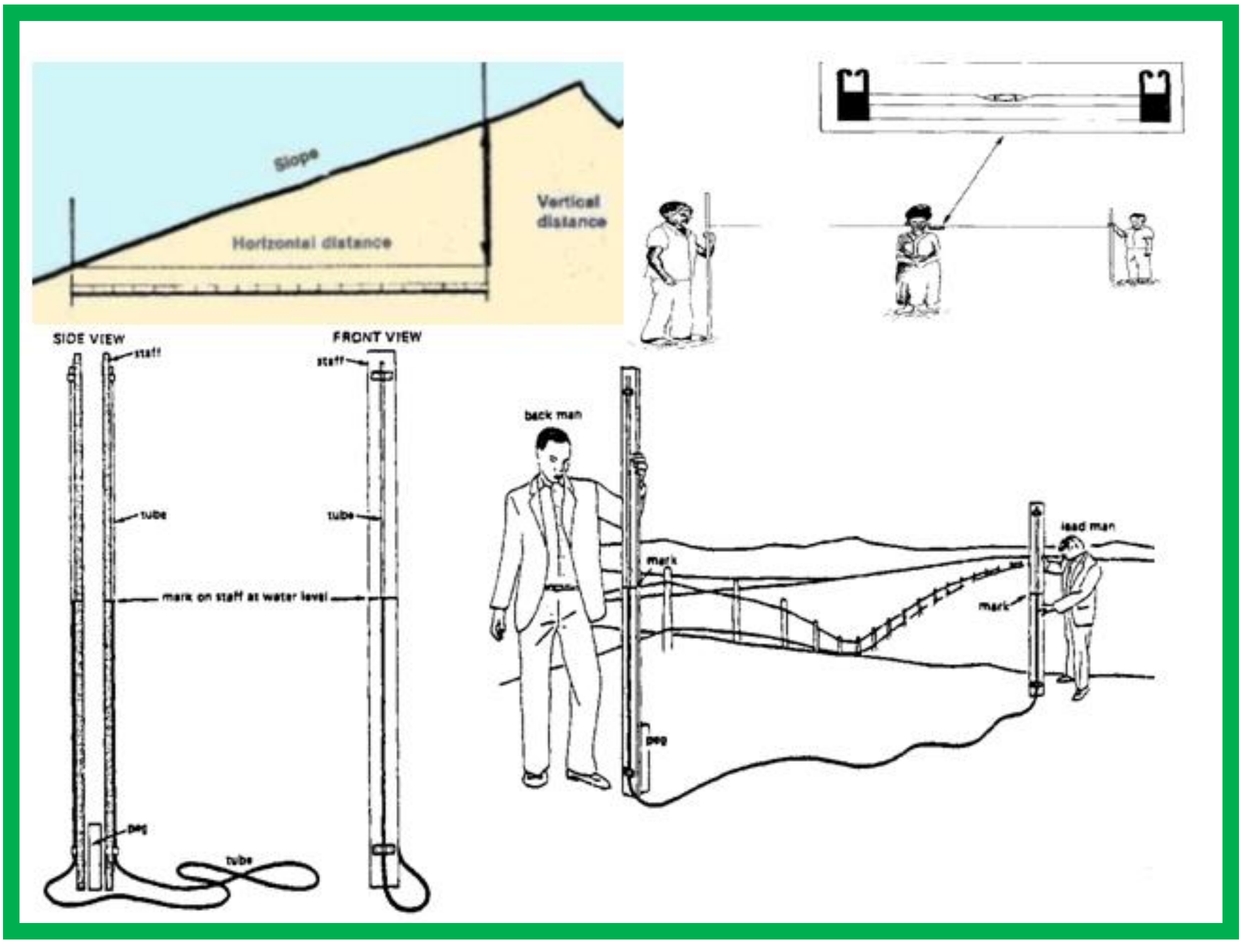
KEY TOOLS AND METHODS FOR IMPLEMENTATION OF SWC MEASURES



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1. NTRODUCTION

The implementation of any physical structures on any land use system requires detailed knowledge about some technical tools and equipment which can determine the quality of the physical structure to be constructed. The construction of any physical structure requires the identification of slope percentage, vertical interval and horizontal distance and identification of appropriate contour lines where further lay out and designing of the physical structure can take place during the construction period. These issues have been briefly discussed within each module of the training package on Biophysical SWC measures. Lacking the essential knowledge and skills related to these tools will undoubtedly affect the quality of the physical structure and further leads to great destruction of our soils. During the main training program, we may raise and discuss the importance of identifying slope measurement, soil types and depth. But, before that the participants should know how to deal with these issues. The technical tools include:

- Simple survey methods,
- Background information on slopes,
- Methods to calculate peak run off-rates for channel design

To equip the technical staff at various levels and farmers with the concept of each of the technical tools and their effective utilization, it is necessary to organize a separate and detailed training program on these topics to address the issues in depth as part and parcel of the main training program on Biophysical SWC. This portion will be used as springboard for the implementation of all design and layout of each of the technologies indicated within the training package on biophysical SWC measures.

Therefore, it is important to organize a separate and in-depth training program that can equip DAs and farmers with each of technical tools, their equipment and methods of utilization to improve their knowledge so that they will be in a position to implement good quality physical SWC structures in their local areas.

2. SIMPLE SURVEYING TOOLS AND METHODS

2.1Simple Surveying Tools

A. LINE LEVEL

The line level is a simple surveying instrument which can be used to lay out contours and gradients, and also to measure the slope of land. It is simple to operate and is easier to transport than other similar surveying tools such as the A-frame. It is especially quick and very accurate when used properly. However a line level does require three people to operate it.

B. WATER TUBE LEVEL

The water tube level is a simple surveying instrument which is used for laying out contours in fields. It is easy to understand, and farmers can quickly learn how to operate it for themselves.
The concept itself - of matching up levels of water - is especially easy to understand. Advantages of the water tube level are that it can be operated by only two people and is more sensitive than the line level on very low slopes. It is, however, slightly less portable than the line level, and is not so simple to use for determining slopes or laying out graded contours.

C. A-FRAME

A-frame is a cheap and easy to make tool. It can be made from readily available materials and are easy to use. An A-frame consists of three pieces of wood, fixed together in the shape of a capital letter "A". The A-frame is held upright, and a weight on a string hangs down from the top of the "A" to act as a plumb-line. If the A-frame is on perfectly level ground, the string crosses the horizontal bar of the "A" at a certain point. This point is marked during calibration. The applications of each simple surveying tool are detailed below.

2.2 Simple Surveying Methods

A. MARKING/LAYING OUT CONTOUR LINES WITH THE LINE LEVEL

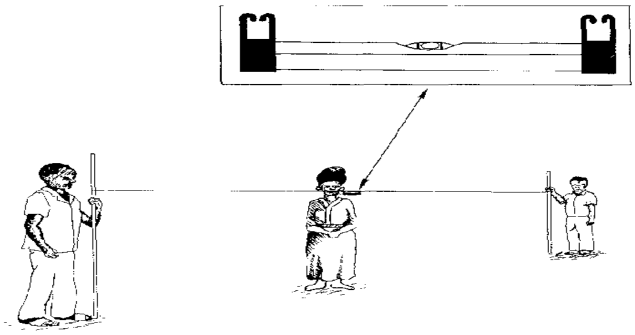
a) Definition

Contour lines are horizontal lines across the slope joining points of the same elevation. Contour lines are used to line out conservation measures which have to be level.

b) Materials

The following items are needed:

- Water-level
- Thin plastic rope, 11 m long and about 2 mm in diameter
- 2 wooden poles, 2 m long, marked every 10 cm
- Meter-band or meter-stick
- Short poles for marking the ground



Operator A (Head person) **Operator B (Rear person)**

Figure1: Use of Line Level (Source: http://www.fao.org/docrep/U3160E/u3160e0a.htm)

c) Preparation steps

1. First check the proper functionality of the sprit level by putting it on a level surface and turning it around.
2. In outlining the work, always start from the outlet of the runoff.
3. Each pole is held by an operator and the line level read by a third person in the middle. The first pole is held by operator "A" who remains stationary. Operator "B" then moves up and down the slope by the order of the middle person until the level reads dead centre (see figure 1). For graded structures, the height of the string on the poles varies depending on the intended gradient. However, for level structures, we need strings to be tied on similar height of poles.
4. The two positions are marked using pegs, and while "A" moves to "B's" old position, "B" moves onwards to new position and the process continue until the length of contour required has been completed.
5. The true contour is then "cleared" by eye to give a better shape for ploughing.

d) Marking contour lines

6. Proceed across the slope to mark contour lines with line level as shown in figure 2 below. Survey 10 m at a time. In difficult topography, it might be inconvenient to survey 10m at a time; so you can make 5 m (half the rope) by hanging the spirit level at the middle (2.5m).

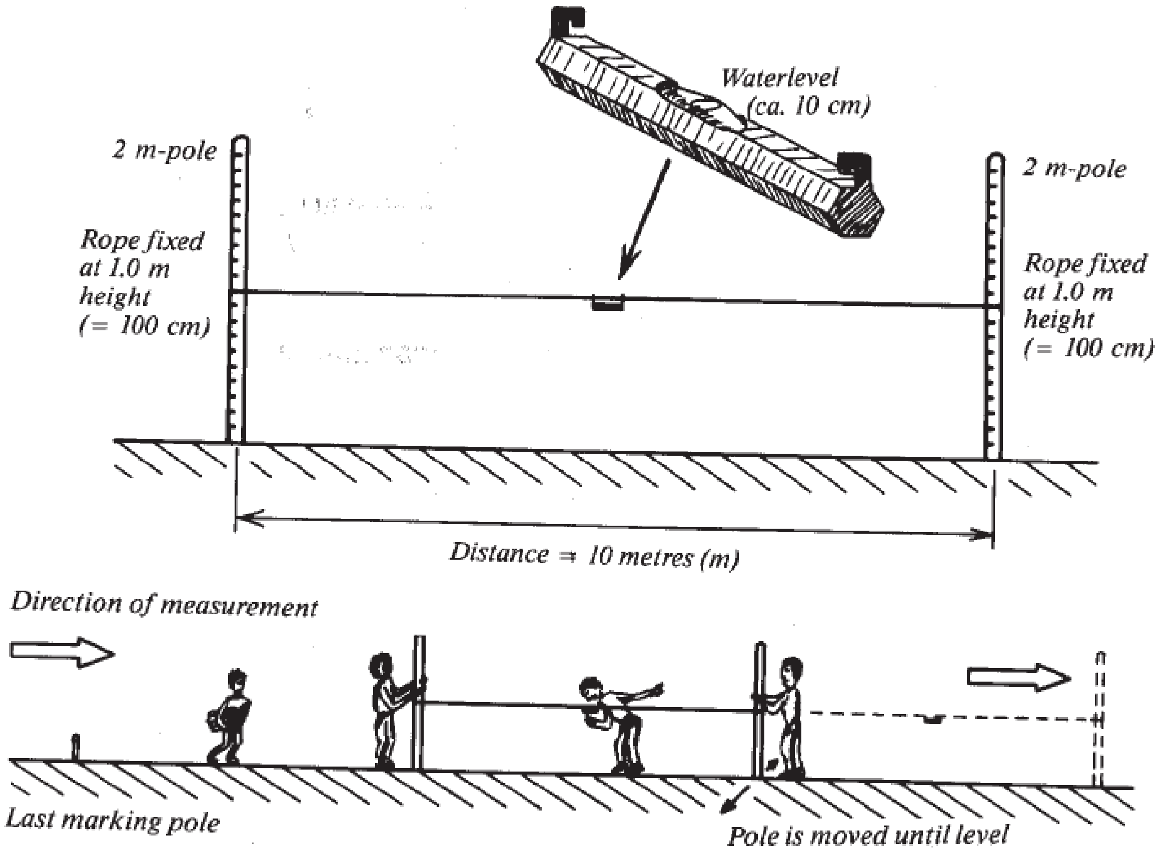


Figure2. Marking/laying out contour lines with the line level (Source: CBPWD Guideline, 2005)

e) How to Survey Land for Levelling

1. The centre of the field is used as the starting point. A flat stone is placed in a hole with one side level with the ground surface. This is the "bench mark".
2. Operator "A" places his/her pole on this stone. "B" stands downslope with his/her pole on top of a wooden peg. The peg is driven into the ground until a level is found. The top of the peg will be above ground surface. "A" then moves the pole to this peg, and "B" continues down the field and places his/her pole on another peg.

3. The process is similar for the upslope part of the field, except that the pegs are driven below ground to find the level.
4. During the land levelling process, soil is scraped away from around the upslope pegs, and deposited around the downslope pegs. This continues until the tops of all the pegs are at the new surface level.

Important Points to Remember:
Always check the spirit level;
Each pole should be placed on level ground and held vertically;
Check the centre point of the string each day and its length;
Remember that when laying out a gradient that operator (A) is upslope;
Before excavation starts, remove previous crop residues, if any;
Avoid putting the poles on lumps of soils and hollows.

B. MARKING/LAYINGOUT A CONTOUR WITH THE WATER TUBE LEVEL

a) Description:

- The water tube level is assembled by uncoiling the tube and then filling it with water by siphoning (sucking one end of the tube with the other end dipped in water). Each end of the tube is then tied to one pole.
- The poles are held side by side and the levels of water marked on the poles.
- The two levelling staffs are of the same length with a graduated tape attached to each stave. The tube is filled with water. The ends of the tube are fitted with rubber stoppers to prevent loss of water. The total length of tube defines the range of the instrument.

b) Materials: It consists of:

→ 10-20m of clear plastic piping, with inside diameter 610 mm
→ two poles of 1.5 -2.0 metres length
→ four rubber straps (from inner tube) to attach pipe to poles
→ one to two litres of water

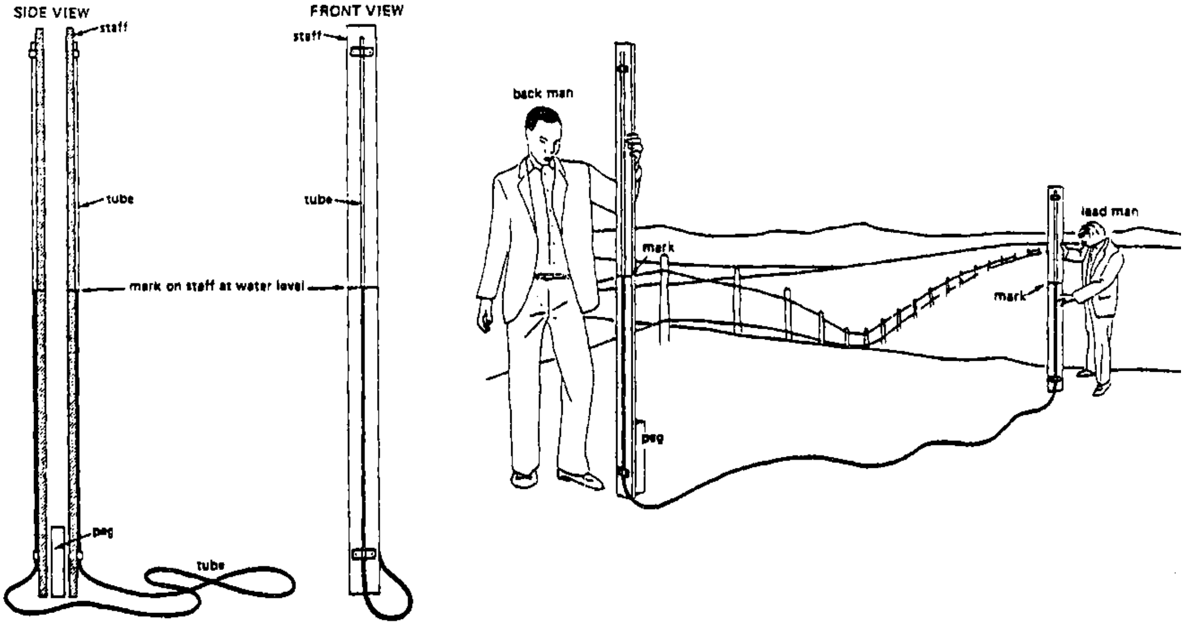


Figure2: Use of Water Tube Level
(Source: http://www.fao.org/docrep/U3160E/u3160e0a.htm)

c) Preparation steps

1. The team begins at the top of the field, and continues downslope. Two operators are necessary to hold the poles, and a third is required to trace the line on the ground with a hoe.
2. One operator ("A") remains stationary holding one pole, while the other, ("B") moves up and down the slope with the other pole until the level of water in each tube matches the "level" mark. The two points are now on the contour.
3. The person with the hoe marks the ground between the poles.
4. Operator "A" now picks up his/her pole and moves to the other side of "B" who remains stationary. It is now "A's" turn to find the correct spot.
5. This procedure is carried on until the end of the field is reached. The distance to the next contour line is paced out, and surveying continues.
6. The true contour can now be "cleared" by eye to make ploughing or excavation easier.

Important Points to Remember:
Work while it is cool - heat causes the tubes to stretch;
Mark the levels again if the water spills;
Make sure the poles are held vertically;
Don't put the poles in hollows or on lumps in the field;

C. A-FRAME

a) Definition

A-frames are a cheap and easy to make tool. They can be made from readily available materials and are easy to use. An A-frame consists of three pieces of wood, fixed together in the shape of a capital letter "A". The A-frame is held upright, and a weight on a string hangs down from the top of the "A" to act as a plumb-line. If the A-frame is on perfectly level ground, the string crosses the horizontal bar of the "A" at a certain point. This point is marked during calibration.

To use the A-frame, it is "walked" across the slope, making sure that the two legs are level each time by checking if the string crosses the horizontal bar at the calibrated point (notch). If not, the forward leg is moved until the string shows the frame is level. The positions of the legs on the ground are marked with pegs, and then the frame is pivoted around to mark a new point on the slope.

***b)* Requirements**

- Two straight wooden poles (1.5-2 m long), and one straight pole (1-1.5 m long).
- String, hammer, nails, pencil and notcher.
- A round stone.

***c)* Procedures in using A-frame**

Step 1: Making the A-frame

1. Use the poles and nails to make a frame in the shape of an "A" (Picture 1).

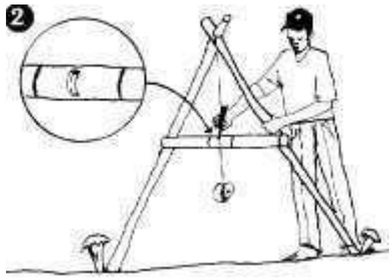
2. Tie one end of the string to the top of the "A".

3. Tie the stone to the other end of the string, so it hangs down just below the horizontal crossbar of the "A".

Calibrating the A-frame

4. Stand the A-frame upright on reasonably level ground. Mark on the ground where the two legs stand.

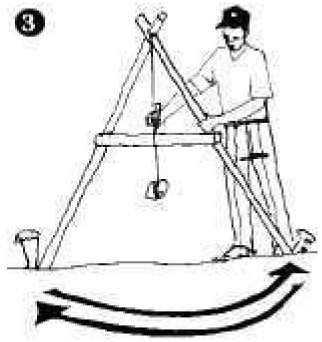
5. Hold the A-frame still, and use the pencil to mark lightly on the crossbar where the string crosses it (Picture 2).



6. Turn the A-frame round, so that each leg stands exactly where the other had stood.

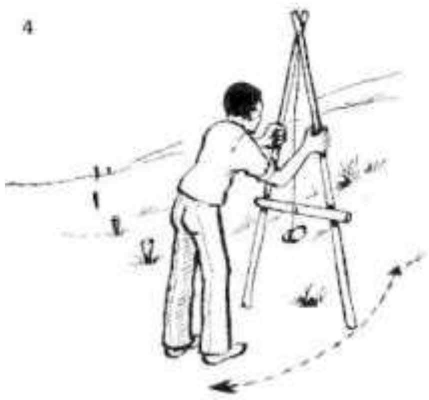
7. Make a second light mark on the crossbar where the string crosses it.

8. The two marks on the crossbar should be fairly close together. Halfway between them shows where the string would cross if the A-frame was standing on exactly level ground. Make a heavy pencil mark or notch the bar with a knife at this point (Picture 3).



Step 2: Locate the contour lines using the A-Frame

1. Choose a place on the slope to begin. Stand the A-frame up and mark where the first leg stands with a peg or large stone.
2. Keeping the A-frame upright, and without moving the first leg, swing the second leg up or down the slope until the string crosses the crossbar exactly at the heavy pencil mark (Picture 4).



3. Mark where the second leg stands with another peg or stone.

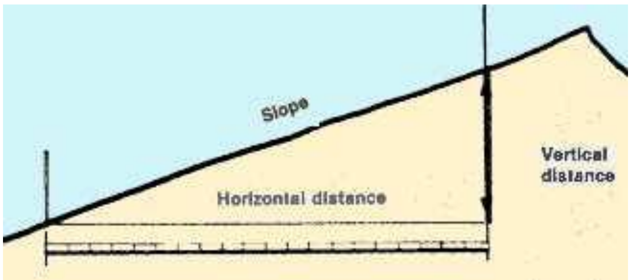
4. Keeping the second leg in the same place, lift the first leg up and pivot it around. Move it up and down the slope until you find the place where the string crosses the crossbar at the heavy pencil mark.
5. Mark where the first leg is now standing with another peg or stone.
6. Continue in this manner to the end of the field.
7. The line of pegs or stones will mark a contour line: they will all be at the same height on the slope. The pegs are usually not in a straight line. If necessary, make a smooth curve by moving them a little up or down.
8. To mark another contour line, move up or down the slope a certain distance - usually about 20 m (20 paces) on a gentle slope, or a drop of 1.5 m on steeper slopes. Repeat the process from Step 9 above onwards.

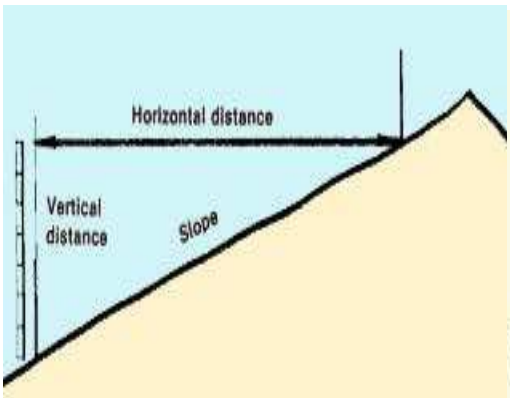
Step 3: Prepare the contour lines:
After finding and marking the contour lines, prepare them until ready for planting. The width of each area to be prepared should be one meter. The stakes will serve as guide during ploughing.

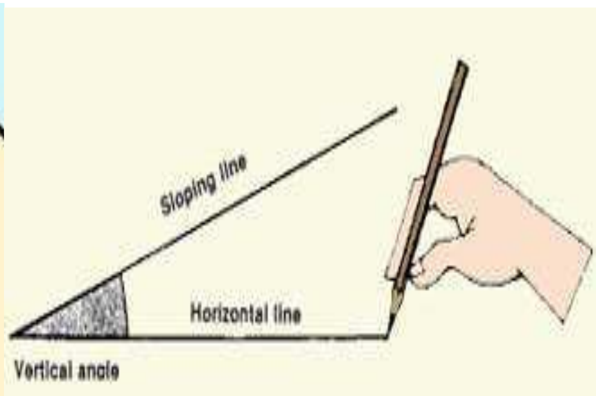
Step 4: Plant seeds of nitrogen-fixing trees and shrubs
On each prepared contour line, two furrows are laid out. Plant two to three seeds per hill at a distance of about 0.6cm. Cover the seeds firmly with soil. When fully grown, the hedgerows bank the soil and serve as source of fertilizer. Examples of hedgerow species are desmodium (*Desmodium* sp.) and leucaena (*Leucaena leucocephala*). (*Source:* http://www.fao.org/docrep/x5301e/x5301e0a.htm).

D. MEASURING SLOPE GRADIENTS

a) Definition
Slope gradient is the degree of inclination or steepness of the land feature. Slope gradient is also defined as the change in vertical distance or elevation over a given horizontal distance, or the change in horizontal distance over a given vertical distance; it is the vertical angle made by the sloping line and a horizontal line. Slope is measured either in percentage of length (%) or in degree.







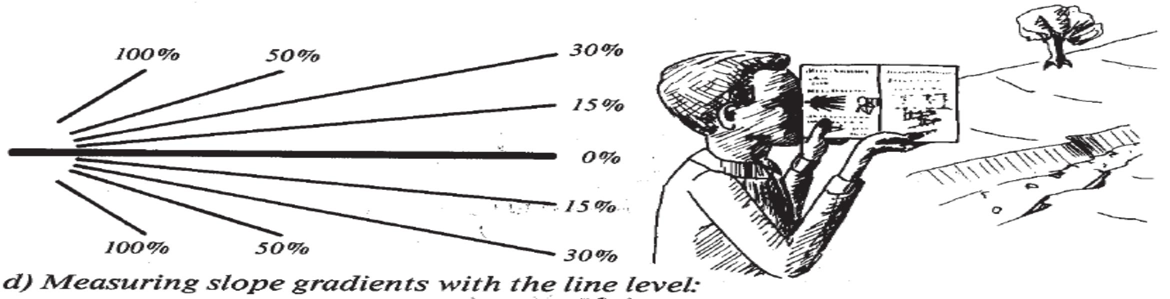
(***Source:*** ftp://ftp.fao.org/fi/CDrom/FAO_Training/FAO_Training/General/x6707e/x6707e05.htm) *b) Materials:*

The following items are needed:

- Waterlevel or this page of the book (see c) below)
- Thin plastic rope, 11 m long, meter band or meter stick
- 2 wooden poles, 2 m long, marked every 10 cm
- Small poles for marking on the ground

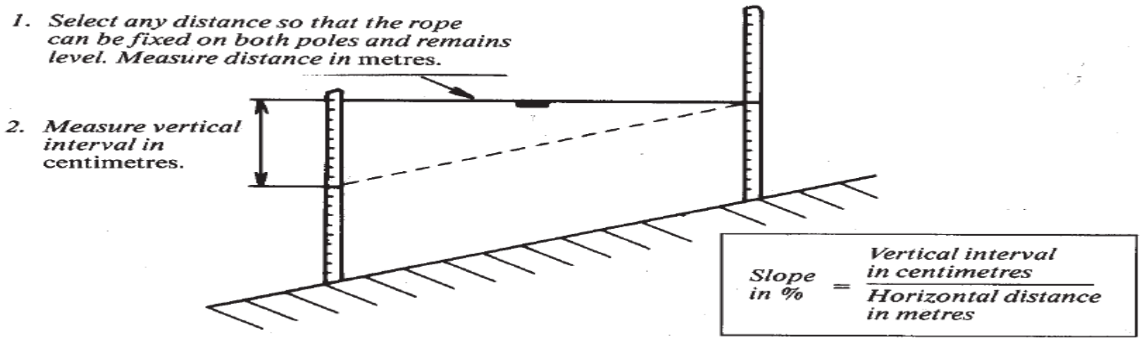
c) Estimating slope gradients with the figure below:

Hold the book horizontally as demonstrated (somebody may help you in checking) and look with one eye along the book upslope or downslope. Select the line that best fits the actual slope and read the percentage given or an estimation between two lines.



d) Measuring slope gradients with the line level:

Follow the steps given below and use the formula to calculate the slope percentage. Take care that you use the correct units (1 metre = 100 centimetres, cm)



(Source: CBPWD Guideline, 2005)

E. MEASURING VERTICAL INTERVALS WITH THE LINE LEVEL

a) Definition:

A vertical interval between two points is the difference in elevation between them. Vertical intervals are used along the slope to mark the spacing between two conservation measures. Vertical intervals of structures on slopes steeper than 15% are calculated on the basis of the depth of soil observed on the slope.

b) Materials

The following items are needed:

- Water-level
- Thin plastic rope, 11 m long
- 2 wooden poles, 2 m long, marked every 10 cm
- Meter-band or meter-stick
- Short poles for marking the ground

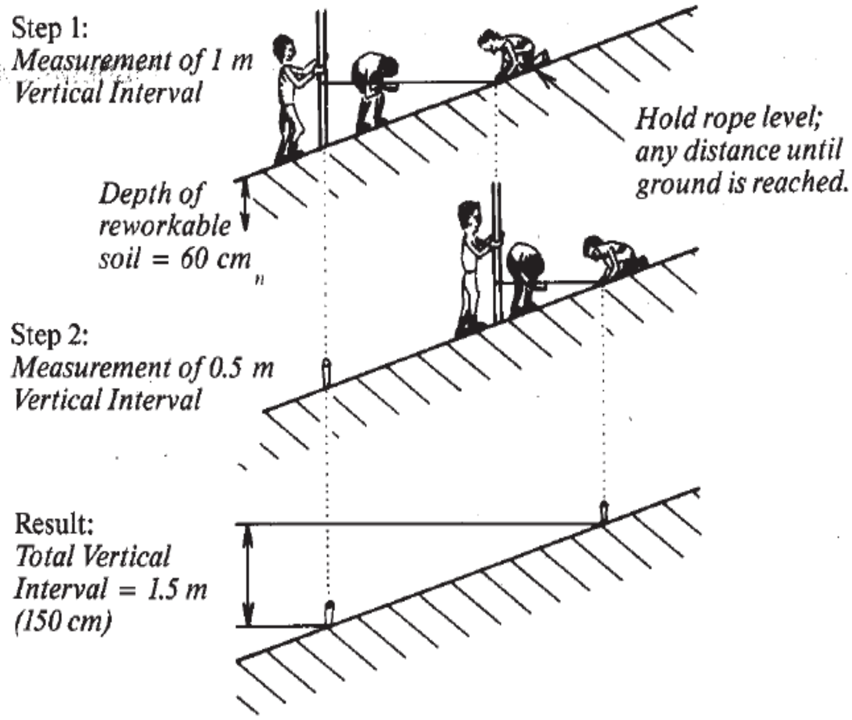
❖ On slopes of less than 15% gradients (see ***(c)*** under of measuring slope gradient above), the vertical interval is 1 meter.

❖ On slopes of more than 15% gradients, the vertical interval is two and half times the soil depth.

Examples:

Slope (%)	Depth of Soil	Vertical Interval, m (cm)
5	(more than 50 cm)	1 m (= 100 cm)
10	(more than 50 cm)	1 m (= 100 cm)
18	60 cm (= 0.60 m)	1.50 m (= 150 cm)
25	80 cm (= 0.80 m)	2.00 m (= 200 cm)
35	50 cm (= 0.50 m)	1.25 m (= 125 cm)
45	25 cm (= 0.25 m)	0.62 m (= 62 cm)

c) Marking 1.5 m (150 cm) vertical interval:



(Source: CBPWD Guideline, 2005)

F. HORIZONTAL DISTANCE (HD) OR SPACING

Definition:
The horizontal distance (HD) is defined as the horizontal difference in height between the centre lines of two terraces. Spacing is the distance between two consecutive physical structures.
In topographical surveys, you measure distances along **straight lines.** These lines either join two fixed points or run in one direction starting from one fixed point. They are plotted in the field with pegs, pillars or ranging poles.
Horizontal Distance can be calculated based on the following formula:

HD = (VI)/land slope (%)
Where, HD = indicates the horizontal distance of the bund (meters)
VI = vertical interval (meters)
S = land slope (%)

Beside the mathematical calculation of spacing, the spacing for physical structures are determined by several factors such as run-off from the upper site, agricultural activities, soil infiltration, permeability and rainfall, farmers demand, the integration/harmonization of different development with physical measures.

Moreover, the relationship between horizontal distance and vertical intervals can be indicated by the following formula.

HD = VI*100/S, while VI = S/100*HD (meters)

Example: If S, 50% and HD is 2.5 m, find the VI

VI = S/100*HD

VI = 50/100*2.5m

VI = 1.25m

G. MARKING GRADED LINES WITH THE LINE LEVEL

a) Definition:

Graded lines are lines across the slope, which have a very small lateral gradient. They are used to line out conservation measures which are graded to drain excess water.

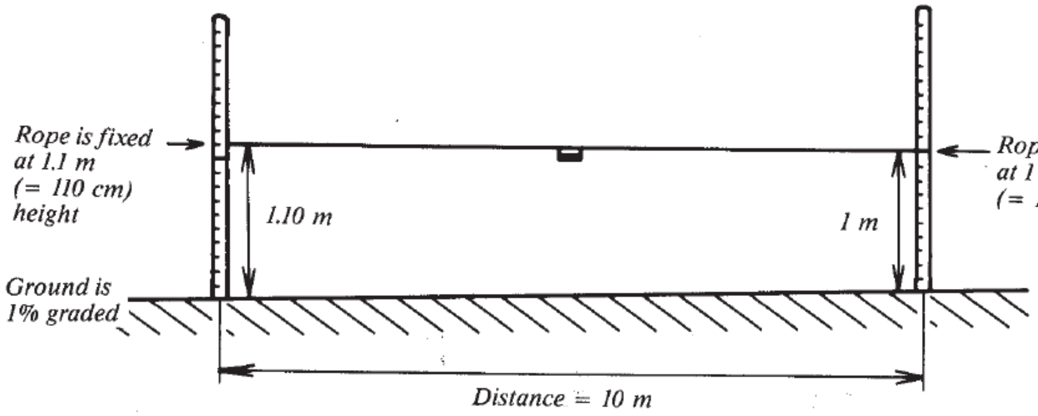
b) Materials:

The following items are needed:

- Water-level
- Thin plastic rope, 11 m long and about 2 mm in diameter
- 2 wooden poles, 2 m long, marked every 10 cm
- Meter-band or meter-stick
- Short poles for marking the ground

c) Preparation:

For lining out 1% graded measures, the line level also uses a difference of 1% over 10 m length. That means the rope has to be fixed on the poles with 10 cm difference as shown below:

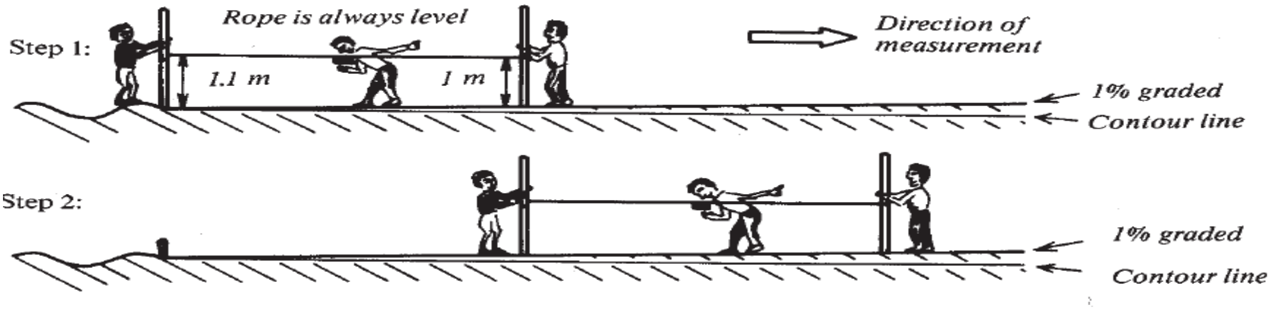


For lining out 2% graded measures, fix one end of the rope at 1.2 m (=120 cm) on the pole, and one end at 1 m (= 100 cm) to give a total difference of 20 cm over 10 m length.

For 0.5% graded measures, fix rope with 5 cm difference.

d) Marking 1% graded lines on ground:

Always start lining out at waterway or river and proceed slightly upslope (1%). Always use the pole with the rope fixed higher up, nearer to the waterway, and the pole with the rope fixed at 1 m, farther away, as shown below.



(***Source:*** CBPWD Guideline, 2005)

H. HOW TO IDENTIFY THE TEXTURE OF A SOIL

a) Definition:

Soil texture is mainly concerned with the size and shape of the mineral particles of the soil. Particles are sand, silt and clay and they have the following diameters:

Sand: 0.05–2 mm (particles visible)
Silt: 0.002–0.05 mm (particles hardly visible)
Clay: less than 0.002 mm (particles not visible)

Clayey soils have more than 50% clay particles.
Silty soils have more than 50% silt particles.
Sandy soils have more than 50% sand particles.

Loams are soils with mixed particles of sand, silt and clay.

b) Significance of soil texture for soil conservation:

Soil erosion depends much on the infiltration rate of a soil. The infiltration rate again depends on the soil texture. In a sandy soil, the infiltration rate is higher than in a silty soil. In a clayey soil, it may be initially high (for heavy black clay with cracking), but becomes low when the soil is moist to wet. Other factors influencing the infiltration rate are soil structure, humus content, soil moisture, soil depth and soil surface roughness.

In moist agroclimatic zones, the decision for selecting graded or level structures on cultivated land mainly depends on the soil texture found on the slope where conservation is planned. For clayey soil, graded structures are recommended, because the infiltration in the basins is too slow. For silty to sandy soil, level structures are recommended because the water retained in the basins will infiltrate more quickly.

c) How to differentiate between clayey, silty and sandy soil:

1. Take a small handfull of fine earth from the slope.

2. Slowly add little amounts of water and mix it very well with the earth sample. Stop adding water as soon as the formed soil ball starts to stick to your hand.

3. The soil texture can be roughly estimated with your moist soil sample. Try to form the sample into the different shapes demonstrated on the next page. See how many of the pictures you can form with your soil. If you cannot form it any further, stop at the previous picture and read the soil texture on the right side. This is the texture of your soil.

Now proceed to the next page and start forming your soil sample following the pictures from top down.

d) Form your sample according to each picture below until the next one is no more possible:

1) The soil remains loose and single grained and can only be heaped into a pyramid:

Sand (1)

2) The soil contains sufficient silt and clay to become somewhat cohesive and can be shaped into a ball that easily falls apart:

Loamy sand (2)

3) The soil can be rolled into a short thick cylinder:

Silt loam (3)

4) The soil can be rolled into a cylinder of about 15 cm length:

Loam (4)

5) The soil can be bent into a U:

Clay loam (5)

6) The soil can be bent into a circle that shows cracks:

Light clay (6)

7) The soil can be bent into a circle without showing cracks:

Heavy clay (7)

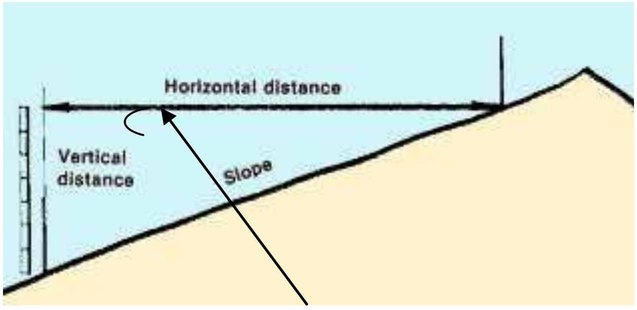
Note: Texture classes (1) to (4) are *sandy to silty soils* which have generally good infiltration. Texture classes (5) to (7) are *clayey soils* which have generally poor infiltration.

(***Source:*** CBPWD Guideline, 2005)

3. BACKGROUND INFORMATION ON SLOPES

a) Concept of the degree of slope

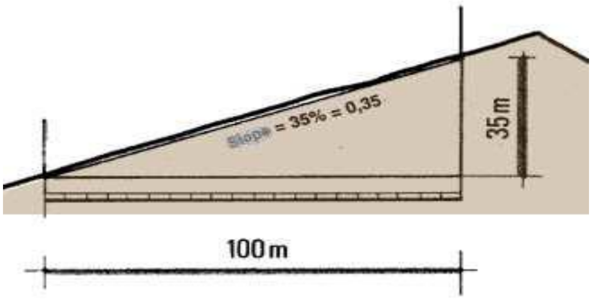
Degree is the measurement unit for an angle between two straight lines diverging from a common point. Thus, ***angle of the slope*** is the angle between the slope line (hypotenuse) and the horizontal distance (base line) indicated as follows.



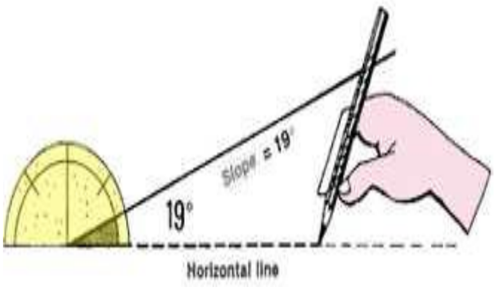
Angle of slope

The slope of a line is therefore expressed in various ways:

- As ***a percentage***, or the number of metres of change in elevation over a horizontal distance of 100 m. This may be written in two ways, either as a *percent (%)* or as a *decimal value, in hundredths*.

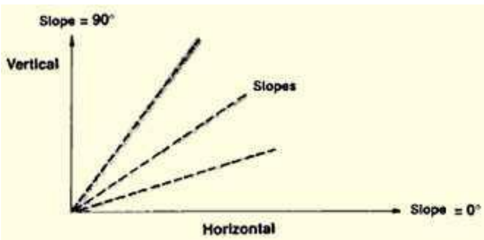


- In ***degrees***, as the measurement of the vertical angle made by the slope and the ***horizontal plane.***



Remember here that:

- degrees are subdivided into 60 minutes (60'), each minute equalling 60 seconds (60");
- a right angle equals 90º, and therefore a slope is always measured between 0º (horizontal) and 90º (vertical) as shown below.



From soil and water conservation point of view, as we levelled the land we changed its landscape to a straight line for which the angle of slope will be 0 degree to reduce the run-off. On the contrary, keeping the vertical line constant and reducing the base line to its zero level will end up with the formation of a perpendicular line with an angle of 90 degrees. At this stage, it is impossible to have a slope of 90 degrees and/or above. When the slope is 90 degree, it is called vertical. Normally no natural land has 90 degree slopes.

Converting percentage of a slope into degrees, or degrees into percentage

- Depending on the instrument you are using to measure a slope directly, you may sometimes have to convert the percentage of the slope into degrees, or the degrees into percentage. For help with such a conversion, you should use the following table (Table 1).

Note: from the table you can see that:

- 1 degree is about 1.75 percent;
- 1 percent is about 0°35';
- A 45° slope = a 100 percent slope.

Table1. Conversion of slope units

From Percent into degrees

Percent	Degrees/ min/s
0.5	0°17'10"
1	0°35'
2	1°08'40"
5	2°51'40"
10	5°42'40"
20	11°18'36"
30	16°42'
40	21°48'05"
50	26°33'55"
100	45°

From degrees into Percent

Degrees/min/s	Percent	Degrees/min/s	Percent
0.25(15')	0.44	11	19.44
0.50(30')	0.87	12	21.26
0.75(45')	1.31	13	23.09
1	1.75	14	24.93
2	3.49	15	26.79
3	5.24	16	28.68
4	6.99	17	30.57
5	8.75	18	32.49
6	10.51	19	34.43
7	12.28	20	36.40
8	14.05	30	57.74
9	15.84	40	83.91
10	17.63	45	100

Remember: 60 min = 1 degree and 60 s = 1 min

Examples:

- A slope of 17 percent is equal to (10 + 5 + 2) percent, which is equivalent to 5°42'40" + 2°51'40" + 1°08'40" = 8°101'120" = 8°103' = 9°43';
- A slope of 9º43' is about equal to (9º + 30' + 15'), which is equivalent to 15.84 percent + 0.87 percent + 0.44 percent = 17.15 percent or 17 percent.

(**Source:** ftp://ftp.fao.org/fi/CDrom/FAO_Training/FAO_Training/General/x6707e/x6707e04.htm)

b) Steepness and erosion

Steepness is a very important factor in controlling erosion. The steeper the slope of land the higher the speed (velocity) of the run-off and even the more higher the removal /erodability/ of soil particles by the erosion force. The relationship between steepness, velocity and erodability is indicated Table2 below.

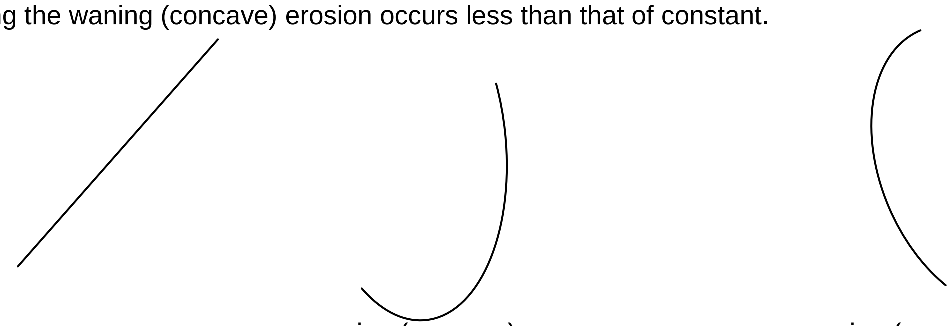
Table2. Relationship between steepness, velocity and erodability

No	Steepness	Speed /velocity/ of run-off	Removal of particles
1	by 2 times	$2^2 = 4$ times	$2^4 = 16$ times
2	by 3 times	$3^2 = 9$ times	$3^4 = 81$ times
3	by 4 times	$4^2 = 16$ times	$4^4 = 256$ times

One important point from Table 2 is that the speed and the extent of run-off depend on the degree and length of slope of the land. The steeper the slope, the higher the velocity of flow of run-off water will take place. In accordance with the law of the falling bodies, velocity varies on square root of the vertical drop. If the land slope is increased 4-fold, then the velocity of water flowing on the slope is approximately doubled (4^2). If the velocity of run-off water is doubled (two times), its energy, i.e. erosive power, is increased by 2^2, because the erosive power varies as the square root of the velocity. Similarly, the quantity of the material of a given size that can be carried out is increased 2^5 (32-fold) and the size of the particles that can be transported by pushing or rolling is increased by 2^6 (64-fold) of the velocity.

c) Forms of slope

Slope can be categorized into different forms. These are a constant (linear), waxing (convex), waning (concave) and combined. Erosion on a waxing slope tends to be higher than that of constant; while along the waning (concave) erosion occurs less than that of constant.



Linear waning (concave) waxing (convex)

The situation at the ground level is more complicated, because in most cases the hillside may show more than one form of slopes.

d) Slope length

The length of the slope is the total length of a sloping land measured along the slope. Slope length also can be measured between two points on a slope.

The total length of the slope is determined as a requirement for estimating the number of bunds or terraces to be made across the slope. If the slope is uniform the plots between bunds and the terraces will be of uniform size. But if the length of the slope is not uniform then the size of the plots between bunds and the terraces will vary, which will take place even within the same plot due to certain factors such as slope percent, soil type and depth and physical nature of the land presence of roughness or rocks. Therefore, it is impossible to have a straight length of a slope on any land.

Exercises

1. On a hillside/degraded land with 15% slope and 2.5 m vertical interval, hillside terracing is required to be constructed. Find out its spacing. Please discuss on the real challenges related to lack of accuracy in identifying and clearly indicating spacing for the construction of physical structures and its alternative solutions.

2. Within X Kebele, there is hillside working area mostly with 25% slope and 0.8m soil depth. But DAs and farmers could agree how to begin and implement contour line measurement. From your practical point of view, please discuss and proposed:
    - How they can identify the 1st contour line?
    - Describe detail activities and necessary steps to accomplish their task on the 1st contour line?
    - Farmers may come across huge rock/s while they are working the contour line and if they ask you for solution, how can you help them?
    - Provide alternative advice on how to identify their next contour line to continue with the same procedure.
3. A group of survey sent for a field work on a hillside/degraded land having all the mix of slope classes except flat (gently slope, sloping, moderately, steep and very steep) to carry out slope measurement. The team was a bit confused about how to start its assignment. Discuss and propose on how you can help this survey group.

4. METHODS TO CALCULATE PEAK RUN-OFF RATES FOR CHANNEL DESIGN

In general, before getting into the design of any drainage management structures (cut-off drain, waterways, graded bunds and broad bed furrows), it is a prerequisite to understand the elements of hydrology particularly ***rainfall*** and ***runoff*** and their relationship. This will help to easily understand and use various alternate methods of runoff estimation for design of cuff drains as well as other drainage structures.

Rain fall and runoff relationships

When it rains part of the rain never reaches the ground and falls on buildings, trees and other materials. This is called interception. The rest of the rain fall reaches the ground and soaks in to the soil. This is called infiltration.

The part of the rainfall which does not infiltrate to the ground but makes its way to Streams, Rivers, Lakes and Oceans is called ***Run-off***. The run-off/drain needs to be managed to minimize the erodability of the soil and the maximum productivity of the water. Run –off is affected by many factors and all can be categorized under two groups: (1) precipitation, and (2) watershed characteristics.

1. Precipitation: involves the following factors.

1.1 ***Rainfall amount:*** during high rainfall, the soil pore space is filled with water which results in decreasing the infiltration rate of the soil.

1.2 ***Rainfall intensity versus run-off-*** If the intensity of rainfall increases, the run-off increases rapidly. There are two method of determining the intensity of rainfall. These are:

i. From the automatic rainfall recording rain gage, and

ii. Measuring the amount of rainfall and recording the time taken.

1.3 ***Duration of rainfall***: longer duration of rainfall produces more runoff than short duration keeping other factors constant.

1.4 ***Duration, frequency and distribution***: a long duration of low intensity rainfall causes less erosion compared to short duration of high intensity rainfall. A fairly well distributed rainfall causes low erosion. A rainfall with high frequency causes more erosion.

2. Watershed characteristics: factors included under this category include:

2.1 ***Shape of a watershed***: a watershed which is long and narrow is likely to have low rate of run-off than one which is broad and compact. In long and narrow watershed, the tributaries will comparatively short, numerous and the drainage areas will be small and produce small run-off. On the other hand, in a broad and compacted watershed, the tributaries will be longer and fewer in number and will drain larger area and produces high run-off.

2.2 ***Size of the watershed***: on larger watershed the total flood flow will take more time to pass the outlet while on small watershed. The flood water collects quickly.

2.3 ***Topography of the watershed***: watersheds with steeper slope (rolling or steep slope) produce more frequent and greater run-off than those which are more level.

2.4 ***Geology of the watershed***: refers to the soil parameters such as texture, depth, structure, permeability and soil temperature. Sand, gravel, and loam soils have larger part of precipitation and absorb water rapidly producing fewer run-offs. On the other hand, a clay soil and rocky areas will absorb water slowly and produce more run-offs. Soil with high organic matter will produce less runoff. Moreover, deep and high temperature soil is producing relatively less run-off.

2.5 *Vegetation*: A watershed with good vegetation cover retards the flow of water over the surface, increases the percolation opportunity and produces fewer run-offs.

2.6 *Surface storage*: A watershed containing lakes and swampy areas producing fewer run-offs than those embracing no such areas.

2.7 *Land management*: a watershed with contour cultivation, terraces, organic fertilizer and mulching will produce fewer run-offs than the unterraced with up & down slope cultivation.

Run-off estimation /Run-off rate/

Structures, channels, ditches and other protection works are designed in such a way that they can carry run-off which occurs with specified return period. Run –off rate is commonly referred to the peak run-off rate. The peak run-off rate is the maximum expected run-off rate from the maximum rainfall of a given period of time. Vegetation controls and temporary structures are usually designed for a peak run-off rate that may be expected to occur once in 10 to 15 years. Permanent structures will be designed for run-off expected only once in 50 to 100 years. Selection of design for return period is also called recurrence internal. Considering the peak run-off rate in designing structures is to avoid risk of designing low or high capacity channels. Low capacity channels would not be required since they allow overtopping and high capacity channels are not required either because they entail unnecessary cost.

There are various methods of predicting peak run-off rate. This is needed for channel design. The main methods are: *simple estimation method, Cook's method, rational method and the run off coefficient method*.

A. Simple estimation method

Run-off equals to Rainfall minus infiltration

The run-off is expressed in terms of the depth which is not convenient to determine the capacity of the disposal structures. Here, there is a need to multiply the result with the area of the catchments. For the watershed which has soils with good infiltration capacity, consider that 50% of the rainfall infiltrates into the soil and the run-off expected in this case is 50% of the rainfall.

B. Cook's method

It is used to estimate the peak run-off rate for smaller catchments areas (<50ha). This method requires the assessment of catchment features that are easy to determine/calculate:

- Size (ha)
- Ground cover;
- Soil type and drainage properties
- Ground slope

Design Steps Using Cook's method to determine peak runoff and channel design

Steps1:

- To estimate the peak runoff using Cook's method, determining first the role played by surface conditions (vegetative cover, soil conditions and topography) of the runoff area is important;
- Determine the runoff area from a map or by field survey;
- Determine the summarized value or characteristic of the surface conditions of the runoff area using Table 1;
- Using the summarized value and runoff area got, read or interpolate the peak runoff from Table 2;

Table 1: Value of summarized characteristics

Vegetation cover	Soil conditions	Topography
Forest or thick grass cover 10	Well drained soils e. g. Sand 10	Slope 0-5% 5
Scrub or medium grass cover 15	Moderately pervious soils e.g. Silt 20	Slope5-10% 10
Cultivated land 20	Slightly pervious soil e.g. loam 25	Slope10-30% 15
Bare or sparse cover 25	Shallow soils with impeded drainage 30	Slope more than 30% 20
	Clay and rock 40	Mountainous 25

Example 1: Find the summarized characteristics for a land with the following surface conditions. The land is cultivated having a loam soil on a 35% slope.

Solution: The summarized characteristics for the land would be found as follows:

- For cultivated land the value under the first column of Table 1 (vegetative cover), for a cultivated land is 20, from the second column of soil conditions (Table 1), you have the value of 25 for loam soils and from the third column of topography you have a value of 20 for a 35% slope. Thus, the summarized characteristics = 20 + 25 + 20 = 65.

Table 2: Runoff values in cubic meters per second

Runoff Area (ha)	Summarized characteristics of the runoff area										
	30	35	40	45	50	55	60	65	70	75	80
2	0.1	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.8
4	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.3	1.5
6	0.3	0.4	0.6	0.7	0.8	1.0	1.2	1.4	1.6	1.9	2.1
8	0.4	0.6	0.7	0.8	1.1	1.3	1.6	1.8	2.1	2.4	2.7
12	0.5	0.7	0.9	1.2	1.5	1.8	2.2	2.5	3.0	3.4	3.8
16	0.6	0.8	1.1	1.4	1.8	2.3	2.7	3.1	3.7	4.2	5.0
20	0.7	1.0	1.4	1.8	2.3	2.8	3.4	4.0	4.7	5.7	6.1
30	1.0	1.4	2.0	2.5	3.3	4.0	4.8	5.7	6.7	7.6	8.8
40	1.1	1.5									
50	1.2	1.8									

Example 2: Find the runoff to be produced from a catchment with a square runoff area of 20 hectares with the summarized characteristics calculated in the example 1 above.

Solution: To find the runoff, you have to have two pieces of information: the runoff area (from Table 2 above) and the summarized characteristics (from example 1 above). Thus, runoff area = 20 ha, the summarized characteristics is 65.Then read from Table 2 the value corresponding to the value of 20 for runoff area and the value of 65 for summarized characteristics. Therefore, the reading for the runoff from the Table is 4 m^3/sec.

Step 2: Find out the value of permissible flow velocity.

- Permissible velocity is the velocity of water allowed to flow in a channel without causing ***scour*** in the channel bed and that does not allow ***siltation*** in the channel.

- In constructing the drain, the velocity of water flowing in the drain should not exceed the maximum permissible/allowable velocity for the soil type. In this case erosion will not be created.
- The ability of water to cause scouring and erosion varies with lining material (earth, grass, stone or concrete); and for each of these, there is a maximum permissible velocity above which scouring can occur (see Table 3).
- The maximum permissible/allowable velocity is governed by soil type and degree of vegetative/grass cover in the channel.

Table 3: Maximum permissible velocity in channels (m/sec) – Hudson 1981

Surface material/soil type	Vegetative/grass cover		
	Bare	**Good/Medium grass cover**	**Very good grass cover**
Very light silty sand	0.3	0.75	1.5
Light loose sand	0.5	0.9	1.5
Coarse sand	0.75	1.25	1.7
Sandy soil	0.75	1.5	2.0
Loam	.9	1.5	2.1
Firm clay loam	1	1.65	2.3
Stiff clay or stiff gravelly soil	1.5	1.8	2.5
Coarse gravels	1.5	1.8	Unlikely
Shale, hardpan, soft rock, etc.	1.8	2.1	-
Hard cemented conglomerates	2.5	-	-

Step 3: Compute the cross-sectional area of the channel.
The cross-sectional area should be able to accommodate the peak runoff rate (Q_p) and fulfill the permissible flow velocity (V) requirement. It is computed by the following equation:

$$\mathbf{Q_p = A \times V \rightarrow V = Q_p / A}$$

Where,

Q_p = Peak discharge (m^3/s)

V = Maximum permissible velocity (m/s)

A = Cross-sectional area of the drain (m^2)

Step 4: Compute the various dimensions using Table 4 to suit the area of the cross-section obtained in **Step 3**. The dimensions of the channel are its depth, bottom width and top width. Geometrical formulas used to find the size of the channel for parabolic and trapezoidal shapes is shown in figure 2 below.

Example 3: From table 4 below it is given that the channel depth is 0.5m and the gradient is 0.5%. Therefore, the discharge found from the Table is 0.95 m^3/sec.

Table 4: Discharge in cubic meter per second per width

Depth of channel (m)	Gradient (%)		
	1.0	0.5	0.25
0.3	0.6	0.4	0.25
0.4	0.9	0.65	0.45
0.5	1.3	0.95	0.65
0.6	1.8	1.3	0.95
0.7	2.25	1.7	1.2
0.8	2.8	2.15	1.5
0.9	3.4	2.65	1.8
Source: Daniel Danano (1996).			

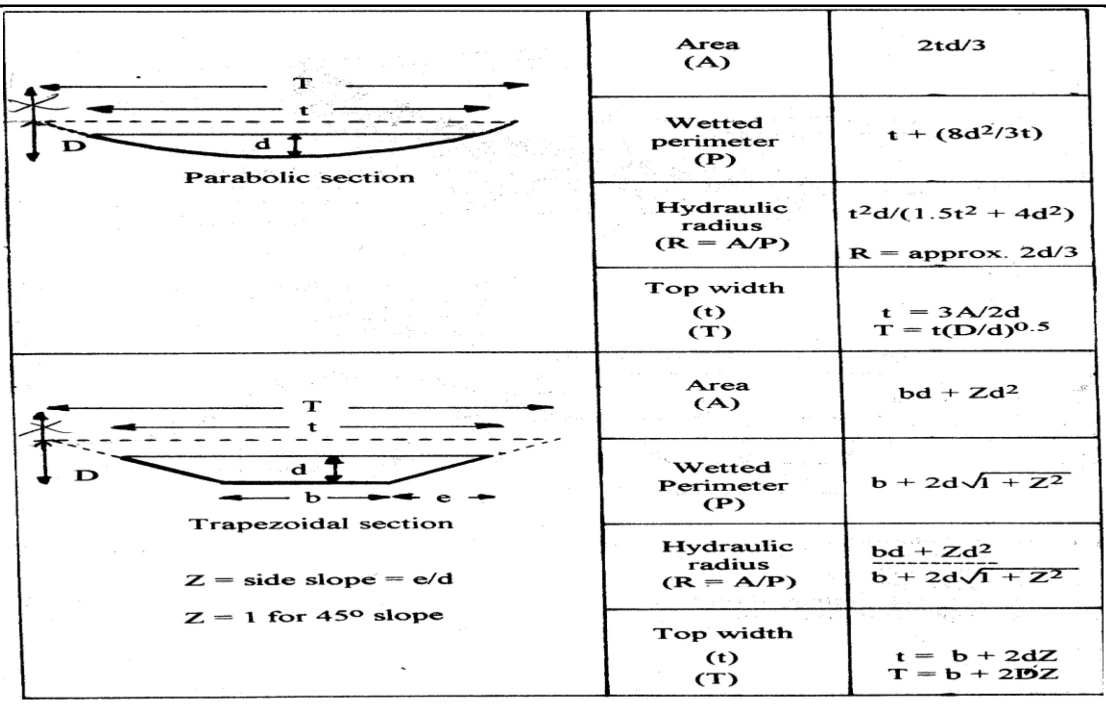


Figure1: Channel cross section, wetted perimeter, hydraulic radius and top width formulae

Step 4: Determine estimated channel width.

- The width of the channel expressed in meters for a trapezoidal or parabolic section can be calculated by dividing the estimated runoff in cubic meter/second (see Table 2) by the value of the discharge obtained from Table 4 above.

$$\text{Channel width} = \frac{\text{Estimated runoff}}{\text{Discharge of channel}}$$

Example: For a 12 ha of land with the following surface condition(cultivated, loam soil on 35% slope and for the channel slope of 1%,if the velocity is 1.5 m/s & the channel depth is 0.5m). Find the width of the channel?

Solution:

- Peak runoff from table 7= 2.5m^3/sec
- Discharge o the channel from table 8= 1.3 m^3/sec/m
- Width of the channel = $\frac{2.5 m^3/sec}{1.3\ m^3/sec/m}$ = 1.9m

C. The rational method

$$Q = CIA/3.6 \quad \text{(US Soil Conservation Service)}$$

Where, Q = Design peak flow rate, m^3/s

C = Runoff coefficient, (from Table 5 below)

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

A = the run off producing area (ha)

Or the following table prepared from the rational method can also be used to determine catchment peak discharge per hectare depending on the soil type, cover and slope of the area; and then the total discharge could easily be generated by multiplying with the total area.

Table5. Peak runoff discharge rate (m3/s/ha) based on max. Rainfall intensity of 150mm/hr (also assume the time of concentration of 30 minute)

Soil Type	Vegetation	Topography	Run off coefficient(K value)	$Qpm^3/sec/ha$
Sandy loam	**Woodland**	Flat (<5% slope)	0.10	0.0417
		Rolling (5-10% slope)	0.25	0.1042
		Hilly (10-30% slope)	0.30	0.1250
	Pasture	Flat (<5% slope)	0.10	0.0417
		Rolling (5-10% slope)	0.16	0.0667
		Hilly (10-30% slope)	0.22	0.0917
	Cultivated	Flat (<5% slope)	0.30	0.1250
		Rolling (5-10% slope)	0.40	0.1667
		Hilly (10-30% slope)	0.52	0.2167
Clay and silt loam	**Woodland**	Flat (<5% slope)	0.30	0.1250
		Rolling (5-10% slope)	0.35	0.1458
		Hilly (10-30% slope)	0.50	0.2083
	Pasture	Flat (<5% slope)	0.30	0.1250
		Rolling (5-10% slope)	0.36	0.1500
		Hilly (10-30% slope)	0.42	0.1750
	Cultivated	Flat (<5% slope)	0.50	0.2083
		Rolling (5-10% slope)	0.60	0.2500
		Hilly (10-30% slope)	0.72	0.3000
Tight clay	**Woodland**	Flat (<5% slope)	0.40	0.1667
		Rolling (5-10% slope)	0.50	0.2083
		Hilly (10-30% slope)	0.60	0.2500
	Pasture	Flat (<5% slope)	0.40	0.1667
		Rolling (5-10% slope)	0.55	0.2083
		Hilly (10-30% slope)	0.60	0.2500
	Cultivated	Flat (<5% slope)	0.60	0.2500
		Rolling (5-10% slope)	0.70	0.2917
		Hilly (10-30% slope)	0.82	0.3417

Design Steps Using Rational method to determine peak flow and to fix flow depth and bottom

Step 1:

Compute time of concentration, tc, with the following formula.

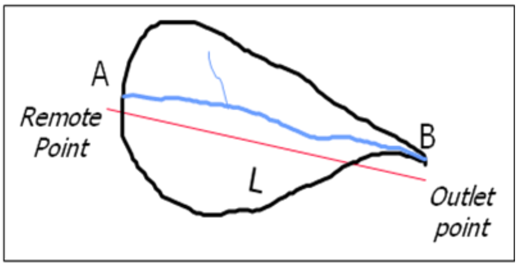
$$tc = 0.019471 \times \frac{L^{0.77}}{G^{0.385}}$$

tc : time of concentration (minutes)

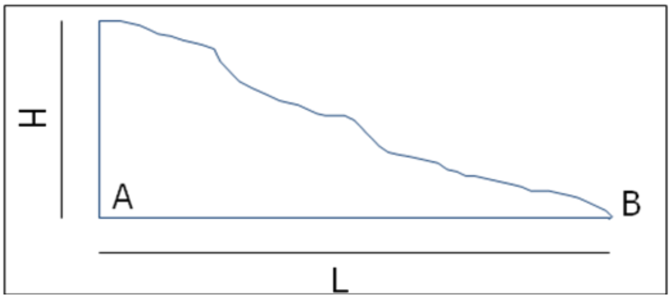
L : maximum length of travel of water (m)

G : slope of the catchment, H/L, H is the difference in elevation between the outlet & remote point.

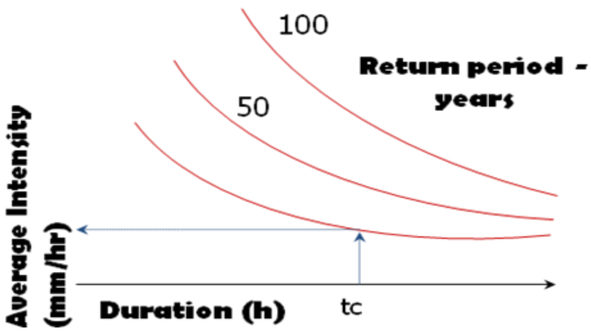
Determination of H and L from the catchment map.



Catchment map



Step 2: Find the corresponding intensity (I) for duration equal to tc for a certain return period, from the Intensity - duration - frequency curve prepared for the area.



Intensity - duration - frequency curve (sample)

I= P*{2/(1 + Tc)}

Tc= Time of concentration, hr

I= Intensity of rainfall amount, mm/hr

P= Maximum daily rainfall at 30 minute interval (85-108mm)

As it is shown on the intensity - duration - frequency curve above, the blue dotted arrows show how to find the intensity for the duration equal to t_c. In the sample the return period of 15 years is considered. It is also possible to utilize the depth - duration - frequency curve. In that case, first the rainfall depth is obtained and later on the dividing the obtained rainfall depth by the duration (t_c) results in the required intensity value. The Intensity-duration-frequency curve is prepared as follows:

- get a record of rainfall intensity values with the corresponding durations
- select from the record, rainfall amount with similar duration (eg. 5, 10, 15, ...minutes)
- make a frequency analysis on each set of data (rainfall amounts for 5, 10, 15 ... minutes of duration).
- collect the rainfall intensity values & duration corresponding to a given . ...frequency.
- repeat the previous step for various frequencies.
- plot the rainfall intensity values versus duration for desired frequencies (1, ...10, 20,... years)
- the resulting plot yields intensity-duration -frequency curves.

Step 3: Select suitable rational runoff coefficient *(Kr),* having knowledge of the surface cover of the catchment area. Use the following Table 6.

Table 6: Values of Runoff Coefficient

Land Use/Cover	**Runoff Coefficient**		
	Slope (0-5%)	**Slope (5-10%)**	**Slope (10-30%)**
CULTIVATE LAND			
Open Sandy loam	0.25-0.30	0.4	0.52
Clay and silt loam	0.5	0.6	0.72
Tight Clay	0.6	0.7	0.82
PASTURES			
Dense cover	0.1	0.16	0.22
Medium cover	0.3	0.36	0.42
Open pastures	0.4	0.55	0.6
FOREST/WOODLAND			
Dense cover	0.1	0.25	0.3
Medium cover	0.3	0.3	0.5
Scattered	0.4	0.5	0.6

Step 4: Compute Qp using the rational formula.

$$Qp = \frac{Kr \times I \times C}{3.6}$$

The rational formula is one of the most used methods for the determination of peak discharge. It makes use of the rainfall intensity (I) (mm/hr), rational runoff coefficient (kr), which is different from that of the seasonal runoff coefficient (K), and the area of the catchment (km^2). In the formula, the constant 3.6 appears to take care of the unit conversion.

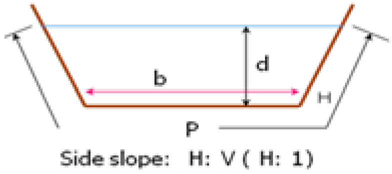
Step 5: Compute hydraulic radius R, (use Manning's formula)

$$V = \frac{S^{1/2} R^{2/3}}{n} \rightarrow \mathbf{S} = \sqrt{V * S * R^{-2/3}}$$

Here the maximum permissible velocity corresponding to the riprap size is used. The bigger the size of the riprap, the higher will be the permissible velocity and vice versa. The bed slope is estimated from the damsite map. The Manning's roughness coefficient is dependent on the channel condition and discharge (Garg, 1989). Therefore, the value corresponding to specific condition can be looked from tables.

Step 6: Compute Flow area, **A**

$$A = \frac{Qp}{v}$$



Step7: Compute wetted perimeter, *P*.

$$P = \frac{A}{R}$$

Step 8: Compute flow depth, *d*. the solution gives two values.

$$d1 = \frac{P + \sqrt{P^2 - 4A\left(2\sqrt{H^2+1} - H\right)}}{2\left(2\sqrt{H^2+1} - H\right)} \qquad d2 = \frac{P - \sqrt{P^2 - 4A\left(2\sqrt{H^2+1} - H\right)}}{2\left(2\sqrt{H^2+1} - H\right)}$$

Step 9: Compute bottom width:two values are computed corresponding to y values.

$$b_1 = P - 2y_1\sqrt{H^2+1}$$

$$b_2 = P - 2y_2\sqrt{H^2+1}$$

From (*y1, b1*) & (*y2, b2*) select the reasonable pairs, i.e. non-negative one.

D. Runoff coefficient method

This method gives a very rough estimate of runoff.

R= KP

Where, k=the runoff coefficient from table 6
P=the rainfall (mm)
R= the runoff depth (mm)

Example: find the runoff from a cultivated land of silt loam soil having a slope of 8%, assuming the rainfall of 45 mm.

Solution: From Table 6 above the value of K corresponding to silt loam soil and 8% slope is .060. This means that 60% of the rainfall is runoff.
R = KP = .060 x 45mm = 27mm