Soil and Water Conservation

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Course outline

- Soil-water-plant relationship and application in agricultural engineering projects.
- Principles of soil conservation.
- Classes, types and forms of soil erosion.
- Classification, processes, factors, analysis and measurements of water erosion and wind erosion.
- Erosion control
- contouring, strip cropping, mulching and tillage practices – principles, designs, efficiency and limitations.
- Principles, classification, design, construction, operation, maintenance, efficiency and limitation of terraces.
- Vegetated water courses, selected mechanical conservation structures, windbreaks and shelter belts.
- Principles, significance and classification of irrigation and drainage

Reading Lists:

1.Soil and Water Conservation Engineering, by Glenn O. Schwab et. al
2. Michael, A.M.: Irrigation: Theory and Practice
3. Design of Small Dams: USDA: Bureau of Land Reclamation
4. Soil Conservation: N.W. Hudson
5. Field Engineering for Agricultural Development: N.W. Hudson.

Introduction

- Measures that provide for the management of water and soil
- Conservation practices involves the soil, the plant and the climate, each of which is of utmost importance.
- The engineering approach to soil and water conservation problems involves the physical integration of soil, water and plants in the design of a co-ordinated water management
- The engineering problems involved in soil and water conservation may be divided into the six following phases:
  - Erosion control
  - Drainage
  - Irrigation
  - Flood control
  - Moisture conservation and
  - Water resource development

The conservation of these vital resources implies utilization without waste so as to make possible a high level of production which can be continued indefinitely.

Types of Erosion

Two major types of erosion

- ✓ Geological erosion
- ✓ Accelerated erosion

Geological erosion: includes soil-forming as well as soil eroding processes which maintain the soil in a favorable balance.

Accelerated erosion: includes the deterioration and loss of soil as a result of man's activities. Although, soil removal are recognized in both cases, only accelerated erosion is considered in conservation activities.

The forces involved in accelerated erosion are:

1. Attacking forces which remove and transport the soil particles and
2. Resisting forces which retard erosion.

Soil erosion by water

Water erosion is the removal of soil from the lands surface by running water including runoff from melted snow and ice. Water erosion is sub-divided into raindrop, sheet, rill, gully and stream channel erosion.

Major Factors Affecting Erosion by Water

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

Climate: - Precipitation, temperature, wind, humidity and solar radiation

Temperature and wind: - evident through their effect on evaporation and transpiration. However, wind also changes raindrop velocities and angle of impact. Humidity and solar radiation are less directly involved since they are associated with temperature.

Soil: Physical properties of soil affects the infiltration capacity of the soil. The extend to which it can be dispersed and transported. These properties which influence soil include:

Factors affecting soil erosion by water

- Soil structure
- Texture
- Organic matter
- Moisture content
- Density or compactness
- Chemical and biological characteristics

Vegetation

Major effect of vegetation in reducing erosion are:

- Interception of rainfall
- Retardation of erosion by decrease of surface velocity
- Physical restraint of soil movement
- Improvement of aggregation and porosity of the soil by roots and plants residue
- Increase biological activities
- Transpiration – decrease soil moisture resulting in increased storage capacity.

These vegetative influences vary with the season, crops, degree of maturity, soil & climate as well as with kind of vegetative materials namely: roots, plant tops, plant residue

Topography

Features that influence erosion are:

- ✓ degree of slope
- ✓ Length of slope
- ✓ Size and shape of the watershed
  - ✓ Straight
  - ✓ Complex
  - ✓ Concave
  - ✓ Convex.

Raindrop characteristics

- The relationship between erosion and rain fall momentum and energy id determined by raindrop mass, size distribution, shap, velocity and direction. The characterization and measurement of these individual factors demand the utmost ingenuity and precision.
- The energy equation that has been developed by wischmeier and smith (1958)

$$E=916+331\log i$$

E=kinetic energy

- The resistance of a soil to erosion depends on many factors and so to measure erodibility numerically an assessment has to be made of each factor.
- -nature of soil -
slope of land -
kind of crop.

Erosivity-is the aggressiveness or potential ability of rain to cause erosion.
Erodibility-is the vulnerability or susceptibility of the soil to erosion.

Factors influencing erodibility

- Two groups of factors.
- 1.physical features of the soil. i.e what kind of soil
- 2.treatment of the soil . i.e what is done with it. the part concerned with treatment has much the greater effect. And is also most difficult to access. i.e average increase in soil loss per unit increase in E I.

These is a great deal of experimental evidence to suggest a link between erosive power and the mass and velocity of falling drops.

- Bisal(1960) suggests in a similar lab.

  G =k D V1.4

  S=weight of soil splashed in grams

  k=constant for the soil type

  D=drop diameter in mm

  v=impact velocity m/s.

In both these studies the combination of power of drop velocity and drop mass are not very different from combining mass and velocity into the parameter kinetic energy.

- Rose (1960) challenges the above assumption that results such as these proves that splash erosion is dependent only on the K.E. of natural or artificial rain, and shows that if such a relationship exist it is equally valid , though different relationship will exist between erosion and momentum or any other function of mass and velocity .since mass occurs in the same form in the formula for both momentum and energy, it is necessary to vary velocity in order to resolve the problem of whether energy or momentum is the better index of erosivity. Conclusively-it has been shown that for natural rain the relationships between intensity and either momentum or kinetic energy are equally close and of the same pattern.

Estimating erosivity from rainfall data

- The EIzo index. R=EIzo

  This is the product of kinetic energy of the stem and the 30-mints intensity. This latter term requires some explanation .

-It is the greatest average intensity experienced in any 30-min period during the stem.

-This amount could be doubled to set the same dimension as intensity, i.e. inches/hour, mm/hr. The measure of erosivity is described as the EIzo index. it can be computed for individuals storms, and the storm values can be summed over periods of time to give weekly, monthly, or annual values of erosivity .

Application of an index of erosivity

- The ability to access numerically the erosive power of rainfall has two main applications. In practical soil conservation it helps : 1.to improve the design of conservation works. 2.in research, it helps to increase our knowledge and understanding of erosion.

Soil detachment and transportation

- The process of soil erosion involves soil detachment and soil transportation . Generally, soil detachability increases as the size of the soil particles increase and soil transportability increases with a decrease in particle size.
- detachment causes damage because:

1. The soil particles are removed from the soil mass and thus easily transported.
2. The five materials and plant nutrients are removed.
3. Seeds may be separated and washed out of the soil.

Sheet erosion

Uniform removal of soil in thin layers from sloping land- resulting from sheet or overland flow occurring in thin layers. minute rilling takes place almost simultaneously with the first detachment and movement of soil particles. the constant meander and change of position of these microscopic rills.

Rill erosion

Removal of soil by water from small but well defined channels or streamlets where there is a concentration of overland flow. Obviously,rill erosion occurs when these channels have become sufficiently large and stable to be readily seen.

Gully erosion

Gully erosion produces channels larger then rills. These Channels carry water during and immediately after rain.

Principles of gully erosion

The rate of gully erosion depends primarily

- on the runoff producing characteristics of the watershed
- the drainage area
- soil characteristics
- the alignment
- size and shape of gully
- the slope in the channel.

Gully development processes

1. Water fall erosion at the gully head.
2. Channel erosion caused by water flowing through the gully or by raindrop splash on unprotected soil.
3. Alternate freezing and thawing of exposed soil banks.
4. Slides or mass movement of soil in the gully.

Four stages of gully development

Stage1 Channel erosion by down ward scour of the topsoil. This stage normally proceeds slowly where the topsoil is fairly resistant to erosion

Stage2: upstream movement of the gully head and enlargement of the gully in width and depth. The gully cuts to the horizon and the weak parent material is rapidly removed.

stage3: Healing stage with vegetation to grow in the channel.

Stage 4: Stabilization of the gully. The channel reaches a stable gradient, gully walls reach and stable slope and vegetation begins to grow in sufficient abundance to anchor the soil and permit development of new topsoil

Sediment movement in channels

Sediments in streams is transported by :

1. Suspension
2. Siltation
3. Bad load movement.

Suspension: suspended sediment is that which remains in suspension in flowing water for a considerable period of time without contact with the stream bed.

saltation: sediment movement by saltation occurs where the particle skip or bounce along the stream bed. In comparison to total sediment transported ,saltation is considered relatively unimportant.

Sediment movement in channels

Bed load: Bed load is sediment that moves in almost continous contact with the stream bed being rolled or pushed along the bottom by the force of the water.

Mavis (1935),developed an equation for unigranular materials ranging in diameter from 0.35 to 0.57 millimeters and specifically from 1.83 to 2.64.

Universal soil loss equation

Smith and wisehmeier (1957,1962) developed an equation for estimating the average annual soil loss.

A=RKLSCP

Am=2.24RKLSCP metric unit.

A=average soil loss +/a tons/acre.

R=rainfall erosivity index.

k=soil erodibity index.

L=slope length factor

S=slope gradient factor.

C=cropping management factor.

P=conservation particle factor.

Ls= topographic factor evaluated.

Personal management

soil loss under standard management .This varies normally from 0-1.

P:values depends on land and slope it also depends on the type of farming system we have.

Example A:Determine soil loss from the following condition.

K=0.1 ton/acre

S=10%

L=400

C=0.15

A= RKLSCP.

$=0.1 \times 400 \times 0.1 \times 0.18 \times 0.6 \times R$

B=Also determine soil loss from the following condition.

K=0.1 ton/acre

L=400

S=80%

C=0.18

P=0.6

if the soil loss is 6.7 ton/acre what is the max slope length and corresponding tar ale spacing to reduce soil loss to 3 tons/acre .

we want max Ls value to reduce soil lose to 3 tons/acre.

Ls=2x 3/67 =0.9

Therefore =70' max slope length

V.I /70 = 8/100 $\Rightarrow$ V.I = 5.6'

practical application of using universal soil loss equation.

1. To predict erosion.
2. To select crop management practices.
3. To predict erosion from catch crops.

Land use

- Very suitable → land classification.
- Fairly suitable → according to suitability factor.
- Not suitable → a particular crop.

<u>Land capability classification.</u>

- The type of soil.
- Depth of soil.
- Texture.
- Land slope.
- Past erosion on the land.

Soil erosion by wind

Wind erosion is more frequent when the mean annual rainfall is low.

Major factor that affects soil erosion by wind are:

1. climate
2. Soil characteristics
3. Vegetation

climate:

Rainfall affects soil moisture.

Temperature humidity.

Wind.

Wind characteristics that affects soil erosion.

- Duration.
- Turbulent of the wind (velocity).

For any given soil condition the amount the amount of soil which will be blown depends on two factors:

- The wind velocity.
- The roughness of the soil surface.

Soil:

factors — soil texture.

— density of soil particle and density of soil mass.

— organic matter content.

— soil moisture.

<u>Vegetation:</u>

— height of vegetation.

— density of cover.

— types of vegetation.

— seasonal distribution of vegetation.

<u>Types of soil movement by wind</u>

1. Suspension.
2. Saltation.
3. Surface. creep

These three distinct types of movement usually simultaneously.

suspension → particle were carried about 1m above on the surface.(i.e. above 3ft)

saltation → This is caused by the pressure of the wind on the soil particle and its collision with other particles.

surface creep → This movement is mostly pronounced on the surface of the soil.

Mechanics of wind erosion

wind erosion process may also be broken into the three simple but distinct phases:

1. Initiation of movement.
2. Transportation.
3. Deposition.

1. <u>Initiation of movement.</u>

Initiation of movement as a result of turbulence and wind velocity.

Fluid threshold velocity→ The main velocity required to produce soil movement by direct action of wind.

Impact threshold velocity → the minimum velocity required to initiate movement from the impact of soil particle carried in saltation.

2. **Transportation** → the quantity of soil moved is influenced by the particle size gradation of particle, wind velocity and distance across the erodindg area.

The quantity of soil moved varies as the cube of the excess wind velocity over and above the constant threshold velocity directly as the square of the particles diameter and increases with the gradation of the soil.

Six shape bulk density

consider them as groups. we use equivalent diameter to test the level of compa:

Standard particle → is any spheres with bulk density of 2.65.this has certain erodibility.

Soil particle → this also has a diameter shape and bulk density.

Equivalent diameter → is the diameter of standard particle that has an erodibility which is equal to the erodibility of soil particle.

Ed = bxd/2.65 → diameter of soil particle.

Q x (V-Vc)

Vc=threshold velocity.

V=wind velocity

when V = Vc =no movement.

Deposition: deposition of sediment occurs when the gravitational force is greater then the force holding the particles in the air.

→ this generally occurs when there is a decrease in wind velocity.

Soil **<u>physical factors</u>** played also a major role.

→ Mechanics of wind.

→ soil moisture condition.

→ effect of organic matter.

i.e. various climatic factors.

Control of wind erosion.

Two major types of wind erosion control consist of

1. Those measures that reduce surface wind velocity (vegetation tilling soil after rain)
2. Those that affect soil characteristics such as:

— conservation of moisture and tillage.
— contouring (terracing)

generally → vegetative measure
→ tillage practices
→ mechanical methods.

Damages done by wind

1. crop damage
   — particularly at seeding stage .
   — expose of land use.
2. The change in soil texture
3. Health.
4. Damage to properties (road and building).

Contouring, strip cropping and tillage.

- One of the base engineering practices in conservation farming is the adjustment of tillage and crop management from uphill to downhill to contour operations.
- contouring, strip cropping and terracing are important conservation practices for controlling water erosion.
- Surface roughness, ridges, depression and related physical characteristics influencing depression storage of precipitation.

contouring

When plow furrows, planter furrows, and cultivation furrows run uphill and downhill then forms natural channels in which runoff accumulates. As the slope of these furrows increases the velocity of the water movement increases with resulting destructive erosion.

In contouring tillage operations are carried out as nearly as practical on the contour. a guide line is laid out for sash plow land and the back furrows or dead furrows are plowed on these lines.

- Disadvantage: is used alone on steeper slopes or under conditions of high rainfall intensity and soil erodibility, these is an increased hazard of gullying because row breaks may release the stored water.
- Strip cropping: strip cropping consist of a series of alternate strips of various types of crops laid out so that all tillage and crop management practices are performed across the slope or on the contour.

The three general types of strip cropping are:

1. Contour strip cropping with layout and tillage held closely with the exact contour and with the crops following a definite rotational sequence.
2. Field strip cropping with strips of a uniform width placed across the general slope.
3. Buffer strip cropping with strips of some grass or legume crop laid out between contour strips of crops in the regular rotations, then may be even or irregular in width.

when contour strip cropping is combined with contour tillage or terracing, it effectively divides the length of the slope, checks the velocity of runoff, filters out soil from the runoff water and facilitates absorption of rain.

strip cropping layout

The three general methods of laying out strip cropping are:

1. Both edges of the strips on the contour
2. One or more strips of uniform width laid out from a key or base contour line.
3. Alternate uniform width and variable width correction or buffer strips.

methods of layout vary with topography and with each individual's preference.

Tillage practices: tillage is the mechanical manipulation of the soil to provide soil conditions suited to the growth of crops, the control of weeds and for the maintenance of infiltration capacity and aeration. Indiscriminate tillage, tillage without thought of topography , soil climate and crop conditions will lead to soil deterioration through erosion and loss of structure.

TERRACING

This is a method of erosion control accomplished by constructing broad channels across the slope of rolling land.

Reasons for constructing terrace

If surface runoff is allowed to flow unimpeded down the slope of arable land these is a danger that its volume or velocity or both may build up to the point where it not only carries the soil dislodged by the splash erosion but also has a scouring action of its own.

various names given to this techniques are:

— terraces (U.S.A).

— ridge or bund (common-wealth countries).

functions

- To decrease the length of the hillside slope , thereby reducing sheet and rill erosion.
- Preventing formation of gullies and retaining runoff in areas of inadequate precipitation.
- In dry regions such conservation of moisture is important in the control of wind erosion

Types of terraces (terrace classification)

a . two major types of terraces are:

1. bench terrace .
2. broad base terrace.

- Bench terrace→ reduces land slope
- Broad base terrace → removes or retain water on sloping land.

broad base terrace → has its primary functions classified as:

— graded

— level.

graded terrace → primary purpose of thus type is to remove excess water in such a way as to minimize erosion.

level terrace → primary purpose of thus type of terrace is moisture conservation erosion control is a secondary soil profile .the embankment for thus type of terrace is usually constructed of soil of soil taken from both sides of the ridge. This is necessary to obtain a sufficiently high embankment to prevent over topping and breaking through by the entrapped runoff water.

TERRACE DESIGN

The design of terrace system involves the proper spacing and location of terraces, the design of channel with adequate capacity and development of a farmable x-section.

Terrace spacing

spacing is expressed as the vertical distance between the channels of successive terraces. The vertical distance is commonly known as the V.I .

V.I = as + b = V.I =0.3(as + b)

a = constant for geographical location.

b = constant for soil erodibility.

s = average land slope above the terrace in %

Terrace grades

- Terrace grades : refers back apart from the fact that it must provide good drainage ,it must also remove runoff at non erosive velocity.
- Terrance length: size and slope of the field outlet possibilities, rate of runoff as affected by rainfall and soil in filtration and chemical capacity are factors that influence terrace length.

Planning the terrace system

- a. <u>selection of outlets</u>: or disposal area:

  — vegetated outlets (preferable)

The design runoff for the outlet is determined by summation of the runoff from individual terrace. outlets are of many types such as :

— natural draws.

— constructed channels.

— sod flumes.

— permanent pasture or meadow.

— road ditches.

- b. Terrace location : factors that influence terrace location includes; land slope, soil conditions.
- Lay out procedure :

  — determine the predominant slope above the terrace.

  — obtain a suitable vertical interval.

  — stakes the Wight channel is

terrace construction : a variety of equipment is available for terrace construction which necessitated a classification of four machine according to thuds of moving soil.

Factors affecting rate of construction

- Equipment
- soil moisture
- crop and crop residues
- degree and regularity of land
- soil tilth
- gullies and other obstruction
- terrace length
- terrace cross-section
- experience and skill of operator

Design of Soil and Water Conservation Structures

1. INTRODUCTION

1.1 What is soil and water conservation?

Soil and Water Conservation (SWC) are activities that maintain or enhance the productive capacity of land in areas affected by or prone to soil erosion. ***Soil erosion,*** on the other hand, is the movement of soil from one part of the land to another through the action of wind or water (Figure 1.1). Thus, soil erosion by water is caused by raindrop impact surface sealing, and crust formation leading to high runoff rate and amount, high runoff velocity on long and undulating slopes, and low soil strength of structurally weak soils with high moisture content due to frequent rains. Soil erosion by wind is caused by lack of vegetation cover, dry pulverized soils, strong wind speeds, and poor land management practices such as continuous tillage and over-grazing.

Figure 1.1 (a) These long, steep slopes require soil conservation structures *(photos by B. Mati)* **(b) Badly gullied semi-arid land requires multi-faceted rehabilitation measures.**

Therefore, SWC includes the prevention, reduction and control of soil erosion alongside proper management of the land and water resources. Effective erosion management involves:

- Reduction of the amounts and velocity of surface runoff,
- Maintaining good soil cover through mulching and canopy cover
- Conservation and retention of soil moisture,
- Prevention or minimizing the effects of raindrop impact on the soil
- Maintaining favourable soil structure for reducing crusting
- Re-shaping the slope to reduce its steepness and slope length so as to minimize runoff flows
- Maintenance or improvement of soil fertility, and
- Removal of unwanted excessive runoff safely.

Based on these principles, erosion control measures are grouped into two broad categories:

(i) Preventive techniques, and
(ii) Control measures.

The erosion preventative measures mainly comprise the ***agronomic soil and water conservation*** practices that improve land productivity without construction of structures (see Training Manual 4 in these series). The erosion control measures involve the ***construction of various structures*** for the control, diversion or conservation of runoff, which is the focus of this Training Manual (Figure 1.2). For improved agricultural productivity, both the agronomic and structural measures of soil and conservation are necessary, especially on steeply sloping lands, where water conservation or drainage of excessive water are required.

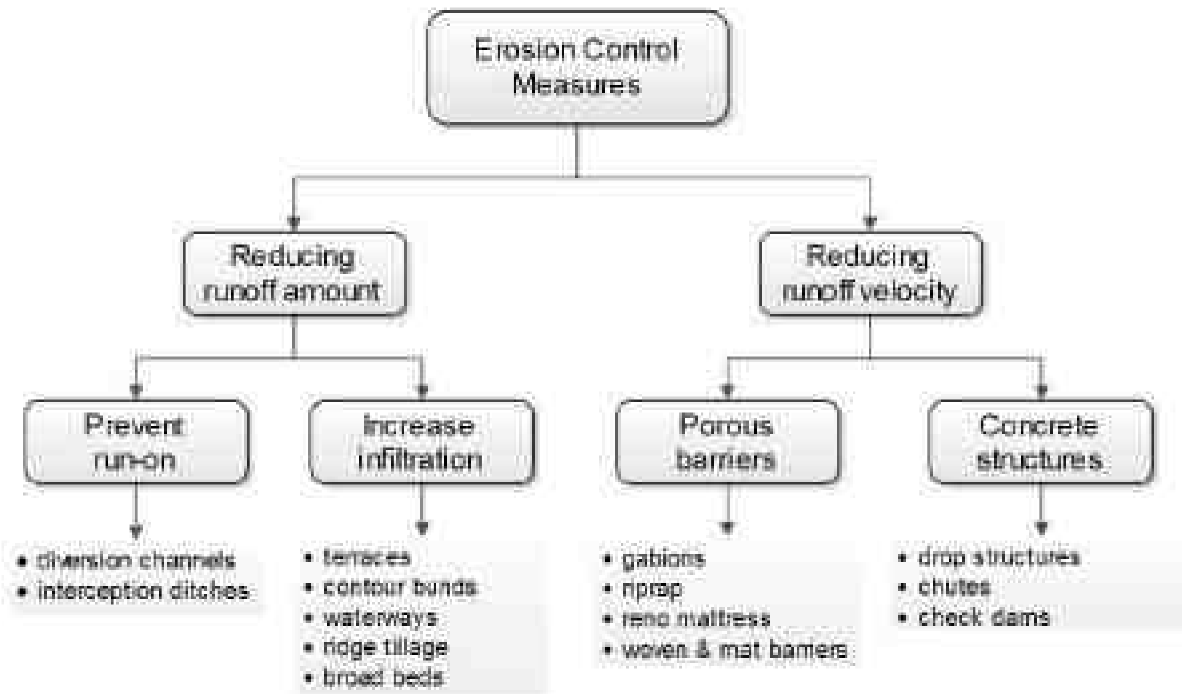

Figure 1.2 Flow chart depicting various methods of erosion control measures

1.2 What are soil and water conservation structures?

Soil and water conservation structures include all mechanical or structural measures that control the velocity of surface runoff and thus minimize soil erosion and retain water where it is needed. They usually consist of engineering works involving physical structures, made of earth, stones, masonry, brushwood or other material for the construction of earthworks such as terraces, check dams, and water diversions, which reduce the effects of slope length and angle. SWC structures can be designed to either conserve water or to safely discharge it away. They supplement agronomic or vegetative measures but do not substitute for them. Suitability of SWC structure depends on:

- Climate and the need to retain or discharge the runoff.
- Farm sizes.
- Soil characteristics (texture, drainage, and depth).

- Availability of an outlet or waterway.
- Labor availability and cost.
- The adequacy of existing agronomic or vegetative conservation measures.

1.3 Determining amounts of runoff for design of SWC structures

1.3.1 Characteristics of surface runoff

Surface runoff (or simply runoff) is the portion of precipitation that makes its way towards the stream channels, lakes or oceans as surface or subsurface flows. Runoff occurs when precipitation rate exceeds infiltration rate, and is the most destructive component of rainfall. In the design of SWC structures, the most important factors used are (i) peak runoff rates, (ii) runoff volume, and (iii) temporal distribution of runoff rates and volumes.

Factors affecting runoff

These include both catchment factors and rainfall factors.

1.3.2 Catchment factors

Runoff is influenced by catchment factors such as topography, vegetation, infiltration rates, soil storage capacity and drainage pattern. In addition the size of the catchment, its shape, orientation, geology and surface culture also affect runoff. The larger a catchment, the more runoff it will generate. Slope steepness is particularly important as soil erosion is more prone on steeper slopes. Surface culture includes the soil tilth, whether there is vegetative cover or not, and other land management activities, e.g. cultivation that would increase erosion.

1.3.3 Rainfall factors

Rainfall factors associated with surface runoff and erosion include; rainfall amounts, storm duration, intensity and distribution, as well as seasonal patterns, e.g. Dry areas are more prone to erosion that wet areas because prolonged dry spells destroy vegetation cover, and rain storms tend to be high intensity and thus erosive. The most significant component of rainfall is its intensity, which is a function of the energy the raindrops impact on the soil. The intensity-duration relationship of rainfall gives an indication of expected runoff. For example:

$$I = a/(t+b)$$

Where: I = Rainfall intensity
T = Duration of rainfall (min)
a & b are constants

For any given duration, the graph or equation will indicate the highest average intensity which is probable for a storm of that duration. This is calculated as:

$$\mathbf{I = kT^x/t^n}$$

Where,
T = is the return period in years
T = is the duration in minutes **k,**
x, and **n** are all constants

Calculations involving rainfall probability must relate to a chosen return period, e.g. for conservation works on small farms, about 10 years.

Time of Concentration (T_c)

The storm duration which corresponds with the maximum rate of runoff is known as the time of concentration (T_c). It is assumed that during the time of concentration, all parts of the watershed are contributing simultaneously to the discharge at the outlet. T_c is also described as the longest time for water to travel by overland flow from any point in the catchment to the outlet. It is equivalent to the time it takes water to flow from the furthest corner of the catchment to the outlet.

Design storm

A design storm, is a storm of known return period. It is used as a basis for designing structures. For example, a 10-year, 1-hour rainfall is the maximum rainfall amount expected in a 1-hour period with a 10-year return period.

Design runoff rates

The capacity to be provided in a structure that must carry runoff may be termed as the design runoff rate. Structures and channels are designed to carry runoff that occurs within a specified return period (T_R). e.g. 10 years for vegetative waterways, and 100 years for permanent channels.

1.3.4 Estimation of surface runoff

It is important to know the quantities of water to be handled. If the objective is to impound water e.g. dams, peak volumes are used, if the purpose is to convey water e.g. channels/waterways, peak runoff rates are used. It is necessary to estimate runoff or design of conservation and also conveyance structures, to avoid failure due to overtopping. Estimates of the rates of surface runoff therefore depend on two processes: (i) estimating the rate of rainfall, and (ii) estimating how much of the rainfall becomes runoff. The runoff rate is more crucial and is determined using various methods or equations as described here below:

a) The Runoff Coefficient

The simplest method is to use a single coefficient which represents the ratio of rainfall loss. If half of the rainfall is "lost" by infiltration, the other half appears as runoff, then the coefficient, C is 0.5.

Examples of runoff coefficients:

- Woodland on flat sandy loam, C=0.10
- Woodland, flat tight clay C = 0.40
- Cultivated, hilly clay soil, C = 0.60
- Urban, rolling, 50% built up, C = 0.65.

b) Catchment Characteristics or Cook's method

The method consists of summing numbers each of which represents the extent to which runoff from the catchment will influence a particular characteristic. The effect of four features is considered in Cook's method, which are (i) the relief, (ii) soil infiltration, (iii) vegetal cover, and (iv) soil surface storage.

Each of these is considered in turn and the condition of the watershed compared with four descriptions, i.e. extreme, high, normal, and low. Each description/feature has a number. For example, an arithmetic total (e.g. 30+10+15+10=65) is the watershed characteristic and will lie between the extreme values of 100 and 25. The main problem of this method which estimates by addition is that the errors are propagated.

c) Runoff Curve Numbers

This is an extension of Cook's method, which allows for variations in the physical conditions of a catchment and also the land use. Like in Cook's method, four variables are considered and in each case, a selection has to be made from a list of options. Ten categories of land use or cover are offered (row crops, pasture, woods, fallow, farmstead etc) with a choice of soil conservation practices such as contouring and terracing. The hydrologic condition of the catchment is graded good, fair or poor and a subjective assessment of this factor is designated one of four major hydrologic soil groups described earlier. The method relies on subjective non-measurable assessment.

e) The Rational Formula

The Rational method predicts runoff through this equation:

$$Q = 0.0028CIA$$

Where:

Q = The design peak runoff rate in m3/s

C = Runoff coefficient (a function of catchment vegetation, slope, surface culture)

A = Area of the watershed in hectares

I = Rainfall intensity in mm/hr for the design return period and for a duration equal to the time of concentration of the watershed.

The Rational method is developed on the assumption that (i) rainfall occurs at uniform intensity for a duration equivalent to the time of concentration, and (ii) rainfall occurs at a uniform intensity over the entire area of the catchment.

1.4 General principles for the design of SWC structures

The design of SWC structures considers severity and extent of erosion damage or risks, the factors causing erosion, as well as the suitability of land to the identified intervention. SWC control measures are directed at protecting the soil from raindrop impact and hydraulic forces of runoff. The process involves three areas of attention: (i) Reduction of raindrop impacts on soil; (ii) Reduction of overland flows; (iii) Increase infiltration rate, and (iv) Slowing runoff velocities.

1.4.1 Factors considered

Soil and water conservation structures are usually made by hand labour or machinery although some terraces develop naturally from vegetative barriers. They are particularly important on steep slopes where annual crops are grown and in marginal rainfall areas where there is a need to conserve rainfall in situ. The selection and design of structure depend on many factors such as:

- Climate and the need to retain or discharge runoff.
- Farm size and system (large or small-scale, mechanized or non-mechanized).
- Cropping pattern (perennial or annual, with or without rotations).slope steepness.
- Soil characteristics (erodibility, texture, drainage, depth, stoniness and risk of mass movement).
- The availability of an outlet or waterway for safely discharging runoff away from cropland.
- Labour availability and cost
- The availability of material e.g. stone
- The adequacy of existing agronomic or vegetative conservation measures.

1.4.2 Structures for retention or discharge of runoff

Structure can be designed either to retain or discharge runoff. They can also be designed so that part of the runoff is retained but the excess, during heavy storms, is discharged. In the higher rainfall areas(e.g. over 1,250 mm per annum), where crops are rarely short of water, or where there is a risk of water logging at certain times, it is usually to design structures to discharge runoff if there is no suitable outlet such as a natural waterway, artificial waterway or grassed slope. Discharging water onto a footpath, road or existing gully would aggravate soil erosion. On large-scale farms it is usually possible to set land for waterways. In densely settled area this is much more difficult.

In the drier areas (e.g. less than 750 mm per annum) it is usually desirable to keep rainwater in situ and to prevent runoff. Other factors that must be considered in reaching a decision, besides the availability of a discharge area or waterway, include the soil type, soil depth land slope and the risk, if any, of retaining water in situ. Soils in higher rainfall areas that are prone to water logging because they are shallow or because of the clay content, such as the grey soil (planosols) or black cotton soils (vertisols) in other areas, normally require structures that will drain water. Some soil on steep slopes, such as the areas with Andosols, it is better to drain water. Also, areas prone to landslides become unstable if they very wet, and conservation structures should be designed to drain the water away.

When there is a need to discharge water but no suitable space for a waterway, there are two options. One is to change the land use to a permanent crop or fodder grass that does not require conservation structure. The other is to use contour barriers designed to conserve all the runoff.

1.4.3 Size of conservation structure

The design of any structure to retain or discharge runoff should be based on a reasonable estimate of the volume of runoff (m^3) to be retained or the peak rate of runoff (m3/s) to be discharged. A retention structure can rarely be made big enough to capture all runoff during exceptionally wet period, unless the catchment area is very small. One alternative with retention structures is to incorporate a spillway to take the overflow.

Similarly the design of a structure to discharge runoff can rarely be based on the heaviest storm possible. Usually it is based on the heaviest storm that can be expected in a given period (e.g. 10 years) with the knowledge that a heavier storm, of a magnitude that occurs once in twenty, fifty or a hundred years, could take place (the frequency in years with which a storm of a given amount is likely to occur is known as the return period).

1.4.4 Risks

The risk of damage due to an exceptional storm should be considered when designing structures. If the risk cannot be eliminated, it must be minimized by ensuring that the structures are stable when they are made and carefully maintained afterwards. Failure to pay attention to this point can lead to damage during heavy storms and greater erosion than erosion than if the structures had not been installed in the first place. Where there are a series of structures on a hills slope there is a risk if a structure is breached near the top, then those downhill would also get damaged.

1.5 Types of conservation structures

The main SWC structural measures used on croplands comprise diversion ditches (cut-off) drains), retention (infiltration) ditches, terraces and waterways. Supportive cultural measures such as grass or vegetative material for stabilizing the structures are also required for selection of proper species. The identification of appropriate types of SWC structures should take into account the need to retain runoff in areas where water is short or discharge runoff where it is in excess. The design of structures to discharge runoff, such as diversion ditches and waterways, should be based on an estimate of the peak rate of runoff. Structures which are intended to discharge runoff should not be installed unless there is safe place for disposal of water e.g. a natural or artificial waterway or permanent vegetation.

In higher rainfall areas e.g. areas receiving more than 1000mm of rain per annum, and where crops rarely lack water, or where there is a risk of water it is usually necessary to design structures to discharge runoff. However, it would be a mistake to design a structure to discharge runoff if there is no suitable outlet such as a natural waterway, artificial waterway or grassed slope. Discharging water onto a footpath, road or existing gully will aggravate the problem of erosion. In the drier area (less than 750 mm per annum) it is usually desirable to keep rainwater in situ and prevent runoff.

1.6 Benefits of conservation structures

Soil and water conservation bears benefits over a longer time span after construction. However, some benefits such as increased crop yields can be can be attained within the first year. In general, the benefits of SWC can be summarized as follows:-

- Increased agricultural productivity (higher yields, fodder for livestock livestock)
- Conservation of potentially productive land i.e. SWC supports sustainable agriculture

- Reduced nutrient loss from the soil, and thus less fertilizer requirements
- Environmental conservation, by storing more water within the soil profile and thus improved catchment hydrology
- Soil drainage benefit in areas prone to floods or waterlogging,
- SWC benefits irrigation and drinking water supplies, by protecting reservoirs from sedimentation
- SWC protects infrastructure such as roads from erosion damage, e.g. gullies.

1.7 Limitations

The planning and construction of SWC structures on smallholder farms can be complicated by the small sizes of plots on given slope. This is because farm boundaries are not necessarily aligned to the contour or following a natural feature such as a crest line or drainage line. Thus, it is difficult to get appropriate site and space for an artificial waterway. Sometimes, the best site for a waterway may already be occupied by a footpath or a gully. Attempting to plan one farm in isolation from the others is likely to cause failure. A catchment plan is needed but there are social implications which must first be resolved.

SWC structures can be expensive to install. In particular, gully control structures can be very expensive. There is also a lot of labour needed to excavate terraces, especially bench terraces. SWC requires some level of engineering design, and thus technical know-hoe can be a limitation. SWC structures function by retaining water in-situ, thus denying runoff to downstream areas. This can be a potential source of conflict which should be addressed.

1.8 Management and maintenance

SWC structures require regular maintenance and repairs if they get damaged. Grazing in cultivated lands treated with SWC structures should not be allowed as the animals can damage the structures. Instead, fodder should be cut and taken to animals preferably under cut and carry systems. Replanting vegetative materials and lining out of construction and channels should be done at least every season.