KATA PENGANTAR

Buku ini merupakan kumpulan dari bahan transparansi kuliah Soil and Water Conservation Engineering yang diperuntukan bagi mahasiswa/i program studi Teknik Pertanian dan program studi lainnya yang berkaitan.

Walaupun buku ini disusun dalam bahasa Inggris, diharapkan tidak mempersulit mahasiswa/i untuk mempelajarnya.

Tentu saja masih terdapat banyak kekurangan didalam penyusunan buku ini. Untuk itu segala kritik dan saran akan diterima oleh penyusun dengan tangan terbuka.

Desember 2006
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I. INTRODUCTION

Soil and water \( \rightarrow \) two of natural resources

Conservation of natural resources \( \rightarrow \) Sustainable :
• Utilization without waste
• To make possible a continuous high level of crop production
• Improving environmental quality

Soil and Water Conservation Engineering:
• Is the application of engineering and biological principles to the solution of soil and water management problem
• Is based on the full integration of engineering, atmospheric, plant and soil sciences

Problems involved in soil and water conservation, i.e:
• Erosion control
• Irrigation and drainage
• Flood control
• Water resource development and conservation

This course focuses on erosion, erosion control, and soil and water conservation
II. EROSION

EROSION

Is the detachment and transport of soil from the land by the action of erosive agents

EROSIVE AGENTS:

1. Water (including runoff from melted snow and ice)
2. Wind

Important erosive agent in humid area (like Malaysia) is WATER EROSION

TWO MAJOR TYPES OF SOIL EROSION:

(1) Natural or Geological Erosion

Under normal climate conditions, and with natural ground cover, soil erosion can often balance out with the rate of soil formation (about 1 mt/ha/year).

(2) Accelerated Erosion

Erosion can be accelerated through the activities of human beings such as: deforestation, agricultural cultivation, surface mining, structures construction etc.

More population need more land for producing food, staying and other purposes (residential, industrial, commercial, recreational etc)
Soil loss become 10, 20, 50, 100 times or more
Erosion losses were not serious until population multiplied and the cultivated acreage increased to meet the need for food.

CONSEQUENCES OF SOIL EROSION:

1. On site:
   Soil deterioration → reduce soil fertility
   - the loss of soil (topsoil)
   - the breakdown of soil structures
   - the decline in organic matter and nutrient
   - reduce available soil moisture and infiltration capacity

2. Off site:
   - sedimentation at downstream:
     o reduce the capacity of rivers, ditches, cannals
     o shortern the design life of reservoirs
   - sediment is also a water pollutant:
     o can foul fish gills
     o inhibit light penetration and photosynthesis
     o increase costs of water treatment
     o detract aesthetics

EROSION DISTRIBUTION
1. Spatial variation
   - Annual rates of erosion (t/ha)

<table>
<thead>
<tr>
<th>Country</th>
<th>Natural</th>
<th>Cultivated</th>
<th>Bare</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>0.1-2</td>
<td>150-200</td>
<td>280-360</td>
</tr>
<tr>
<td>USA</td>
<td>0.03-3</td>
<td>5-170</td>
<td>4-9</td>
</tr>
<tr>
<td>Australia</td>
<td>0-64</td>
<td>0.1-150</td>
<td>44-87</td>
</tr>
<tr>
<td>Ivory coast</td>
<td>0.03-0.2</td>
<td>0.1-90</td>
<td>10-750</td>
</tr>
<tr>
<td>Nigeria</td>
<td>0.5-1</td>
<td>0.1-35</td>
<td>3-150</td>
</tr>
<tr>
<td>India</td>
<td>0.5-5</td>
<td>0.3-40</td>
<td>10-185</td>
</tr>
<tr>
<td>Ethiopia</td>
<td>1-5</td>
<td>8-42</td>
<td>5-70</td>
</tr>
</tbody>
</table>
- Land affected by water erosion

<table>
<thead>
<tr>
<th>Region</th>
<th>Land area (10^6 ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Africa</td>
<td>227</td>
</tr>
<tr>
<td>Asia</td>
<td>441</td>
</tr>
<tr>
<td>South America</td>
<td>123</td>
</tr>
<tr>
<td>Central America</td>
<td>46</td>
</tr>
<tr>
<td>North America</td>
<td>60</td>
</tr>
<tr>
<td>Europe</td>
<td>114</td>
</tr>
<tr>
<td>Oceania</td>
<td>83</td>
</tr>
<tr>
<td>World</td>
<td>1094</td>
</tr>
</tbody>
</table>

- Variation in suspended sediment yield

![Map of global variations in suspended sediment yield](image)

*Fig. 1.3* A tentative map of global variations in suspended sediment yield (after Walling and Webb, 1983).
2. Temporal Variation

Fig. 1.4 Seasonal cycles of rainfall, vegetation cover and erosion in a semi-humid climate (after Kirkby, 1980).

Figure 1.4 Relationship between sediment yield and changing land use in the Piedmont region of Maryland, USA (after Wolman 1967).
PROCESSES AND MECHANICS OF EROSION

Phases of Erosion

1. Particle detachment

- Soil particles are detached from the parent soil mass by the forces exerted by falling raindrops or the shear forces of runoff

- Energy available for erosion
  - Potential energy: \( PE = mgh \) (joules)
    - where \( m \): mass (kg), \( h \): height difference (m) and \( g \): accelerated due to gravity (m/s\(^2\))
  - Kinetic energy: \( KE = \frac{1}{2}mv^2 \) (joules)
    - where \( v \): velocity (m/s)
  - Only 0.2% of falling raindrops and 3 to 4% of running water are expended in erosion

- The soil is also broken up by weathering processes (mechanical: wetting and drying, freezing and thawing; and biochemical), tillage operation, and trampling of people and livestock
2. Sediment transport

- Particles are moved down slope.
- This down slope movement is by the splash action of falling raindrops and by the runoff itself.
- The ability of the runoff to transport the detached particles is a function of the velocity of runoff.

3. Sedimentation or sediment deposition.

- Occurs when the velocity of the runoff is reduced and the load-carrying capacity decreases, causing some or all the sediment to deposit.
- Generally, the larger, heavier particles deposit first with the finer, smaller particles depositing further down slope.

![Diagram of water velocities for erosion, transport, and deposition](image)

**Fig. 2.2** Critical water velocities for erosion, transport and deposition as a function of particle size (after Hjulström, 1935).
Form of Erosion

The forms/types of soil erosion caused by water are:

(1) Splash erosion

- Soil detachment and transport resulting from the impact of water drops directly on soil particles or on thin water surfaces

- On bare soil, it is estimated that 200 Mg/ha is splashed into the air by heavy rains
- Depends on: raindrop mass, size distribution, shape, terminal velocity and direction
(2) Sheet (inter-rill) erosion

- As water collects on the soil surface and begins to run off, it does so in sheets of uniform flow across the soil surface. This sheet flow carries the particles dislodged by raindrop impact along with other particles dislodged by sheer stress exerted by the flows.

- Is as the uniform removal of soil in thin layers from sloping land.

(3) Rill erosion

- As these sheets of runoff move down slope, the flow concentrates because of irregularities in the soil surface and topography. The resulting concentrated flow cuts more deeply into the surface creating rills that may be several inches deep.

- Rill erosion accelerates with increases in runoff, slope steepness and length

- is the most common form of erosion.
- its effects can be easily removed by tillage, but most often overlooked.
- rills can often be found in between crop rows

(4) Gully erosion
- If rill development is allowed to progress, it will form very deep cuts in the soil surface and become a gully
- Because of the high velocities of flow in the gullies, massive removal of soil is possible
- Gullies may be several feet or more deep and generally cannot be repaired with simple tilling of the soil surface
Processes and mechanics of erosion

1. Removal of soil by overland flow
2. Break in vegetation cover
3. Overland flow
4. Depression forming
5. Headwall developing
6. Gully headcut, erosion by undermining (and collapse)
7. Scouring at base of headcut
8. Slope surface
9. Channel flow
10. Incised gully floor
11. Retreat of headwall
12. Slope surface
13. Gully floor

Fig. 2.3 Stages in the surface development of gullies on a hillside.
(5) Stream and channel erosion
   - Erosion can also occur along channel and stream banks and streambeds because of the shear forces exerted on those surfaces by flowing water.
   - The rate of channel erosion is related to the quantity and velocity of flow.
III. FACTOR INFLUENCING EROSION

➢ THE FACTOR INFLUENCING SOIL EROSION:

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

➢ CLIMATE

- Climate factors affecting erosion:
  o Rainfall
  o Temperature
  o Wind
  o Humidity
  o Solar radiation
- Soil loss is closely related to rainfall
  o partly through the detaching power of raindrops
  o partly through the contribution of rain to runoff
- Rainfall parameters related to erosion
  o Rainfall intensity
    - the quantity of rainfall for a certain time period. i.e: mm/hr

<table>
<thead>
<tr>
<th>Maximum 5-min intensity (mm/h)</th>
<th>Number of falls of rain</th>
<th>Average erosion per rainfall (t/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–25.4</td>
<td>40</td>
<td>3.7</td>
</tr>
<tr>
<td>25.5–50.8</td>
<td>61</td>
<td>6.0</td>
</tr>
<tr>
<td>50.9–76.2</td>
<td>40</td>
<td>11.8</td>
</tr>
<tr>
<td>76.3–101.6</td>
<td>19</td>
<td>11.4</td>
</tr>
<tr>
<td>101.7–127.0</td>
<td>13</td>
<td>34.2</td>
</tr>
<tr>
<td>127.1–152.4</td>
<td>4</td>
<td>36.3</td>
</tr>
<tr>
<td>152.5–177.8</td>
<td>5</td>
<td>38.7</td>
</tr>
<tr>
<td>177.9–254.0</td>
<td>1</td>
<td>47.9</td>
</tr>
</tbody>
</table>

o Rainfall duration

<table>
<thead>
<tr>
<th>Date</th>
<th>Rainfall (mm)</th>
<th>Intense rain (≥ 10 mm/h) (mm)</th>
<th>Rainfall duration (h)</th>
<th>Soil loss (g/cm²-width)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.7.73</td>
<td>34.9</td>
<td>17.7</td>
<td>8.00</td>
<td>70.70</td>
</tr>
<tr>
<td>5.5.73</td>
<td>6.7</td>
<td>—</td>
<td>4.16</td>
<td>61.72</td>
</tr>
<tr>
<td>21.5.73</td>
<td>7.1</td>
<td>3.9</td>
<td>2.00</td>
<td>55.98</td>
</tr>
<tr>
<td>27.8.73</td>
<td>16.8</td>
<td>4.6</td>
<td>6.50</td>
<td>50.90</td>
</tr>
<tr>
<td>6.5.73</td>
<td>2.2</td>
<td>1.0</td>
<td>0.33</td>
<td>40.00</td>
</tr>
<tr>
<td>8.8.74</td>
<td>17.0</td>
<td>8.8</td>
<td>13.50</td>
<td>36.78</td>
</tr>
<tr>
<td>16.7.74</td>
<td>7.6</td>
<td>6.4</td>
<td>13.00</td>
<td>28.66</td>
</tr>
<tr>
<td>13.7.74</td>
<td>16.5</td>
<td>9.0</td>
<td>10.50</td>
<td>24.71</td>
</tr>
<tr>
<td>19.6.73</td>
<td>39.6</td>
<td>—</td>
<td>23.83</td>
<td>20.38</td>
</tr>
<tr>
<td>27.6.73</td>
<td>18.6</td>
<td>2.3</td>
<td>13.83</td>
<td>18.99</td>
</tr>
</tbody>
</table>

Data for bare soil and 11° slope.

o Raindrop size and distribution

*Figure 3.7 The relation between median volume drop diameter and intensity*
- Terminal velocity

- Rainfall Erosivity
  - Is the potential ability of rain to cause erosion
  - Closely related to energy of rainfall (kinetic energy)
  - Formulas for kinetic energy of rainfall:
    1. Wischmeier and Smith (1958)
      \[
      KE = 11.87 + 8.73 \log I
      \]
      KE is kinetic energy in J/m².mm and I is rainfall intensity in mm/h
      In metric unit: \( KE = 210 + 89 \log I \)
      Where KE in ton.m/ha.cm and I in cm/h
    2. Other equivalent formula: \( KE = 9.95 + 8.44 \log I \)
    3. Hudson (1965) for tropical area:
      \[
      KE = 29.8 - \frac{127.5}{I}
      \]
    5. Onaga, Shirai and Yoshinaga (1988)
\[ KE = 9.81 + 10.6 \log I \]

- Wischmeier and Smith (1958): soil loss by splash, overland flow and rill erosion is related to a compound index of kinetic energy and maximum 30-minute intensity \( (I_{30}) \) — called \( EI_{30} \) index.

- Hudson (1965): erosion is almost entirely caused by rain falling at intensity greater than 25 mm/h — called \( KE>25 \) index.

- Lal (1976): from small plots, soil loss have high correlation with the amount of rain \( (A) \) and maximum intensity over 7.5 minute period — called \( AI_m \) index.
Example:

Table 3.4 Calculation of erosivity

<table>
<thead>
<tr>
<th>Time from start (mm)</th>
<th>Rainfall (mm)</th>
<th>Intensity (mm/h)</th>
<th>Kinetic energy (J m⁻² mm⁻¹)</th>
<th>Total kinetic energy (col 2 × col 4) (J/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–14</td>
<td>1.52</td>
<td>6.08</td>
<td>8.83</td>
<td>13.42</td>
</tr>
<tr>
<td>15–29</td>
<td>14.22</td>
<td>56.88</td>
<td>27.56</td>
<td>391.90</td>
</tr>
<tr>
<td>30–44</td>
<td>26.16</td>
<td>104.64</td>
<td>28.58</td>
<td>747.65</td>
</tr>
<tr>
<td>45–59</td>
<td>31.50</td>
<td>126.00</td>
<td>28.79</td>
<td>906.89</td>
</tr>
<tr>
<td>60–74</td>
<td>8.38</td>
<td>33.52</td>
<td>26.00</td>
<td>217.88</td>
</tr>
<tr>
<td>75–89</td>
<td>0.25</td>
<td>1.00</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

Kinetic energy is calculated using Hudson

Erosivity indices

Wischmeier index (EI30):

maximum 30-minute rainfall = 26.16 + 31.50 mm
= 57.66 mm

maximum 30-minute intensity = 57.66 × 2
= 115.32 mm/h

total kinetic energy = total of column 5
= 2,277.74 J/m²

EI30

= 2,277.74 × 115.32
= 262,668.98 J mm m⁻² h⁻¹

Hudson index (KE > 25):

total kinetic energy for rainfall intensity ≥ 25 mm/h = total of column 5, lines 2, 3, 4 and 5 only
= 2,264.32 J/m²
SOIL

- Correspond to soil detachability and soil transportability
  - Erodibility: the resistance of the soil to erosion
- Erodibility ↑ → will suffer more erosion
- Erodibility varies with:
  - Soil texture
  - Aggregate stability
  - Organic matters
  - Shear strength
  - Infiltration capacity
  - Chemical content
- Erodibility indices
Table 3.5 Indices of soil erodibility for water erosion

<table>
<thead>
<tr>
<th>Static Laboratory Tests</th>
<th>Static Field Tests</th>
<th>Dynamic laboratory tests</th>
<th>Dynamic Field Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Dispersion ratio</strong></td>
<td>% silt + % clay in undispersed soil</td>
<td>% silt + % clay after dispersal of the soil in water</td>
<td>Erodibility index</td>
</tr>
<tr>
<td><strong>Clay ratio</strong></td>
<td>% silt + % clay</td>
<td>% clay</td>
<td>Simulated rainfall test</td>
</tr>
<tr>
<td><strong>Surface aggregation ratio</strong></td>
<td>surface area of particles &gt;0.05 mm</td>
<td>(% silt + % clay in dispersed soil) - (% silt + % clay in undispersed soil)</td>
<td>Water-stable aggregate (WSA) content</td>
</tr>
<tr>
<td><strong>Erosion ratio</strong></td>
<td>dispersion ratio</td>
<td>colloid content/moisture equivalent ratio</td>
<td>Water drop test</td>
</tr>
<tr>
<td><strong>Instability index (Is)</strong></td>
<td>% silt + % clay</td>
<td>$A_{gw} + A_{hew} + A_{bws}$</td>
<td>Erosion index</td>
</tr>
<tr>
<td></td>
<td>(Is)</td>
<td>where $A_g$ is the % aggregates &gt;0.2 mm after wet sieving for no pretreatment and pretreatment of the soil by alcohol and benzene respectively</td>
<td></td>
</tr>
</tbody>
</table>

- **Static Laboratory Tests**
  - Dispersion ratio
  - Clay ratio
  - Surface aggregation ratio
  - Erosion ratio
  - Instability index (Is)
  - Pseudo-textural aggregation index (Ipta)

- **Static Field Tests**
  - Erodibility index
  - Soil cohesion

- **Dynamic laboratory tests**
  - Simulated rainfall test
  - Water-stable aggregate (WSA) content
  - Water drop test
  - Erosion index

- **Dynamic Field Tests**
  - Erodibility index ($K$)

**Moderator**
- Middleton (1930)
- Bouyoucos (1935)
- André and Anderson (1961)
- Lugo-Lopez (1969)
- Hénin, Monnier and Combeau (1958)
- Combeau and Monnier (1961)
- Chici, Bazzoffi and Mbagwu (1989)
- Chorley (1959)
- Rauws and Govers (1988)
- Woodburn and Kozachyn (1956)
- Bryan (1968)
- Bruce-Otine and Lal (1975)
- Voznesensky and Arthurs (1940)
- Wischmeier and Mannering (1969)
Wischmeier and Mannering (1969)

\[ K = 2.8 \times 10^{-7} M^{1.14} (12 - a) + 4.3 \times 10^{-3} (b - 2) + 3.3 \times 10^{-3} (c - 3) \]

\[ \text{K : particle size parameter (\% silt+\% very fine sand)x(100-100\% clay)} \]
\[ \text{a : percent organic matter} \]
\[ \text{b : soil structure code (1. very fine granular; 2. fine granular; 3. medium or coarse granular; and 4. blocky, platy or massive)} \]
\[ \text{c : profile permeability class ( 1. rapid; 2. moderate to rapid; 3. moderate; 4. slow to moderate; 5. slow; and 6. very slow)} \]

VEGETATION

- Vegetation acts as a protective layer or buffer between the atmosphere and the soil
- The major effects of vegetation in reducing erosion:
- Interception of rainfall by adsorbing the energy of the raindrops canopy cover, and thus reducing surface sealing and runoff
- Retardation of erosion by decreased surface velocity
- Physical restraint of soil movement
- Improvement of aggregation and porosity of the soil by roots and plant residue
- Increase biological activity in the soil
- Transpiration, which decrease soil water resulting in increased storage capacity and less runoff

  o Varies with:
    - Season
    - Crop
    - Degree of maturity of vegetation
    - Soil
    - Climates

  o The mean annual soil loss was 43 t/ha for bare plot, and 3.8 t/ha for the covered plot (Zanchi, 1983)

➢ TOPOGRAFI

  o Topographic features that influence erosion:
    - Degree of slope
      On steep slope → runoff water is more erosive and can more easily transport detached sediment downslope

      for slope < 4 m \( S = 3.0(\sin \theta)^{0.8} + 0.56 \)
      for slope > 4 m and \( s < 9 \% \) \( S = 10.8 \sin \theta + 0.03 \)
      for slope > 4 m and \( s \geq 9 \% \) \( S = 16.8 \sin \theta - 0.50 \)
      where \( \theta \) : field slope steepness in degrees = \( \tan^{-1}(s/100) \)
      \( s \) = field slope in percent
- **Shape of slope**
  - Convex. The intensity of erosion processes reach the maximum at the bottom part.
  - Concave. The intensity of erosion processes reach the maximum at the end of the upper part.
  - straight (uniform)
  - combine

- **Length of slope**
  Longer slope → more runoff accumulates and greater erosive forces

McCool et al (1989): length factor  \[ L = \left( \frac{I}{22} \right)^m \]
\[
m = \frac{\sin \theta}{\sin \theta + 0.269(\sin \theta)^{0.8} + 0.05}
\]

\(l\) : slope length in m

\[
L_S = \left(\frac{l}{22.13}\right)^n (0.065 + 0.045s + 0.0065s^2)
\]
n : 0.5 for convex slope, 0.4 for straight slope and 0.14 for concave slope

- Slope exposure
  The soil of the sun-exposed slopes dries much quicker
  \(\rightarrow\) rapid decomposition of organic substances \(\rightarrow\) reduces its consistence  \(\rightarrow\) increase the danger of water erosion

- Size and shape of the watershed
  \(\rightarrow\) affect volume and velocity of accumulate runoff
IV. PREDICTION OF EROSION RATE

Soil Loss Equation

1. Zingg (1940)
   - The first soil loss equation
   - For hillslopes: 
     \[ E = \alpha \tan^m \theta L^n \]
     Where
     - \( E \) : soil loss per unit area
     - \( \theta \) : the slope angle
     - \( L \) : the slope length
     - \( m \) and \( n \) : constants, generally \( m=1.4 \) and \( n=0.6 \)

2. Universal soil loss equation, USLE (Wischmeier and Smith, 1978)
   - Is as widely accepted method
   - For estimating sediment loss from upland
   
   \[ E = R.K.L.S.C.P \]
   
   - \( E \) : average annual soil loss, Mg/ha
     In American unit, t/a
   - \( R \) : Rainfall and runoff erosivity factor
     - Unit:
       o American unit
       o Metric unit: MJ-mm/ha-h-y
       o Conversion: 1 metric unit = 1.73 x American unit
     - Based on mean annual EI
       o If \( E \) in foot-tons/acre and \( I_{30} \) in in/h, \( R \) in American unit: 
         \[ R = E I_{30} / 100 \]
       o If \( E \) in J/m2 and \( I_{30} \) in mm/h, \( R \) in metric unit
         \[ R = E I_{30} / 1000 \]
     - Based on mean annual precipitation
       o Roose (1975): \( R = 0.5P \)
         \( R \) in American units and \( P \) in mm
o Morgan (1974): \( (KE > 25) = 9.28P - 8838 \)

\[ R = (KE > 25) \times I_{30} / 1000 \]

\( KE > 25 \) in J/m\(^2\), \( P \) in mm, \( I_{30} \) in mm/h an \( R \) in metric unit

o Foster et al (1981): \( R = 0.276PxI_{30} / 100 \)

\( R \) in metric unit, \( P \) in mm and \( I_{30} \) in mm/h

- Based on geographic location

\[ I_{30} = 75 \text{ mm/h} \]

(max \( I_{30} \) recommended by Wischmeier and Smith, 1978)

Then: \( 1 \text{ kJ/m}^2 \) (erosivity) = \[ 1 \text{ kJ/m}^2 \times 10^4 \text{ m}^2/\text{h} \times 1/10^3 \]

MJ/kJ x 75 mm/h = 750 MJ-mm/ha-h-y (erosivity index)
K : Soil erodibility index
- Is as mean annual soil loss per unit of R for standard condition of bare soil, recently tilled up and down slope with no conservation practice and on a slope of 9° and 22 m length.
- Wischmeier and Mannering (1969)
\[ K = 2.8 \times 10^{-7} M^{1.14} (12 - a) + 4.3 \times 10^{-3} (b - 2) + 3.3 \times 10^{-3} (c - 3) \]
- Nomograph

Fig. 5.6 Soil erodibility K factor nomograph in SI units. (Source: Foster et al., 1981.)

Divided values by 1.3 to obtain K values in the American unit

LS : the factor of slope length (L) and slope steepness (S)
- Expressed the ratio of soil loss under a given slope steepness and slope length to soil loss from the standard condition of a 9° slope, 22 m length, for which LS=1.
- Wischmeier and Smith (1978): slope and length factor

\[
LS = \left( \frac{l}{22.13} \right)^n (0.065 + 0.045s + 0.0065s^2)
\]

\(n\): 0.5 for convex slope, 0.4 for straight slope and 0.14 for concave slope.
slope steepness factor

\[
\begin{align*}
S &= \begin{cases} 
3.0(\sin \theta)^{0.8} + 0.56 & \text{for slope } < 4 \text{ m} \\
10.8\sin \theta + 0.03 & \text{for slope } > 4 \text{ m and } s < 9 \% \\
16.8\sin \theta - 0.50 & \text{for slope } > 4 \text{ m and } s \geq 9 \%
\end{cases}
\end{align*}
\]

where \(\theta\): field slope steepness in degrees = \(\tan^{-1}(s/100)\)
\(s\): field slope in percent

length factor

\[
L = \left( \frac{l}{22} \right)^m; \quad m = \frac{\sin \theta}{\sin \theta + 0.269(\sin \theta)^{0.8} + 0.05}
\]

C: The crop management factor
- The ratio of soil loss under a given crop that from bare soil.
- In US, depend on crop rotation and management practices. For other country, it is more appropriate to use average annual values.
Table 5.2 C-factor values for the Universal Soil Loss Equation

<table>
<thead>
<tr>
<th>Practice</th>
<th>Average annual C-factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare soil</td>
<td>1.00</td>
</tr>
<tr>
<td>Forest or dense shrub, high mulch crops</td>
<td>0.001</td>
</tr>
<tr>
<td>Savanna or prairie grass in good condition</td>
<td>0.01</td>
</tr>
<tr>
<td>Overgrazed savanna or prairie grass</td>
<td>0.10</td>
</tr>
<tr>
<td>Maize, sorghum or millet: high productivity</td>
<td>0.20–0.55</td>
</tr>
<tr>
<td>conventional tillage</td>
<td></td>
</tr>
<tr>
<td>Maize, sorghum or millet: high productivity</td>
<td>0.50–0.90</td>
</tr>
<tr>
<td>conventional tillage</td>
<td></td>
</tr>
<tr>
<td>Maize, sorghum or millet: low productivity no</td>
<td>0.02–0.10</td>
</tr>
<tr>
<td>or minimum tillage</td>
<td></td>
</tr>
<tr>
<td>Maize, sorghum or millet: high productivity</td>
<td>0.12–0.20</td>
</tr>
<tr>
<td>chisel ploughing into residue</td>
<td></td>
</tr>
<tr>
<td>Maize, sorghum or millet: low productivity</td>
<td>0.30–0.45</td>
</tr>
<tr>
<td>chisel ploughing into residue</td>
<td></td>
</tr>
<tr>
<td>Cotton</td>
<td>0.40–0.70</td>
</tr>
<tr>
<td>Meadow grass</td>
<td>0.01–0.025</td>
</tr>
<tr>
<td>Soya beans</td>
<td>0.20–0.50</td>
</tr>
<tr>
<td>Wheat</td>
<td>0.10–0.40</td>
</tr>
<tr>
<td>Rice</td>
<td>0.10–0.20</td>
</tr>
<tr>
<td>Groundnuts</td>
<td>0.30–0.80</td>
</tr>
<tr>
<td>Bananas, coffee, cocoa with crop cover</td>
<td>0.10–0.30</td>
</tr>
<tr>
<td>Pineapple on contour: residue removed</td>
<td>0.10–0.40</td>
</tr>
<tr>
<td>Pineapple on contour: with surface residue</td>
<td>0.01</td>
</tr>
<tr>
<td>Potatoes: rows downslope</td>
<td>0.20–0.50</td>
</tr>
<tr>
<td>Potatoes: rows across-slope</td>
<td>0.10–0.40</td>
</tr>
<tr>
<td>Cowpeas</td>
<td>0.30–0.40</td>
</tr>
<tr>
<td>Strawberries: with weed cover</td>
<td>0.27</td>
</tr>
<tr>
<td>Pomegranate: with weed cover</td>
<td>0.08</td>
</tr>
<tr>
<td>Pomegranate: clean-weeded</td>
<td>0.56</td>
</tr>
<tr>
<td>Ethiopian tef</td>
<td>0.25</td>
</tr>
<tr>
<td>Sugar cane</td>
<td>0.13–0.40</td>
</tr>
<tr>
<td>Yams</td>
<td>0.40–0.50</td>
</tr>
<tr>
<td>Pigeon peas</td>
<td>0.60–0.70</td>
</tr>
<tr>
<td>Mungbean</td>
<td>0.04</td>
</tr>
<tr>
<td>Chilli</td>
<td>0.33</td>
</tr>
<tr>
<td>Coffee: after first harvest</td>
<td>0.05</td>
</tr>
<tr>
<td>Plantains: after establishment</td>
<td>0.05–0.10</td>
</tr>
<tr>
<td>Papaya</td>
<td>0.21</td>
</tr>
</tbody>
</table>

After Wischmeier and Smith (1978); Roose (1977); Singh, Babu and Chandra (1981); El-Swaify, Dangier and Armstrong (1982); Hurni (1987); Hashim and Wong (1988).
P: The erosion control practice factor
- The ratio of soil loss where the practice is applied to the soil loss where it is not
- If no erosion control practice, P=1.0

Table 5.3 P-factor values for the Universal Soil Loss Equation

<table>
<thead>
<tr>
<th>Erosion-control practice</th>
<th>P-factor value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Contouring: 0–1° slope</td>
<td>0.60*</td>
</tr>
<tr>
<td>Contouring: 2–5° slope</td>
<td>0.50*</td>
</tr>
<tr>
<td>Contouring: 6–7° slope</td>
<td>0.60*</td>
</tr>
<tr>
<td>Contouring: 8–9° slope</td>
<td>0.70*</td>
</tr>
<tr>
<td>Contouring: 10–11° slope</td>
<td>0.80*</td>
</tr>
<tr>
<td>Contouring: 12–14° slope</td>
<td>0.90*</td>
</tr>
<tr>
<td>Level bench terrace</td>
<td>0.14</td>
</tr>
<tr>
<td>Reverse-slope bench terrace</td>
<td>0.05</td>
</tr>
<tr>
<td>Outward-sloping bench terrace</td>
<td>0.35</td>
</tr>
<tr>
<td>Level retention bench terrace</td>
<td>0.01</td>
</tr>
<tr>
<td>Tied-ridging</td>
<td>0.10–0.20</td>
</tr>
</tbody>
</table>

* Use 50% of the value for contour bunds or if contour strip cropping is practised.
After Wischmeier and Smith (1978); Roose (1977); Chan (1981a).

- Also can be calculated by using:

$$P = P_c x P_s x P_t$$

Where P: contouring factor based on slope
Pc: strip cropping factor for strip recommended
(1.0 for contouring only or alternating strips of corn and small grain; 0.75 for 4-year rotation with 2 year of row crop; and 0.50 with 1 year of row crop)
Pt: terrace sediment factor (1.0 for no terrace; 0.2 for terraces with graded channel sod outlet; and 0.1 for terraces with underground outlets)
Table 5.3  Contouring Factor \( P_c \), Maximum Slope Lengths, and Maximum Strip Crop Widths for Different Slopes*

<table>
<thead>
<tr>
<th>Land Slope (%)</th>
<th>( P_c ) value</th>
<th>Maximum Slope Length(^a) (m)</th>
<th>Maximum Strip-Crop Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 - 2</td>
<td>0.6</td>
<td>120</td>
<td>40</td>
</tr>
<tr>
<td>3 - 5</td>
<td>0.5</td>
<td>90</td>
<td>30</td>
</tr>
<tr>
<td>6 - 8</td>
<td>0.5</td>
<td>60</td>
<td>30</td>
</tr>
<tr>
<td>9 - 12</td>
<td>0.6</td>
<td>36</td>
<td>24</td>
</tr>
<tr>
<td>13 - 16</td>
<td>0.7</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>17 - 20</td>
<td>0.8</td>
<td>18</td>
<td>18</td>
</tr>
<tr>
<td>21 - 25</td>
<td>0.9</td>
<td>15</td>
<td>15</td>
</tr>
</tbody>
</table>

*Factor for farming upslope and downslope is 1.0. \(^a\)

\(^a\)Maximum slope length for strip cropping can be twice that for contouring only.

Table 5.4 Prediction of soil loss using the Universal Soil Loss Equation

Problem
Calculation of mean annual soil loss on a 100-m long slope of 7° on soils of the Rengam Series under maize cultivation with contour bunds spaced at 20 m intervals, near Kuala Lumpur.

Equation
Mean annual soil loss = $R \times K \times LS \times C \times P$

Estimating $R$ (Rainfall erosion index)
Method 1:
Mean annual precipitation ($P$)
From Roose (1975), mean annual rainfall erosion index ($R$) in US units

\[
R = 2,695 \text{ mm} = 0.5 \times 2,695 = 1,347.5 = 1,347.5 \times 1.73 = 2,331.18
\]
Conversion to metric units

Method 2:
From Morgan (1974), mean annual erosivity ($KE > 25$)

\[
9.28 P - 8,838 = (9.28 \times 2,695) - 8,838 = 16,171.6 \text{ J/m}^2
\]
Multiply by $I_{30}$ (use 75 mm/h; maximum value recommended by Wischmeier and Smith 1978)

\[
I_{30} = 16,171.6 \times 75 = 1,212,870 = 1,212.87
\]
Divide by 1,000 to give $R$ value in metric units

Method 3:
From Foster et al. (1981), mean annual $EI_{30}$ (kg.m.mm)/(m$^2$.h)

\[
EI_{30} = 0.276 P \times I_{30} = 0.276 \times 2,695 \times 75 = 55,786.5 = 557.9
\]
With these units, divide by 100 to give $R$ value in metric units

Best estimate: discard result from Method 3 which is rather low. Take average value of Methods 1 and 2:

\[
R = 1.772
\]

Estimating $K$ (Soil erodibility index)
From Whitmore and Burnham (1969), the soils have a 43% clay, 8% silt, 9% fine sand and 40% coarse sand; organic content about 3%.

Using the nomograph (Fig. 3.2), gives a first approximation $K$ value

\[
K = 0.05
\]

Estimating $LS$ (Slope factor)
For slope length ($l$) and slope steepness ($s$) in metres and per cent respectively,

\[
LS = (l/22)^{0.5} (0.065 + 0.045s + 0.0065s^2)
\]
With contour bunds at 20 m spacing, $l = 20$ m and $s = 12\%$ (approximation of 7°)

\[
LS = (20/22)^{0.5} (0.065 + 0.045 \times 12) + (0.0065 \times 12^2)
\]

\[
LS = 0.95 \times 1.54 = 1.46
\]

Estimating $C$ (Crop management factor)
According to Table 5.2, the $C$ value for maize ranges between 0.2 and 0.9, depending on the productivity. For many tropical farming conditions, $C$ for maize lies between 0.4 and 0.9 (Roose 1975), depending on the cover.

During the 3-month period from seeding to harvest, the cover is likely to vary from 9 to 45 per cent in the first month, to 55 to 93 per cent in the second month, and 45 to 75 per cent in the third month. Therefore, we might assume $C$ values of 0.9, 0.4 and 0.7 for the three respective months.

Maize can be planted at any time of year in Malaysia but assume planting after the April rains, allowing growth, ripening and harvesting in June and July which are the driest months. Land is under dense secondary growth prior to planting (assume $C = 0.001$) and allowed to revert to the same after harvest (assume $C = 0.1$).
Determine the soil loss for the following condition: location Memphis-Tennessee, \( K = 0.01 \) Mg/ha-year, \( l = 120 \) m, \( s = 10 \% \) \((5.7^0)\), \( C = 0.18 \) and field is to be contoured. Corn-corn-meadow rotation with good management.

Answer

From erosivity map: \( R = 5000 \)

\[
m = \frac{\sin \theta}{\sin \theta + 0.269(\sin \theta)^{0.8} + 0.05} = \frac{\sin 5.7}{\sin 5.7 + 0.269(\sin 5.7)^{0.8} + 0.05}
\]

\(= 0.52\)

\[
L = \left(\frac{l}{22}\right)^m = \left(\frac{120}{22}\right)^{0.52} = 2.41
\]

\(S = 16.8 \sin \theta - 0.50 = 16.8 \sin 5.7 - 0.50 = 1.17\)

From table \( P_c = 0.6 \), so \( P = P_c x P_s x P_t = 0.6 \times 0.75 \times 1 = 0.45\)

Then: \( E = R.K.L.S.C.P = 5000 \times 0.01 \times 2.41 \times 1.17 \times 0.18 \times 0.45 = 11.4 \) Mg/ha-year
V. MEASUREMENT OF SOIL EROSION

- Data on soil erosion and its controlling factor can be collected in the field or in the laboratory.
- Field experiment:
  - Results realistic and reliable data
  - Conditions are vary both in time and space difficult
  - May classified into two groups:
    - Small sample area or erosion plots
    - Over a large area (as a drainage basin)
- Erosion plots
  - Bounded plots
    - Employed at permanent research experimental stations
    - Each plot is physically isolated piece of land of known size, slope steepness, slope length and soil type
    - The standard plot:
      - 22 m (72.6 ft) long
      - 1.8 m (6 ft) wide
      - Area = 39.6 m$^2$ ≈ 0.01 acre ≈ 0.004 ha
      - 9 % slope
      - The edges should extend 15 - 20 cm above the soil surface and embedded in the soil to a sufficient depth
• At the downslope end is positioned a collecting tank for sediment and runoff
• Runoff discharge can be monitored automatically by using flume (such as H flume) completed with level recorder
- Large plot
  - Would contain interill areas, rills and small ephemeral channels
  - Other erosion control practice may be included

  ○ Gerlach trough
    - As a simple gutters, 0.5 m long and 0.1 m broad, closed at the side and fitted with a movable lid
    - An outlet pipe runs from the base of gutter to a collecting bottle

*Figure 6.3* Gerlach troughs.
River basin

- The rate of erosion and soil loss in the watershed upstream is determined by measuring sediment yield at the outlet of a river basin.

Rainfall simulator

- Many studies use rainfall simulator which is designed to produce a storm of known energy and drop size characteristic can be repeated on demand.
- Rainfall classification: based on the drop former use
  - Tubing tips
  - Nozzles
Laboratory experiment
  Conducted as follows:
  - Filling container with soil
  - Weighing them dry
  - Subjecting them to a simulated rain storm of preselected intensity (rainfall simulator)
  - Measuring the weight loss from the containers on dryng
VI. CONTROL OF EROSION

➢ The aim of soil conservation

Consists of:
1. Maintaining soil loss below a threshold level (erosion rate ≤ soil formation rate) → sustain maximum level of production
2. Reduce erosion to control the loss of nutrients, to decrease sedimentation rate and to limit crop damage and to prevent land deterioration

➢ Soil loss tolerance

o Is as the maximum permissible rate of erosion at which soil fertility can be maintained over 20 years
o In practice, it is not possible to determine the rate of soil formation
o Rate of soil formation:
  ▪ 0.01 - 7.7 mm/y for throughout the world (Buol, Hole and McCracken, 1973)
  ▪ Average rate is 0.1 mm/y (Zachar, 1982)
  ▪ 0.1 - 0.2 mm/y for USA (Kirby, 1980)
  ▪ 0.1 mm/y for UK (Evans, 1981)
  (0.1 mm/y ≈ 1 t/ha with bulk density 1.0 Mg/m³)

o Soil loss tolerance:
  ▪ Hudson (1981) : generally 11 t/ha/y. For sensitive area (thin soil) is 2 t/ha/y
  ▪ Schertz (1983) : for soil deeper than 2 m is 15 - 20 t/ha/y
➢ Principle of soil conservation

- Protecting the soil from raindrop impact
- Increasing the infiltration capacity of the soil to reduce runoff
- Improving aggregate stability of the soil to reduce soil detachment
- Increasing surface roughness to reduce the runoff velocity

➢ Soil conservation method

- **Agronomic measures.** It utilize the role of vegetation to protect the soil against erosion
- **Soil management.** It is concerned with ways of preparing the soil to promote plant growth and improve its structure so that it is more resistant to erosion
- **Mechanical or Physical method.** Involving engineering structures, depend upon manipulating the surface topography

<table>
<thead>
<tr>
<th>Practice</th>
<th>Rainsplash</th>
<th>Control over Runoff</th>
<th>Wind</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D</td>
<td>T</td>
<td>D</td>
</tr>
<tr>
<td>Agronomic measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Covering soil surface</td>
<td>*</td>
<td>*</td>
<td>*</td>
</tr>
<tr>
<td>Increasing surface roughness</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Increasing surface depression</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Soil management</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fertilizers, manures</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Subsoiling, drainage</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mechanical measures</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contouring, ridging</td>
<td></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Terraces</td>
<td></td>
<td>+</td>
<td>*</td>
</tr>
<tr>
<td>Shelterbelts</td>
<td></td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>Waterways</td>
<td></td>
<td></td>
<td>-</td>
</tr>
</tbody>
</table>

- no control; + moderate control; * strong control
D = detachment, T = transport
➢ Approach to soil conservation

○ Cultivated land  
  Relies strongly on agronomic methods combined with sound soil management, whilst mechanical measures play only a supporting role

○ Non cultivated land  
  Consist of pasture land, forest and rough land

○ Urban area
Figure 7.5 Soil conservation strategies for urban areas (after El-Swaify, Dangler and Armstrong 1982).
CROP AND VEGETATION MANAGEMENT

➢ Use the protective effect of plant covers and plant residue (mulch) to reduce erosion

➢ Depends on:
  o Type of plant
  o Plant density
  o Planting pattern

➢ Management methods:

  o Rotation
    ▪ Crop rotation: to plant different crops on the same field consecutively in rotation
    ▪ Main crop – rotation crop – main crop – rotation crop
    ▪ Suitable crops for use in rotations are:
      - Legumes and grass (good ground cover, improve organic matter) → reduce erosion and increase fertility
      - Crops that have ability to reduce soil loss such as cowpeas, soya beans, etc
    ▪ Hudson (1981) tobacco-grass-tobacco-grass-grass is more effective than tobacco-tobacco-grass-grass-grass
    ▪ Location rotation → shifting cultivation
      Can be practiced at low ratio of population and land area
  o Cover crops
- **Cover crops** are grown as a conservation measure either during the off season or as ground protection under trees.
  - It reduce erosion to less than 0.05 t/ha/y (Maene et al., 1979)
  - Permanent grass cover in vine yard reduce erosion to less than 7% of that in vine yard with bare soil (Gril et al., 1989)

- **Good cover crops:**
  - Quick to establish
  - Provide an early canopy cover
  - Aggressive enough to suppress weeds
  - Posses a deep-root system to improve macroporosity

- **Disadvantage of cover crops:**
  - A satisfactory cover will not be attained
  - Need cost which may outweigh the benefits
  - Compete for available moisture. It reduce the available water in the top of 40 cm of top soil in the summer (Husse, 1991)

- **Coomons cover crops:** *Pueraria phaseoloides,* *Calapogonium mucunoides,* *Centrosema pubescens* and grass

- **Grass commonly planted:** *axonopus compressus,* *digitaria didactyla,* *cynodon dactylon* (Bermuda grass), *zoysia japonica,* etc.

- **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
  - Strip cropping of maize with soybean on 20 slope gave an annual soil loss of 9.5 t/ha compare with 15.7 t/ha for maize alone (Singh et al., 1979)
- Rotations that provide strips of close growing perennial grasses and legumes alternating with grain and row crops
- Three general types of strip cropping:
  a. Contour strip cropping. Lay out and tillage are held closely to the contour and the crops follow a definite rotational sequence
  b. Field strip cropping. Strip of uniform width are place across the general slope
  c. Buffer strip cropping. It has strips of a grass or legume crop between contour strips of crops in the regular rotations
- **Recommended strip widths**
  - 2 – 5 % slope: 30 m
  - 6 – 9 % slope: 25 m
  - 10 – 14 % slope: 20 m
  - 15 – 20 % slope: 15 m

- **Multiple cropping**
  - Involves either sequential cropping, growing two or more crops a year in sequence (intercropping) and growing two or more crops on the same piece of land at the same time → multi-storey canopy
  - Mixed maize-cassava reduced annual soil loss to 86 t/ha compared with 125 t/ha for cassava as a monoculture (Lal, 1977)
- High density planting
  - Increase canopy coverage
  - Increasing density of maize from 25,000 to 37,000 plants/ha, reduced the annual soil loss from 12.3 to 0.7 t/ha (Mohammad and Gumbs, 1982)

- Mulching
  - Is the covering of the soil with crop residues, such as straw, maize stalks, palm fronds or standing stubble
  - Mulch application:
    - Spreading crop residues on the surface of the soil
    - Incorporate the mulch in the soil
  - A mulch should cover 70 - 75% of the soil surface
  - Lalang grass at a rate 3 t/ha to maize grown reduced soil loss between October 1978 - July 1979 to 0.5 t/ha
compare to 7.5 t/ha without mulch (Mokhtaruddin and Maene, 1979)

Annual soil loss was 24.6 t/ha from uncultivated bare land, but only 1.1 t/ha from land covered with straw mulch applied 5 t/ha (Woodburn, 1942)

- The relationship between Manning’s n and mulch rate (kg/m²) for maize straw (Foster et al., 1982):
  \[ n_m = 0.071M^{1.12} \] for interrill erosion
  \[ n_m = 0.105M^{0.84} \] for rill erosion

- Disadvantage:
  - Tillage tools become clogged with the residue
  - Weed and pest control become difficult
  - Planting under residue is not always successful
SOIL MANAGEMENT

➢ The aim: to maintain the fertility and structure of the soil

➢ High fertility soil:
  o Produce high yield
  o Good plant cover
  o Have stable structure
  o High infiltration capacity

  As the key top soil conservation

➢ Management methods:
  o Organic Matter
    ▪ Effects:
      - Improves the cohesiveness of the soil
      - Increase water retention capacity
      - Promote a stable aggregate structure
    ▪ Types of organic matter:
      - As green manure. They are usually leguminous crops ploughed in, have a high rate of fermentation
      - As straw. Take time to decompose. Have longer effect
      - As a manure which has already undergone a high degree of fermentation
    ▪ Bonsu (1985): combination of cow dung at 5 t/ha and wheat straw mulch at 4 t/ha gave lowest soil loss and highest yield compared to other practices in Ghana
  o Tillage practice
    ▪ Its provides a suitable seed bed for plant growth and helps to control weeds
Tillage tools pulled by the tractor are designed to apply an upward force to cut and loosen the compacted soil, to invert it and to smooth and shape the surface → increase roughness

- Soil loss (SL) and roughness (R) relationship: 
  \[ SL = \alpha e^{-0.5R} \]

- The effect of tillage on erosion depends on: surface residue, aggregation, surface sealing, infiltration and water movement

- Tillage practice used for soil conservation

---

**Table 9.2 Tillage practices used for soil conservation**

<table>
<thead>
<tr>
<th>Practice</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Standard practice of ploughing with disc or mouldboard plough, one or more disc harrowings, a spike-tooth harrowing, and surface planting.</td>
</tr>
<tr>
<td>No tillage</td>
<td>Soil undisturbed prior to planting which takes place in a narrow, 2.5–7.5 cm wide seed-bed. Crop residue covers of 50–100% retained on surface. Weed control by herbicides.</td>
</tr>
<tr>
<td>Strip tillage</td>
<td>Soil undisturbed prior to planting which is done in narrow strips using rotary tiller or in-row chisel, plough-plant, wheel-track planting or listing. Intervening areas of soil untillled. Weed control by herbicides and cultivation.</td>
</tr>
<tr>
<td>Mulch tillage</td>
<td>Soil surface disturbed by tillage prior to planting using chisels, field cultivators, discs or sweeps. At least 30% residue cover left on surface as a protective mulch. Weed control by herbicides and cultivation.</td>
</tr>
<tr>
<td>Reduced or minimum tillage</td>
<td>Any other tillage practice which retains at least 30% residue cover.</td>
</tr>
</tbody>
</table>

- Soil Stabilizers
  - To improve soil structure
  - Soil stabilizers:
- Organic by-products. They bind soil particles into aggregate
- Polyvalent slats.
  - Such as gypsum
  - They make clay particle to flocculate
- Various synthetic polymers. They bind soil particles into aggregate
- Soil stabilizer groups:
  - Hydrophobic.
    - Base on bitumen
    - Such as propylene oxide
    - Decrease infiltration and increase runoff
    - Effective for only short time
  - Hydrophylic
    - Increase infiltration and decrease runoff
    - Such as polyacrylamide, ethylene oxide

**CONTOURING**

- This practice is performing of field operations, such as plowing, planting, cultivating and harvesting, approximately on the contour
- The effectiveness varies with the length and steepness of the slope
- Only effective during storm of low rainfall intensity
- It reduces runoff by impounding water in small depressions and the development of rills. But depression storage is reduced after consolidation take placed
- Harrold (1947) : contour cultivation together with good waterways reduce watershed runoff by 75 to 80 % at the
beginning season, and dropped to as low as 20% at the end of the year

- In a field with nonuniform slopes, all crops cannot be on the true contour
- To establishes row directions, a guideline (true contour) is laid out at one or more elevation in the field

**Contour Bunds**

- Contour bunds are earth banks, 1.5 to 2 m wide, thrown across the slope:
  - to act as a barrier to runoff
  - to form a water storage area on their upslope side, and
  - to break up a slope into segments shorter in length than is required to generate overland flow

- Suitable for slope of 1 to 7°
- The bank spaced at 10 to 20 m intervals
- The effectiveness of contour bunds

*Table 10.1 Capacity of contour bunds to reduce erosion in Wallo Province, Ethiopia (after Hurni 1984)*

<table>
<thead>
<tr>
<th>Bund form</th>
<th>6°</th>
<th>14°</th>
<th>27°</th>
<th>33°</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slope</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.90</td>
<td>0.70</td>
<td>0.40</td>
<td>0.30</td>
</tr>
<tr>
<td>Width (m)</td>
<td>0.19</td>
<td>0.07</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Storage capacity (m$^3$)</td>
<td>20</td>
<td>15</td>
<td>10</td>
<td>8</td>
</tr>
<tr>
<td>Spacing (m)</td>
<td>30</td>
<td>115</td>
<td>115</td>
<td>125</td>
</tr>
<tr>
<td>Predicted annual soil loss (t/ha)</td>
<td>114</td>
<td>59</td>
<td>48</td>
<td>45</td>
</tr>
<tr>
<td>Capacity of bunds to store soil (t/ha)</td>
<td>100 (1)</td>
<td>51 (1)</td>
<td>42 (1)</td>
<td>36 (1)</td>
</tr>
<tr>
<td>Percentage of soil loss stored behind bunds in first and second year</td>
<td>100 (2)</td>
<td>0 (2)</td>
<td>0 (2)</td>
<td>0 (2)</td>
</tr>
</tbody>
</table>

- As an alternative technique:
  - Contour stone bunds
- Small stone structures
  - 25 - 30 cm high
  - Set in a shallow trench

- Permeable rock dams
  - Long low structures
  - Over 100 m in length
  - 50 - 70 cm in high
  - Made from stones laid across valley floors
TERRACING

➢ Terracing is a method of erosion control accomplished by constructing earth embankments and or channel across the slope
➢ Terrace function:
  a. To intercept surface runoff and convey it to a stable outlet at a non-erosive velocity
  b. To shorten slope length
➢ Terrace classification
  a. Construction method :
    - Mangum terrace
    - Nichols terrace

  Mangum terrace

  Nichols terrace

  Broad-based terrace

  Narrow-based terrace

b. Width :
  - Broad-base terrace
  - Narrow-base terrace

c. Shape :
  - Broad-base : Three segment section broad-base and conservation bench broad-base
- **Bench**

![Diagram: Bench Terrace](image)

- **Alignment**
  - Non-parallel. They follow the contour regardless of alignment
  - Parallel

- **Grade**
  - Graded or channel terrace. They are designed to removed excess water in such way as to minimized erosion
  - Level terrace. They are constructed to conserved water and control erosion

- **Outlet**
  - Blocked outlets. All water infiltrates the terrace channel
  - Permanently vegetated outlets (Grassed waterway or a vegetated area)
  - Underground outlets. Water is removed through subsurface drains

---

**Fig. 8.2** Classification of terrace shapes. (a) Three-segment section broadbase. (b) Conservation bench broadbase. (c) Bench.
Type of bench terraces

FIGURE 6.4 Types of bench terraces
(a) Level bench  (b) outward-sloping bench  (c) inward-sloping (or reverse-slope) bench  (d) step terraces  (e) irrigation terraces

If the soil is to shallow, or the land slope too step, where bench terracing may not be practical → Intermittent terrace (small level or reverse slope terrace each carrying one line of trees)
Terrace system
- should be coordinated with the water management system for the farm, giving adequate consideration for proper land use
- should be planned by watershed area and should include all terrace that may be constructed later

Terrace design
It involves:
- specifying the proper spacing
- location of terrace
c. channel with adequate capacity

d. development of a farmable cross section

a. Terrace spacing

- Spacing is express as the vertical distance between the channels of successive terraces.
- Commonly known as **vertical interval** (VI)
- The horizontal interval (HI) is found by dividing VI by the slope (m/m).
- HI for parallel terrace is usually selected as even number of rounds for row crop equipment

- Empirical formula

  1. USSCS : \( VI (m) = aS + b \)
     
     \( a \) varies from 0.12 in the south of US to 0.24 in the north.
     
     \( b \) varies between 0.3 and 1.2 according to the erodibility of the soil. \( S \) is the average land slope in %

  2. Zimbabwe : \( VI (ft) = (S + f)/2 \)
     
     \( F \) varies from 3 to 6 according to the erodibility of soil

  3. Algeria : \( VI (m) = S/10 + 2 \)

  4. Israel : \( VI (m) = XS + Y \)
     
     \( X \) varies from 0.25 to 0.3 according to rainfall. \( Y \) is 1.5 or 2.0 according to the erodibility

  5. Kenya : \( VI (m) = (0.3(S+2))/4 \)

  6. New Soth Wales : \( HI (m) = KS^{-0.5} \)
     
     \( K \) varies from 1.0 to 1.4 according to the erodibility

- Theoretical approach

  Where soil loss data are available, spacing should be base on slope lengths using contouring and the appropriate cover management factor

  \[ E = R.K.L.S.C.P \]

  \[ L = E/(RKSCP) \]

  calculate \( L \) and calculate VI (VI=slope in percentxl)
b. Terrace location
- Factors that influence terrace location:
  - Outlet
  - Land slope
  - Soil condition
  - Proposed land use
  - Boulders, trees, gullies and other impediments
  - Farm roads
  - Fences
  - Row layout
  - Type of terrace
- **General rules for the location of top terrace**
  - The drainage area above the top terrace should not exceed 1 ha
  - If the top of the hill comes to a point, the spacing may increase to 1.5 the regular spacing
  - On long ridges, where the terrace approximately parallel the ridge, the regular spacing should be specified
  - If short, abrupt changes in slope occur, the terrace should be placed just above the break
- **Typical layout**

Fig. 8.6 Typical layout for broadbase graded terraces.
c. Terrace grades

- The gradient of the channel must be sufficient to provide adequate drainage, while removing the runoff at non-erosive velocity
- May range from 0.1 to 0.6 % depending on soil and climate
- ASAE (1989) recommends maximum velocity of 0.5 m/s for extremely erosive soils and 0.6 m/s for other soils

<table>
<thead>
<tr>
<th>Terrace Length or Length from Upper End of Long Terraces (m)</th>
<th>Maximum Slope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>≤30</td>
<td>2.0</td>
</tr>
<tr>
<td>31 – 60</td>
<td>1.2</td>
</tr>
<tr>
<td>61 – 150</td>
<td>0.5</td>
</tr>
<tr>
<td>151 – 365</td>
<td>0.35</td>
</tr>
<tr>
<td>≥366</td>
<td>0.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Minimum Slope (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soils with slow internal drainage</td>
</tr>
<tr>
<td>Soils with good internal drainage</td>
</tr>
</tbody>
</table>

Source: Values for the maximum slope are from Beasley (1963); those for minimum slope are from ASAE (1989).

d. Terrace Length

- Depends on:
  - Size and shape of field
  - Outlet possibility
  - Rate of runoff
  - Channel capacity
- Extremely long graded terraces are to be avoided. Generally between 300 - 500 m.
- There is no maximum length for level terraces, particularly where blocks or dams are placed in the channel every 150 m
e. Terrace cross section

- Should:
  - Provide adequate capacity
  - Have broad farmable side slope
  - Be economical to construct

- Design criteria:
  - The front slope width, $W_f$ is specified to be equal to the machinery width
  - The depth of flow is determined from the runoff rate for 10 year return period storm or for the required runoff volume for storage type terrace

![Terrace Cross Section Diagram]

- When $W_c = W_f = W_b = W$, then $c + f = h + sW$. For balanced cross section, $c = f$

- The terrace is generally constructed with a 5:1 backslope and planted with grass

- For practical reasons, terrace cross section is uniform

Example:
For a channel depth $h$ of 0.33 m and for eight-row equipment 6 m wide on 7% land slope, compute the cut and fill heights and the frontslope and the backslope assuming a balanced cross section

$c = f = (h + sW)/2 = (0.33 + 0.07 \times 6)/2 = 0.38$ m

front slope: $S_f = W/h = 6/0.33 = 18.2 \rightarrow 18:1$ slope ratio

backslope or cutslope: $S_b = W/(h + sW) = 6/(0.33 + 0.07 \times 6) = 8.0 \rightarrow 8:1$ slope ratio
f. Terrace channel capacity

- The channel will carry the design runoff.
- Recommended roughness coefficient is 0.06 and maximum velocity is 0.6 m/s
- Freeboard about 20% of the total depth after allowing for settlement of the fill

g. Construction equipment

- Small equipment: moldboard and disk plows for slope less than 8%.
- Heavy equipment: bulldozer, pan or elevating scraper, motor patrol or blade grader

h. Settlement of terrace ridge

- Depends on:
  - soil and water conditions
  - type of equipment
  - construction procedure
  - amount of vegetation and crop residue
- The percentage of settlement:
  - 10 - 20% if use moldboard plow or bulldozer
  - 10 - 25% if use elevating grader
  - 0 - 5% if use blade grader
VII. CONSERVATION STRUCTURE

➢ Stabilization structure for gully control

  o Temporary structures
    ▪ It is needed if the establishment of vegetation is difficult
    ▪ Usually as small dams
      - 0.4 to 2.0 m height
      - Made from locally materials such as earth, wooden planks, brushwood, bricks or loose rock
      - Are built across gullies to trap sediment and thereby reduce channel depth and slope
      - They must be quick and easy to construct

\[
\text{spacing} = \frac{HE}{K \tan \theta \cos \theta}
\]
HE : dam height (from the gully floor to the crest of spillway), \( \theta \): slope angle, \( K \): constant (\( K = 0.3 \) for \( \tan \theta \leq 0.2 \), \( K = 0.5 \) for \( \tan \theta > 0.2 \))
- An effective composition of rock fill dam: 25% between 100 - 140 mm, 20% between 150 - 190 mm, 25% between 200 - 300 mm and 30% between 310 - 450 mm (Heede, 1976)

- Permanent structure
  - Are required on large gullies to control the overall of water on the headwall (dam), such as:
    - Silt trap dam. Excessive sediment load will be trapped in this dam type
    - Regulating dams. Completed with permanently open pipe outlet that allows the water to drain away
    - Gully head dams. To control the erosive force of the runoff over the gully head by submerging the head of gully

![Figure 12.7 Submerging the head of the gully by a dam](image)

- Are design to deal safely with the peak runoff of 10 years return period
- Completed with energy dissipation to protect both the structure and the channel downstream
  - For structure < 3 m height, completed with a drop spillway
  - For structure 3 - 6 m, completed with a chute or pipe spillway
➢ Stabilization structure to control erosion on steep slope

- **Brush matting**
  - For a short period
  - Live willow stakes are driven into the soil to a depth of 200 mm
  - The stakes are placed 1 m apart to form a row along the contour with a distance of 10 – 20 m
  - Sprouting brushwood is spread over the top of the slope, and tied to the stakes with galvanized wire

- **Wattling**
  - Placing fascines or bundles of woody plant stems (*salix, Leucaena, Baccharis and Tamarix*) in shallow trenches on the contour
  - Row spaced 1 – 6 m
  - The wattling is tied to stakes on downslope side

- **Permanent protection** can be achieved by facing them with a resistant material such as concrete or gabion
  (these are rectangular steel wire mesh baskets, packed tightly with stones 125 – 200 mm in diameter)
Stabilization structures to control channels

- Function: to dissipate kinetic energy of the discharge to a degree that will protect both the structure and the downstream channel from damage or erosion.

- Types of structures:
  a. Drop spillway
    - Scheme

- It controls the stream grade not only at the spillway crest itself, but also through the ponded reach upstream.
- It placed at intervals along channel a continuous steep channel a series of more gently slope.
- Limited up to 3 m drop.
- Capacity: \( q = 0.55CLh^{3/2} \)
q: discharge, m³/s
C: coefficient, recommended C = 3.2
L: weir length, m
h: depth of flow over crest, m

- The kinetic energy must be dissipated or converted to potential energy before the flow is discharging the structure use stilling basin as apron protection

b. Chute spillway
- Scheme

Chute Spillway

<table>
<thead>
<tr>
<th>A. Inlet</th>
<th>B. Conduit</th>
<th>C. Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Straight</td>
<td>1. Rectangular</td>
<td>1. Apron</td>
</tr>
<tr>
<td>2. Flared</td>
<td>2. Trapezoidal</td>
<td>2. Canti-lever</td>
</tr>
<tr>
<td>3. Box</td>
<td></td>
<td>3. SAF</td>
</tr>
</tbody>
</table>
- It is designed to carry flow down steep slope through a lined channel
- For controlling elevation changes up to 6 m
- Capacity is controlled by the inlet section and similar with drop spillway
- Outlet protection: straight apron or Saint Anthony falls (SAF) stilling basin

c. Drop inlet
   - Scheme

<table>
<thead>
<tr>
<th>A. Inlet</th>
<th>B. Conduit</th>
<th>C. Outlet</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Upstream side flared</td>
<td>2. Pipe</td>
<td>2. SAF</td>
</tr>
<tr>
<td>3. Flared</td>
<td></td>
<td>3. Baffle type</td>
</tr>
<tr>
<td>4. Hooded</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. Flat top</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- This application is usually made where water may pond behind the inlet
- Possible conditions
- The neutral slope
  \[ S_n = \tan \theta = \sin \theta = H_f / L = K_c V^2 / 2g \]
  \( K_c \) : friction loss coefficient
  \( H_f \) : friction loss in conduit length
  \( L \) : length of conduit
  \( \theta \) : slope angle of conduit

- Capacity for full pipe flow :
  \[ q = \frac{A \sqrt{2gH}}{\sqrt{1 + Ke + Kb + KcL}} \]
  \( A \) : conduit cross sectional area
  \( Ke \) : entrance loss coefficient
  \( Kb \) : loss coefficient for bends

- Capacity for the conduit at greater than neutral slope and the outlet is not submerged :
  \[ q = AC \sqrt{2gh} \]
  \( C \) : coefficient = 0.6 for sharp edged orifice
Example of the application
VIII. WATER CONSERVATION
- PONDS, RESERVOIRS AND EARTH EMBANKMENTS -

PONDS AND RESERVOIRS

➢ Meaning

  o As a structure for collecting and keeping excessive water
  o Ponds have size usually smaller than reservoir

➢ Types of ponds and reservoir

  o Dugout reservoir
    - Fed by ground water
    - Limited to area having slopes < 4 % and water table depth within 1 m depth
  o On-stream reservoir
    - Fed by surface runoff, stream or spring
    - Might be as:
      • An excavated basin below a spring
      • A reservoir formed by a dam across a stream valley or depression below spring
  o Off-stream reservoir
    - It is constructed adjacent to a continuously flowing stream

➢ Ponds and reservoirs site selection

  General rule for choice of reservoir sites:
  ▪ A suitable dam site must exist. The cost of dam is often controlling factor
- The cost of real estate for the reservoir (road, railroad, dwelling location, etc.) must not be excessive
- Must have adequate capacity
- A deep reservoir is preferable than a shallow one
- Tributary area that are unusually productive of sediment should be avoided
- The quality of the stored water must be satisfactory
- No or less environmental impact
- Water may be used with a minimum of pumping and piping

➢ Storage capacity of reservoir

- Capacity of reservoir on natural sites must usually determined from topographic survey
- The increment of storage between two elevation is computed by: \[ Volume = \frac{1}{2} (A_1 + A_2) \Delta Z \]
Zones of storage in a reservoir

Table 10.3 Volume of Pond-Water Storage

<table>
<thead>
<tr>
<th>Contour Elevation (m)</th>
<th>Area Within Contour Line to Center Line of Dam (ha)</th>
<th>Average Area (ha)</th>
<th>Contour Interval (m)</th>
<th>Volume of Storage (ha-m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>89.5</td>
<td>0.05</td>
<td>0.15</td>
<td>0.5</td>
<td>0.08</td>
</tr>
<tr>
<td>90</td>
<td>0.25</td>
<td>0.45</td>
<td>1.0</td>
<td>0.45</td>
</tr>
<tr>
<td>91</td>
<td>0.64</td>
<td>0.94</td>
<td>1.0</td>
<td>0.94</td>
</tr>
<tr>
<td>92</td>
<td>1.24</td>
<td></td>
<td></td>
<td>Total 1.47 (11.9 ac-ft)</td>
</tr>
</tbody>
</table>

To elevation 91.8, storage is $1.47 - (0.94 \times 0.2/1) = 1.28$ ha-m and water surface area = $1.24 - 0.2 \times (1.24 - 0.64) = 1.12$ ha (2.8 ac).

Water storage requirement

Depend on:
- Water needs (domestic uses, livestock, spraying, irrigation and fire protection)
- Evaporation from the water surface
- Seepage into the soil through the dam
- Storage allowed for sedimentation
- Amount of carry-over from one year to the next
Selection of capacity for a river reservoir

- May be performed with annual, monthly or daily time interval. Monthly data are most commonly used
- Methods:
  - Sequent peak algorithm
    - Calculate the cumulative sum of inflow minus withdrawals (including average evaporation and seepage)
    - Identify the first peak and the sequent peak (next following peak that is greater than the first)
    - The required storage for the interval is the difference between initial peak and the lowest through in the interval

### Table 10.2 Water Requirements for Farm Uses

<table>
<thead>
<tr>
<th>Type of Use</th>
<th>Average use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L/day</td>
</tr>
<tr>
<td>Household, all purposes, per person</td>
<td>190–380</td>
</tr>
<tr>
<td>Fire protection</td>
<td></td>
</tr>
<tr>
<td>Dry cow or steer, per 450 kg weight</td>
<td>75–115</td>
</tr>
<tr>
<td>Milk cow, 450 kg including milkhouse and barn sanitation</td>
<td>130–170</td>
</tr>
<tr>
<td>Horse or mule, 450 kg</td>
<td>45</td>
</tr>
<tr>
<td>Turkeys per 100 head</td>
<td>60</td>
</tr>
<tr>
<td>Chickens per 100 head</td>
<td>35</td>
</tr>
<tr>
<td>Swine per 45 kg</td>
<td>10–20</td>
</tr>
<tr>
<td>Sheep per 45 kg</td>
<td>8</td>
</tr>
<tr>
<td>Orchard spraying, per year of tree age per application</td>
<td>4</td>
</tr>
<tr>
<td>Irrigation (humid regions) per ha</td>
<td></td>
</tr>
<tr>
<td>Irrigation (arid regions) per ha</td>
<td></td>
</tr>
</tbody>
</table>

*Source: Adapted from Midwest Plan Service (1987).*
- **Mass curve (Rippl diagram)**
  - Plot the cumulative net reservoir inflow. The slope of the mass curve at any time is a measure of the inflow at that time.
  - Demands curve representing a uniform rate of demand are straight lines.
  - Draw tangent lines parallel to the demand curve at the high points of the mass curve (at A, B) represent rate of withdrawal.
  - The maximum departure between the demand line and the mass curve represents the reservoir capacity required to satisfy the demand.
Reservoir sedimentation

- The ultimate destiny of all reservoir is to be filled with sediment
- Important data:
  - Specific weight of the settled sediments
    \[ W = \frac{%sand}{100} (W_1 + B_1 \log T) + \frac{%silt}{100} (W_2 + B_2 \log T) + \frac{%clay}{100} (W_3 + B_3 \log T) \]
    
    \( W \): the specific weight (dry) of a deposit with an age of \( T \) years
    
    The percent of sand, silt and clay is on weight basis
    
    \( W_1, W_2 \) and \( W_3 \) : represent the specific weight of sand, silt and clay
    
    \( B_1, B_2 \) and \( B_3 \) : constants

| TABLE 7.2 | Constants in Eq. (7.3) for estimating specific weight of reservoir sediments* |
|------------|---------------------------------|------------------|------------------|
| Reservoir operation | Sand \( W_1 \) | Sand \( B_1 \) | Silt \( W_2 \) | Silt \( B_2 \) | Clay \( W_3 \) | Clay \( B_3 \) |
| Sediment always submerged or nearly submerged | 93 | 0 | 65 | 5.7 | 30 | 16.0 |
| Normally a moderate reservoir drawdown | 93 | 0 | 74 | 2.7 | 46 | 10.7 |
| Normally considerable reservoir drawdown | 93 | 0 | 79 | 1.0 | 60 | 6.0 |
| Reservoir normally empty | 93 | 0 | 82 | 0.0 | 78 | 0.0 |

the percentage of entering sediment that is deposited in the reservoir/retained in reservoir (trap efficiency)
- a function of the ratio of reservoir capacity to total inflow
- The trap efficiency decrease with age

Reservoir sedimentation cannot be prevented, but can be control by reduction in sediment inflow (through soil conservation)

**EARTH EMBANKMENTS**

- **Meaning:**
  - Is as a type of dams
  - Made of earth (soil) → earth-fill dam
  - Utilize natural materials with a minimum of processing
  - May be built with primitive equipment
  - Adapted to earth foundations
  - Total height above ground level ≤ 15 m

- **Types of earth-fill embankment dams:**
  - **Simple type.** It is constructed of relatively homogenous soil material and either is keyed into a impervious foundation stratum

![Diagram](image)

0.1 (a) Simple embankment using “key” construction. (b) Simple embankment
Core or Zone type. A central section (core) of highly impermeable soil is placed within the dam

Diaphragm type. It uses a thin wall of plastic, butyl, concrete, steel or wood to form a barrier against seepage through the fill

General requirements for earth embankment

1. The topographic condition at dam site must allow economical construction
2. Soil material must be available to provide a stable, impervious fill
3. Must have adequate mechanical and flood spillway
4. Large storage embankment should be equipped with a bottom drain pipe for maintenance and fish management
5. Should be provided by safety equipment
6. Provided by maintenance program

Height of dam
- Is the distance from the foundation to the water surface in the reservoir when the spillway is discharging, plus freeboard
- Gross freeboard is the distance between the crest of the mechanical spillway and the top of the dam
- Net freeboard is the distance between the maximum designed high water level or flood peak and the top of settled dam
- Net freeboard should sufficient to prevent wave
  - Wave height for moderate reservoir: \[ h = 0.014(D_f)^{1/2} \]
    
    \( H \): height of wave, m and \( D_f \): length of exposure, m.
- The height of dam should be 5 to 10% higher than the design to allow settlement

➢ Top width

- Should be sufficient to keep phreatic line when the reservoir full
  1. For dams height \( \leq 3.5 \) m, minimum top width is 2.4 m
  2. For dam height > 3.5 m, \( W = 0.4H + 1 \)
    
    \( W \): top width in m, \( H \): maximum height of dam in m

➢ Side slope

- Depend on the height, the shearing resistance of the foundation and the duration of inundation
- On structure < 15 m height with average material, side slope \( \leq 3 : 1 \) on the upstream face and 2 : 1 on the downstream face
- Coarse, uncompactable soil, side slope 3 : 1 or 4 : 1
- For structure > 15 m height → complete analysis
Seepage

- No earth fill dam can be considered impervious seepage
- If rate of seepage height enough soil particles are moved called piping dam failure
- Seepage through earth fill dam reduced by:
  - Placing impervious blanket on upstream face
  - Using a clay core or diaphragm
  - Placing drain blanket and filters at the toe
- Seepage through permeable foundation reduced by extending blanket to upstream
- Can be analyzed by flownet

\[
\text{Total head lost: } H = \Delta H \times \text{no. of equipotential drops} = \Delta H x N_d
\]

\[
\text{Total seepage flow: } q = \Delta q \times \text{no. of flow intervals} = \Delta q x N_f
\]

\[
\text{Darcy: total flow, } q = k\Delta HN_f = kH \frac{N_f}{N_d}
\]

➢ Construction

1. All tree, stumps and major roots should be removed from the site
2. Top soil should be removed and stockpiled for later spreading
3. The fill should be compacted at optimum water content.
4. The thickness of layers:
   - 0.25 m for pervious soil
   - 0.15 m for plastic and cohesive soil
5. The material should be placed nearly horizontal
6. The degree of compaction to be achieved 85 – 100 % of maximum Proctor density
IX. WATER CONVEYANCE AND CANAL DESIGN

Water conveyance related to soil and water conservation, i.e:

1. Vegetated waterways.
   - It is water conveyance (channels) that protected from erosion by using vegetation

2. Open ditches
   - Provide outlets for pipe and surface drains
   - Remove surface water directly
   - Generally drain large area

VEGETATED WATERWAYS

- It is used to handle natural concentration of runoff or to carry the discharge from terrace systems, contour furrows, diversion channels or emergency spillway
- It should not be use for continuous flow

- Capacity
  - Be based on the estimated runoff from the contributing area
  - Use 10 year return period storm (except in flood spillway)
- For long waterways, capacity may be changed due to the changing drainage area
- For short waterways, capacity estimated based on the flow at the waterways outlet

- **Shape**
  - May be: - parabolic — the shape of natural channel
    - Trapezoidal, or
    - Triangular
  - Channels built with a blade equipment may be trapezoidal or triangular
  - Side slope 4 : 1 or flatter to facilitate mowing and crossing of farm equipment
  - Trapezoidal channels required less depth

| Cross-Sectional Area $a$ | Wetted Perimeter, $p$ | Hydraulic Radius $R = \frac{a}{p}$ | Top Width $T$
|-------------------------|----------------------|-------------------------------------|------------------|
| $bd + Zd^2$             | $b + 2d \sqrt{Z^2 + 1}$ | $\frac{bd + Zd^2}{b + 2d \sqrt{Z^2 + 1}}$ | $t = b + 2dZ$
|                         |                      | $T = b + 2dZ$                         |                  |

- **Vegetation**
  - Depend on:
    - Soil and climatic conditions
    - Duration, quantity and velocity of runoff

Note: Freeboard = $D-d$ for all sections
- Ease of establishment
- Time required to develop a good protective cover
- Suitability to the farmer for utilization as a seed or hay
- Cost and seed availability
- Retardance to shallow flows

- **Recommended vegetation (USA)**

<table>
<thead>
<tr>
<th>Geographical Area of United States</th>
<th>Vegetation*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Northeastern</td>
<td>Kentucky bluegrass, red top, tall fescue, white clover</td>
</tr>
<tr>
<td>Southeastern</td>
<td>Kentucky bluegrass, tall fescue, Bermuda, brome, Reed canary</td>
</tr>
<tr>
<td>Upper Mississippi</td>
<td>Brome, Reed canary, tall fescue, Kentucky bluegrass</td>
</tr>
<tr>
<td>Western Gulf</td>
<td>Bermuda, King Ranch bluestem, native grass mixture, tall fescue</td>
</tr>
<tr>
<td>Southwestern</td>
<td>Intermediate wheatgrass, western and tall wheatgrass, smooth brome</td>
</tr>
<tr>
<td>Northern Great Plains</td>
<td>Smooth brome, western wheatgrass, red top, switchgrass, native bluestem mixture</td>
</tr>
</tbody>
</table>

*Recommended vegetation does not necessarily apply to all areas in the region.

- **Velocity**
  - Depend on:
    - type, condition and density of vegetation
    - Erosive characteristic of soil
  - Based on Manning formula: \( v = \frac{1}{n} R^{2/3} S^{1/2} \)

  \[ V : \text{average velocity of flow, m/s} \]
  \[ n : \text{roughness coefficient} \]
  \[ R : \text{hydraulic radius} = \frac{\text{cross area}}{\text{wetted perimeter}} = \frac{A}{P} \]
  \[ S : \text{hydraulic gradient, m/m} \]
### Permissible average velocity

#### Table 7.2 Permissible Velocities for Vegetated Channels

<table>
<thead>
<tr>
<th>Cover</th>
<th>Slope Rangea (%)</th>
<th>Permissible Velocity (m/s)b</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Erosion-Resistant Soils</td>
<td>Easily Eroded Soils</td>
</tr>
<tr>
<td>Bermudagrass</td>
<td>0–5</td>
<td>2.4</td>
</tr>
<tr>
<td></td>
<td>5–10</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>&gt;10</td>
<td>1.8</td>
</tr>
<tr>
<td>Bahia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buffalo grass</td>
<td>0–5</td>
<td>2.1</td>
</tr>
<tr>
<td>Kentucky bluegrass</td>
<td>5–10</td>
<td>1.8</td>
</tr>
<tr>
<td>Smooth brome</td>
<td>&gt;10</td>
<td>1.5</td>
</tr>
<tr>
<td>Blue grama</td>
<td>Tall fescue</td>
<td></td>
</tr>
<tr>
<td>Grass mixtures</td>
<td>0–5</td>
<td>1.5</td>
</tr>
<tr>
<td>Reed canary grass</td>
<td>5–10</td>
<td>1.2</td>
</tr>
<tr>
<td><em>Lespedeza sericea</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weeping lovegrass</td>
<td>0–5</td>
<td>1.0</td>
</tr>
<tr>
<td>Yellow bluestem</td>
<td>Redtop</td>
<td></td>
</tr>
<tr>
<td>Alfalfa</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Red fescue</td>
<td>Common lespedezaa</td>
<td></td>
</tr>
<tr>
<td>Sudan grass</td>
<td>0–5</td>
<td>1.0</td>
</tr>
</tbody>
</table>

*a* Do not use on slopes steeper than 10 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.

*b* Use velocities exceeding 1.5 m/s only where good covers and proper maintenance can be obtained.

*a* Do not use on slopes steeper than 5 percent except for vegetated side slopes in combination with a stone, concrete, or highly resistant vegetative center section.

*a* Annuals—use on mild slopes or as temporary protection until permanent covers are established.

*Source: SCS (1975).*

### Velocity distribution

![Velocity distribution in a grass-lined channel](https://example.com/figure7.2.png)
- **Roughness coefficient**
  - Difficult to evaluate
  - Varies with the depth of flow

*Hydraulic behavior of a medium-length sod-forming grass (Bermuda) tested in channels having 5% bed slope. Order of flows from low to high.*

- \( vR \) is as index of channel retardance
- vegetation retardance classification
### Table 7.3 Classification of Vegetal Cover According to Retardance

<table>
<thead>
<tr>
<th>Retardance</th>
<th>Cover</th>
<th>Condition</th>
<th>Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Reed canary</td>
<td>Excellent stand, tall</td>
<td>0.9</td>
</tr>
<tr>
<td></td>
<td>Yellow bluestem <em>Ischaemum</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Smooth brome</td>
<td>Good stand, mowed</td>
<td>0.3–0.4</td>
</tr>
<tr>
<td></td>
<td>Bermuda</td>
<td>Good stand, tall</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Native grass mixture</td>
<td>Good stand, unmowed</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Tall fescue</td>
<td>Good stand, unmowed</td>
<td>0.5</td>
</tr>
<tr>
<td>B</td>
<td><em>Lespedeza sericea</em></td>
<td>Good stand, not woody, tall</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Grass–legume mixture</td>
<td>Good stand, uncut</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Reed canary</td>
<td>Good stand, mowed</td>
<td>0.3–0.4</td>
</tr>
<tr>
<td></td>
<td>Tall fescue with bird’s foot trefoil or ladino</td>
<td>Good stand, uncut</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Blue grama</td>
<td>Good stand, uncut</td>
<td>0.3</td>
</tr>
<tr>
<td></td>
<td>Bahia</td>
<td>Good stand, uncut</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Bermuda</td>
<td>Good stand, mowed</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Redtop</td>
<td>Good stand, headed</td>
<td>0.4–0.5</td>
</tr>
<tr>
<td>C</td>
<td>Grass–legume mix—summer</td>
<td>Good stand, uncut</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td>Centipede grass</td>
<td>Very dense cover</td>
<td>0.15</td>
</tr>
<tr>
<td></td>
<td>Kentucky bluegrass</td>
<td>Good stand, headed</td>
<td>0.2–0.3</td>
</tr>
<tr>
<td></td>
<td>Bermuda</td>
<td>Good stand, cut</td>
<td>0.1</td>
</tr>
<tr>
<td>D</td>
<td>Red fescue</td>
<td>Good stand, headed</td>
<td>0.3–0.5</td>
</tr>
<tr>
<td></td>
<td>Buffalo grass</td>
<td>Good stand, uncut</td>
<td>0.1–0.2</td>
</tr>
<tr>
<td></td>
<td>Grass–legume mixture—fall</td>
<td>Good stand, uncut</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td><em>Lespedeza sericea</em></td>
<td>After cutting</td>
<td>0.1</td>
</tr>
<tr>
<td></td>
<td>Bermuda grass</td>
<td>Good stand</td>
<td>0.1</td>
</tr>
<tr>
<td>E</td>
<td>Burned stubble</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Source: SCS (1975).*

Edisi 2006

86
- roughness coefficient

For small channel \( n = 0.04 \)
Channel capacity

- The channel must be proportioned to carry the design runoff at average velocities \( \leq \) the permissible velocity

\[ q = av \]

- \( q \): flow rate to be carried by the channel, \( m^3/s \)
- \( a \): cross section area, \( m^2 \)
- \( v \): average velocity, \( m/s \), calculated by using Manning equation

- Nomograph of Manning equation for vegetated waterways
Fig. 7.6  Nomograph of the Manning equation for vegetated channels of retardance Class C (moderate vegetal retardance). (Source: SCS, 1966.)

Fig. 7.7  Nomograph of the Manning equation for vegetated channels of retardance Class D (low vegetal retardance). (Source: SCS, 1966.)
Depth flow of trapezoidal vegetated waterways

A freeboard of 0.1 to 0.15 should be added to the design depth
- The channel should be designed to carry runoff at a permissible velocity under conditions of minimum retardance (short grass) b determination
- Additional depth should be added to the channel to provide adequate capacity under maximum retardance (long grass) d determination

Fig. 7.8 Dimensions of trapezoidal cross sections with 4:1 side slopes. (Redrawn in SI units from Larson and Manbeck, 1960.)
Example:
Design a trapezoidal grass waterway to carry $5 \text{ m}^3/\text{s}$ on a 3 % slope on erosion-resistant soil. The vegetation is to be Bermuda grass, and the channel should have 4:1 slope.

From table permissible velocity, the permissible velocity is 2.4 m/s
From retardance classification table, Bermuda grass is in retardance class D when mowed and in class B when long.
For soil conservation, the mowed condition is more critical
By using nomograph Manning for D class, with $v=2.4 \text{ m/s}$, slope 3 % read $R = 0.31 \text{ m}$
The cross sectional area : $a = q/v = 5/2.4 = 2.08 \text{ m}^2$
By using nomograph for trapezoidal dimension, with $R = 0.31 \text{ m}$ and $a = 2.08 \text{ m}^2$, read bottom width $b = 4 \text{ m}$ and depth of flow $d = 0.41 \text{ m}$

To determined depth of flow \(\rightarrow\) in long condition (class B)
The bottom width $b = 4 \text{ m}$ must be retained
By trial and error, select a depth of 0.5 m, so $a$ become $0.3 \text{ m}^2$ and $R = 0.37 \text{ m}$. By using nomograph for Manning, with $R=0.37$ and slope 3 %, read $v = 1.7 \text{ m/s}$
$q$ become $3.0 \times 1.7 = 5.1 \text{ m}^3/\text{s} \rightarrow$ to hight

Try again for the depth < 0.5 m, and the calculation is repeated until $q \approx 5 \text{ m}^3/\text{s}$. 
The other alternate solution is to select the appropriate additional depth increment as shown in the following table.

**Table 7.4 Approximate Channel Depth Increment for Grassed Waterways with Retardance Increase from Class C (Short) to Class B (Long)**

<table>
<thead>
<tr>
<th>Slope Range (%)</th>
<th>Triangular or Parabolic</th>
<th>Parabolic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$t = 2–6 \text{ m}$</td>
<td>$t = 6–27 \text{ m}$</td>
</tr>
<tr>
<td></td>
<td>Trapezoidal</td>
<td>Trapezoidal</td>
</tr>
<tr>
<td>$b = 2–6 \text{ m}$</td>
<td>$b = 6–27 \text{ m}$</td>
<td>$b \geq 27 \text{ m}$</td>
</tr>
<tr>
<td>1–2</td>
<td>0.17 m</td>
<td>0.15 m</td>
</tr>
<tr>
<td>2–5</td>
<td>0.13</td>
<td>0.12</td>
</tr>
<tr>
<td>$\geq 5$</td>
<td>0.10</td>
<td>0.09</td>
</tr>
</tbody>
</table>

Note: For change from retardance D to B add 0.03 m to the above values for all slopes and cross sections. For change from retardance D to C use 0.03 m as the depth increment for all slopes and cross sections.

Source: Larson and Manbeck (1960) as computed by C. L. Larson.

The depth increment is $0.13 + 0.03 = 0.16$ m
The depth of flow $d$ become $0.41 + 0.16 = 0.57$ m
Freeboard should be include, so the depth $d = 0.57 + 0.1 = 0.67$ m

So, the dimension of vegetated waterways is: bottom width $b = 4$ m, depth $d = 0.67$ m, side slope 4:1
OPEN CHANNEL

➢ Open channel refers to open ditches for drainage
➢ Open ditch:
  o Provide outlets for pipe and surface drains
  o Remove surface water directly
  o May be earth or lined channel
➢ Earth-lined open channel
  o Discharge capacity
    - It is computed from the Manning formula
      \[ v = \frac{1}{n} R^{2/3} S^{1/2} \]
    - q = a v
    - Sufficient to carry the design flow

<table>
<thead>
<tr>
<th>Line No.</th>
<th>Type and Description of Conduits</th>
<th>n Value*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Design</td>
</tr>
<tr>
<td>Channels, Lined</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Asphalitic concrete, machine placed</td>
<td>0.014</td>
</tr>
<tr>
<td>2</td>
<td>Asphalt, exposed prefabricated</td>
<td>0.015</td>
</tr>
<tr>
<td>3</td>
<td>Concrete</td>
<td>0.012</td>
</tr>
<tr>
<td>4</td>
<td>Concrete, rubble</td>
<td>0.017</td>
</tr>
<tr>
<td>5</td>
<td>Metal, smooth (flumes)</td>
<td>0.011</td>
</tr>
<tr>
<td>6</td>
<td>Metal, corrugated</td>
<td>0.021</td>
</tr>
<tr>
<td>7</td>
<td>Plastic</td>
<td>0.012</td>
</tr>
<tr>
<td>8</td>
<td>Shotcrete</td>
<td>0.016</td>
</tr>
<tr>
<td>9</td>
<td>Wood, planed (flumes)</td>
<td>0.010</td>
</tr>
<tr>
<td>10</td>
<td>Wood, unplanned (flumes)</td>
<td>0.011</td>
</tr>
<tr>
<td>Channels, Earth</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Earth bottom, rubble sides</td>
<td>0.028</td>
</tr>
<tr>
<td></td>
<td>Drainage ditches, large, no vegetation</td>
<td>0.032</td>
</tr>
<tr>
<td>12</td>
<td>(a) &lt;0.8 m, hydraulic radius</td>
<td>0.040</td>
</tr>
<tr>
<td>13</td>
<td>(b) 0.8–1.2 m, hydraulic radius</td>
<td>0.035</td>
</tr>
<tr>
<td>14</td>
<td>(c) 1.2–1.5 m, hydraulic radius</td>
<td>0.030</td>
</tr>
<tr>
<td>15</td>
<td>(d) &gt;1.5 m, hydraulic radius</td>
<td>0.025</td>
</tr>
<tr>
<td>16</td>
<td>Small drainage ditches</td>
<td>0.035</td>
</tr>
<tr>
<td>17</td>
<td>Stony bed, weeds on bank</td>
<td>0.025</td>
</tr>
<tr>
<td>18</td>
<td>Straight and uniform</td>
<td>0.017</td>
</tr>
<tr>
<td>19</td>
<td>Winding, sluggish</td>
<td>0.0225</td>
</tr>
</tbody>
</table>

*continued

Table B.1 Roughness Coefficient n for Manning Formula
Table B.1  Roughness Coefficient \( n \) for Manning Formula (Continued)

<table>
<thead>
<tr>
<th>Line No.</th>
<th>Type and Description of Conduits</th>
<th>Minimum</th>
<th>Design</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Channels, Vegetated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(grassed waterways) (Chapter 7)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Dense, uniform stands of green vegetation more than 250 mm long</td>
<td>0.04</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>21</td>
<td>(a) Bermuda grass</td>
<td>0.07</td>
<td>0.23</td>
<td></td>
</tr>
<tr>
<td>22</td>
<td>(b) Kudzu</td>
<td>0.047</td>
<td>0.095</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>(c) Lespedeza, common</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td>Dense, uniform stands of green vegetation cut to a length less than 60 mm</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td>(a) Bermuda grass, short</td>
<td>0.034</td>
<td>0.11</td>
<td></td>
</tr>
<tr>
<td>26</td>
<td>(b) Kudzu</td>
<td>0.045</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>27</td>
<td>(c) Lespedeza</td>
<td>0.023</td>
<td>0.05</td>
<td></td>
</tr>
<tr>
<td>28</td>
<td>Sorghum, 1-m rows</td>
<td>0.04</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>29</td>
<td>Wheat, mature poor</td>
<td>0.08</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Natural Streams</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td>(a) Clean, straight bank, full stage, no rifts or deep pools</td>
<td>0.025</td>
<td>0.033</td>
<td></td>
</tr>
<tr>
<td>31</td>
<td>(b) Same as (a) but some weeds and stones</td>
<td>0.030</td>
<td>0.040</td>
<td></td>
</tr>
<tr>
<td>32</td>
<td>(c) Winding, some pools and shoals, clean</td>
<td>0.035</td>
<td>0.050</td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>(d) Same as (c), lower stages, more ineffective slopes and sections</td>
<td>0.040</td>
<td>0.055</td>
<td></td>
</tr>
<tr>
<td>34</td>
<td>(e) Same as (c), some weeds and stones</td>
<td>0.033</td>
<td>0.045</td>
<td></td>
</tr>
<tr>
<td>35</td>
<td>(f) Same as (d), stony sections</td>
<td>0.045</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>36</td>
<td>(g) Sluggish river reaches, rather weedy or with very deep pools</td>
<td>0.050</td>
<td>0.080</td>
<td></td>
</tr>
<tr>
<td>37</td>
<td>(h) Very weedy reaches</td>
<td>0.075</td>
<td>0.150</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pipe</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>38</td>
<td>Cast iron, coated or uncoated</td>
<td>0.011</td>
<td>0.013</td>
<td>0.015</td>
</tr>
<tr>
<td>39</td>
<td>Clay or concrete drain tile (76–760 mm dia.)</td>
<td>0.011</td>
<td>0.013</td>
<td>0.020</td>
</tr>
<tr>
<td>40</td>
<td>Concrete or clay vitrified sewer pipe</td>
<td>0.01</td>
<td>0.014</td>
<td>0.017</td>
</tr>
<tr>
<td>41</td>
<td>CPT, Corrugated plastic tubing, 76–203 mm dia.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>42</td>
<td>CPT, &gt;305 mm dia.</td>
<td>0.017</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>43</td>
<td>CPT, smooth wall inside</td>
<td>0.009</td>
<td></td>
<td></td>
</tr>
<tr>
<td>44</td>
<td>Metal, corrugated, ring</td>
<td>0.021</td>
<td>0.025</td>
<td>0.026</td>
</tr>
<tr>
<td>45</td>
<td>Metal, corrugated, helical</td>
<td>0.013</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>46</td>
<td>Steel, riveted and spiral</td>
<td>0.013</td>
<td>0.016</td>
<td>0.017</td>
</tr>
<tr>
<td>47</td>
<td>Wood stave</td>
<td>0.010</td>
<td>0.013</td>
<td></td>
</tr>
<tr>
<td>48</td>
<td>Wrought iron, black</td>
<td>0.012</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Wrought iron, galvanized</td>
<td>0.013</td>
<td>0.016</td>
<td>0.017</td>
</tr>
</tbody>
</table>

*Selected from numerous references.
Cross section

- Normally with trapezoidal cross section

Side slope

- Depend on soil texture and stability
- Recommend side slope
- **Bottom width**
  - Calculated by: \( b = 2d \tan \theta / 2 = \frac{2d}{z + (z^2 + 1)^{1/2}} \)
  
  \( b \) : bottom width, L  
  \( d \) : design depth, L  
  \( \theta \) : side slope angle, degree  
  \( z \) : side slope ratio (horizontal/vertical)

- **Depth**
  - Should include freeboard of 20% of the total depth

- **Spoil bank**
  - The excavated soil may be placed on one or both sides of the channel
  - For the ditch with side slope 1:1 \( \rightarrow \)  
    
    berm width = 2xdepth
  
  - For the ditch with side slope 2:1 \( \rightarrow \)  
    
    Berm width = depth

- The minimum berm width is 3 m

- **Velocities**
  - Optimum velocities are based on:

---

**Table 13.1 Maximum Sideslopes for Open Channels**

<table>
<thead>
<tr>
<th>Soil</th>
<th>Shallow Channels up to 1.2 m</th>
<th>Deep Channels, 1.2 m and Deeper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peat and muck</td>
<td>Vertical</td>
<td>( \frac{1}{4} : 1 )</td>
</tr>
<tr>
<td>Stiff (heavy) clay</td>
<td>( \frac{1}{2} : 1 )</td>
<td>1 : 1</td>
</tr>
<tr>
<td>Clay or silt loam</td>
<td>1 : 1</td>
<td>( \frac{1}{2} : 1 )</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>( \frac{3}{2} : 1 )</td>
<td>2 : 1</td>
</tr>
<tr>
<td>Loose sandy</td>
<td>2 : 1</td>
<td>3 : 1</td>
</tr>
</tbody>
</table>

- Selection of limiting velocities, or
- Computed values of critical tractive force (the hydraulic shearing force per unit area on the periphery of the channel)

- Velocity should be low enough to prevent scour, but high enough to prevent sedimentation
- Usually an average velocity of 0.5 - 1.0 m/s for shallow channel is sufficient to prevent sedimentation
- Recommended limiting velocity

### Table 13.2 Fortier and Scobey's Limiting Velocities with Corresponding Tractive Force Values (Straight Channels After Aging)

<table>
<thead>
<tr>
<th>Material</th>
<th>Roughness Coefficient, ( n )</th>
<th>Clear Water Velocity (m/s)</th>
<th>Clear Water Tractive Force (Pa)</th>
<th>Water-Transporting Colloidal Silts Velocity (m/s)</th>
<th>Water-Transporting Colloidal Silts Tractive Force (Pa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine sand, colloidal</td>
<td>0.020</td>
<td>0.46</td>
<td>1.3</td>
<td>0.76</td>
<td>3.6</td>
</tr>
<tr>
<td>Sandy loam, noncolloidal</td>
<td>0.020</td>
<td>0.53</td>
<td>1.8</td>
<td>0.76</td>
<td>3.6</td>
</tr>
<tr>
<td>Silt loam, noncolloidal</td>
<td>0.020</td>
<td>0.61</td>
<td>2.3</td>
<td>0.92</td>
<td>5.3</td>
</tr>
<tr>
<td>Alluvial silts, noncolloidal</td>
<td>0.020</td>
<td>0.61</td>
<td>2.3</td>
<td>1.07</td>
<td>7.2</td>
</tr>
<tr>
<td>Ordinary firm loam</td>
<td>0.020</td>
<td>0.76</td>
<td>3.6</td>
<td>1.07</td>
<td>7.2</td>
</tr>
<tr>
<td>Volcanic ash</td>
<td>0.025</td>
<td>1.14</td>
<td>12.4</td>
<td>1.53</td>
<td>22.0</td>
</tr>
<tr>
<td>Stiff clay, very colloidal</td>
<td>0.025</td>
<td>1.14</td>
<td>12.4</td>
<td>1.53</td>
<td>22.0</td>
</tr>
<tr>
<td>Alluvial silts, colloidal</td>
<td>0.025</td>
<td>1.83</td>
<td>32.1</td>
<td>1.83</td>
<td>32.1</td>
</tr>
<tr>
<td>Shales and hardpans</td>
<td>0.020</td>
<td>0.76</td>
<td>3.6</td>
<td>1.53</td>
<td>15.3</td>
</tr>
<tr>
<td>Fine gravel</td>
<td>0.030</td>
<td>1.14</td>
<td>18.2</td>
<td>1.53</td>
<td>31.6</td>
</tr>
<tr>
<td>Graded loam to cobbles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>when noncolloidal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graded silts to cobbles</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>when colloidal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coarse gravel, noncolloidal</td>
<td>0.025</td>
<td>1.22</td>
<td>20.6</td>
<td>1.68</td>
<td>38.3</td>
</tr>
<tr>
<td>Cobbles and shingles</td>
<td>0.035</td>
<td>1.53</td>
<td>43.6</td>
<td>1.68</td>
<td>52.7</td>
</tr>
</tbody>
</table>

Source: Adapted from Lane (1955).

- Tractive force \( T = wdsK \)
  
  \( T \): tractive force, \( F/L^2 \)
  
  \( w \): unit weight of water (9800 N/m³), \( F/L^3 \)
  
  \( d \): depth of flow, \( L \)
  
  \( s \): slope (hydraulic gradient), \( L/L \)
K : ratio of the tractive force for noncohesive material necessary to start motion on the sloping side of the channel to that required to start motion for the same material on a level channel
K = 1 for an infinitely wide channel of uniform depth

Example:
Design a stable channel with a side slope ratio of 1:1 to carry a flow of 4.42 m$^3$/s on a slope of 0.25 %. The soil is stiff clay, very colloidal, n=0.025, and the water is transporting colloidal silts

From table, the critical tractive force is 22.0 Pa
The maximum depth with K = 1 is
\[ T = wdsK \]
\[ d = \frac{22.0}{(9800 \times 0.0025)} = 0.9 \text{ m} \]

By trial and error
Assuming b=2.44, compute a = 3.01 m$^2$ and p = 4.99 m
manning equation, result \( v = 1.43 \text{ m/s} \) and \( q = 4.30 \text{ m}^3/\text{s} \) which is close enough to the required capacity
**SPILLWAY**

- **Meaning:**
  - It is the safety valve for a dam
  - It must have the capacity to discharge major floods without damage to the dam, and at the same time keeping the reservoir level below some predetermined maximum level
  - May be controlled (provided with crest gates or other facilities so that the outflow rate can be adjusted) or uncontrolled

- **Design capacity**
  
  Depends on:
  - the spillway design flood
  - the discharge capacity of the outlet
  - the available storage

- **Overflow spillway**
  - It is a section of dam designed to permit water to pass over its crest
  - It is widely use on gravity, arch and buttress dams
- Separation and cavitation occur when flow velocity exceed design capacity cause reduce pressure
- Cavities filled with vapor air and other gasses
- May cause the surface a spongy appearance pitting
- Protected by using ramps or corbel
- The discharge of an overflow spillway:

\[ Q = C_w L h^{3/2} \]

\( Q \): discharge, m\(^3\)/s
\( C_w \): coefficient
\( L \): length of the crest, m
\( h \): head on the spillway, m
Approach velocity: if the cross sectional area of the reservoir just upstream from the spillway is \(< 5 \times\) the area of flow over the spillway, so

\[ Q = C_w L (h + \frac{V_0^2}{2g})^{3/2} \]

Example:
An ogee spillway 16 ft long is designed to pass 420 cfs when the water surface elevation upstream of spillway is 23.0 ft. The reservoir bottom is horizontal and at elevation 0.0 ft upstream the spillway. Find the flow when the water-surface elevation upstream of the spillway is 21.5 ft. Assume there are no end contraction and neglect velocity approach.

Assume \( h'/H_d = 0 \) and let \( h/h' = 1.0 \), so \( C_w = 4.03 \)

\[ Q = C_w L h^{3/2} \quad \rightarrow \quad 420 = 4.03(16) h^{3/2} \quad \rightarrow \quad h = 3.5 \text{ ft} \]

When the upstream water elevation is 21.5 ft:
\( h = 21.5 - 19.5 = 2.0 \text{ ft}; \) and \( h' = 3.5 \text{ ft} \)
\( h/h' = 2.0/3.5 = 0.57 \) and \( h'/H_d \approx 0 \) \( \rightarrow \quad C_w = 3.68 \)

\[ Q = 3.68 (16)(2)^{3/2} = 167 \text{ cfs} \]
- **Chute spillway**
  - Use chute (a steep sloped open channel) as conduit
  - Usually constructed of reinforced concrete slabs
    0.25 – 0.5 m thick

- **Side channel spillway**
  - After passing over the crest, water is carried away in a channel (chute or tunnel) running parallel to the crest
  - Usually use in narrow canyon
Shaft spillway
- The water drops through a vertical shaft to a horizontal conduit

Three possible conditions

- Outlet conduit partly full ( weir flow)
- Intermediate condition
- Submerged inlet (pipe flow)
- Siphon spillway
  - For low capacity and space is limited
  - Discharge given by \( Q = C_d A \sqrt{2gh} \)

\( C_d \) is usually 0.9
DAFTAR PUSTAKA

Holy, M. 1980, Erosion and Environment, Pergamon Press, Oxpord

