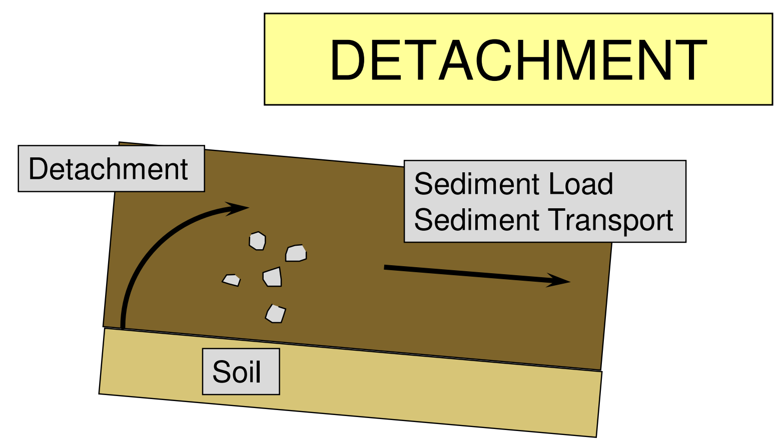


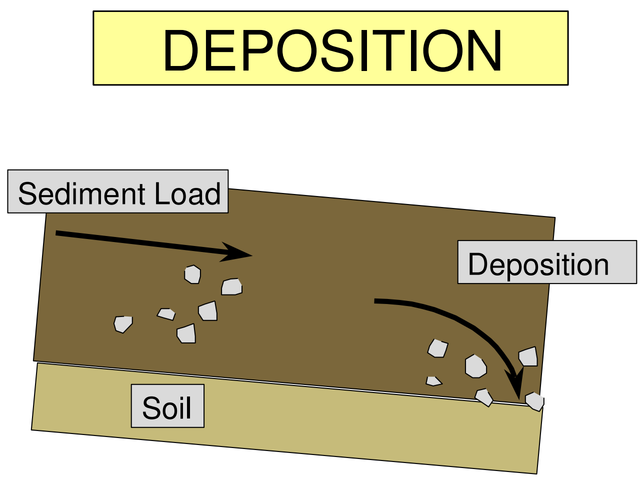
Types of Soil Erosion

WATER EROSION PROCESS

- Initially water flows in a discontinuous sheet
- Eventually it concentrates into small channels or rills. The runoff now has energy to break off particles and cut deeper
- The amount of erosion caused by sheet and rill erosion increases with slope and distance
- Rills may eventually form gullies

THE SOIL WATER EROSION PROCESS





EFFECTS ON ENVIRONMENTAL QUALITY AND PRODUCTIVITY

- LOSS OF OM, CLAY, AND NUTRIENTS REDUCES PRODUCTIVITY
- DAMAGE TO PLANTS
- FORMATION OF RILLS AND GULLIES AFFECTS MANAGEMENT
- SEDIMENTATION IN WATERWAYS, DIVERSIONS, TERRACES, DITCHES
- DELIVERY OF NUTRIENTS TO SURFACE WATER