LECTURES ON

IRRIGATION AND DRAINAGE ENGINEERING

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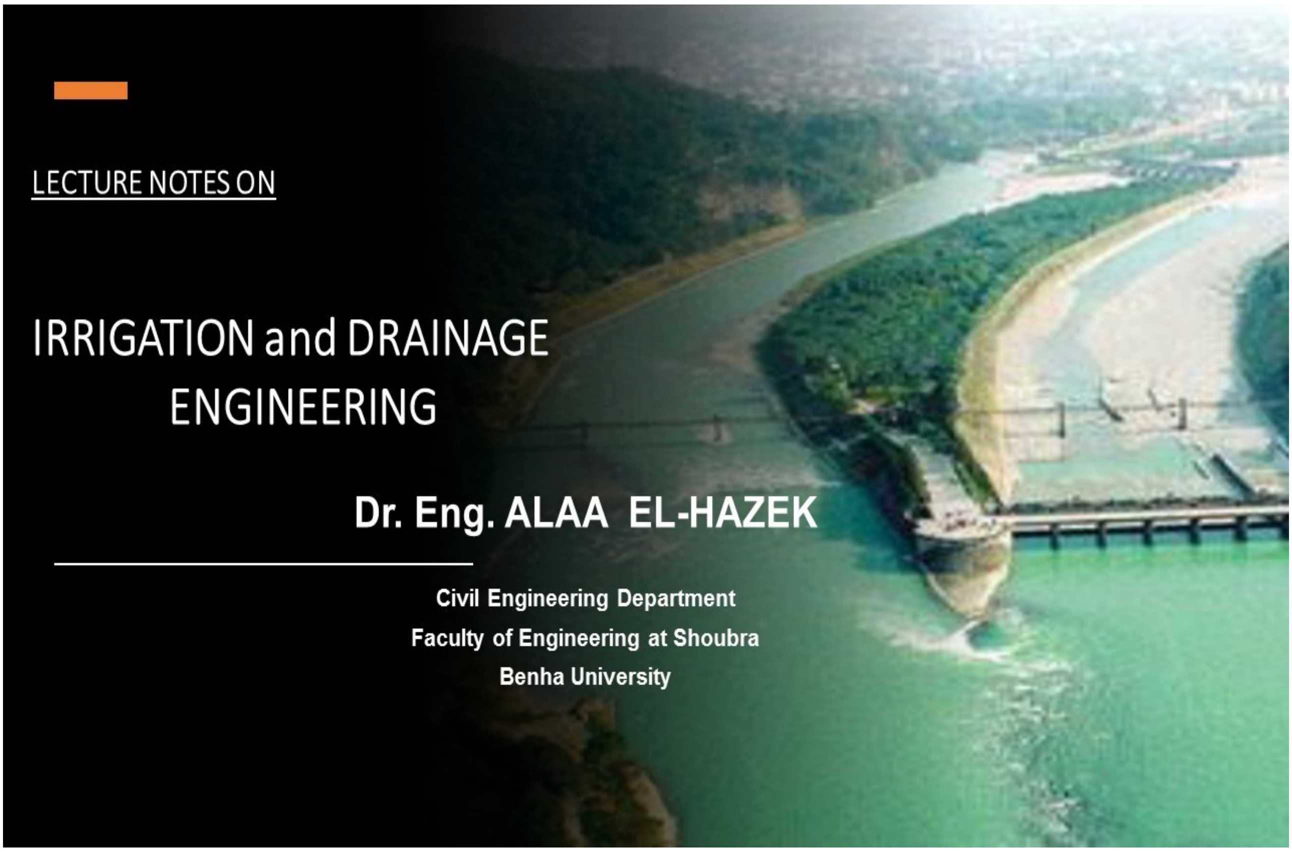

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Chapter 1

Water, Irrigation, and Drainage

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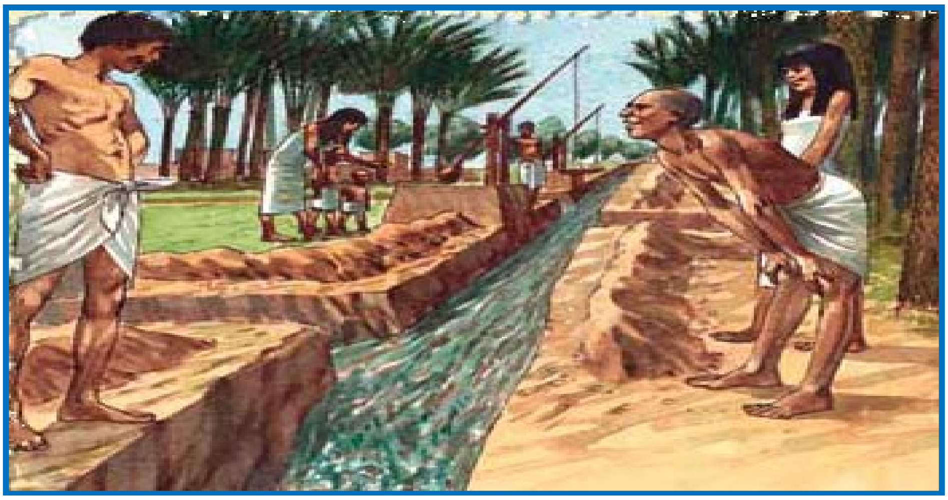

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Water, Irrigation, and Drainage

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Chapter 1

Water, Irrigation, and Drainage

1-1 Water on the Earth:

The hydrologic cycle, as shown in Figure (1-1), describes the continuous re-circulating transport of the waters of the earth, linking atmosphere, land, and oceans.

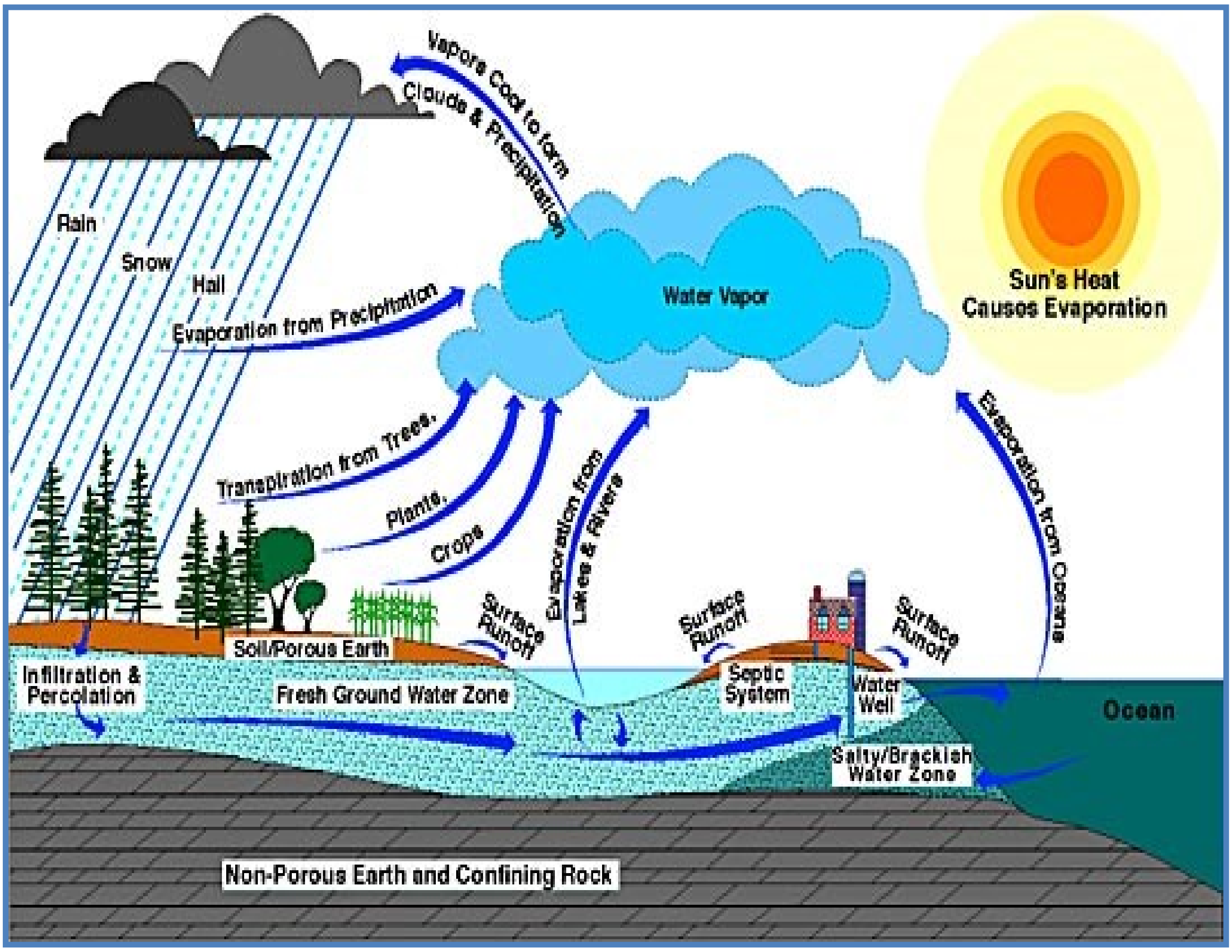


Figure (1-1): Hydrologic Cycle

https://www.slideshare.net/Melodia/the-water-cycle-3119470

Figure (1-2) illustrates the distribution of water in the globe.

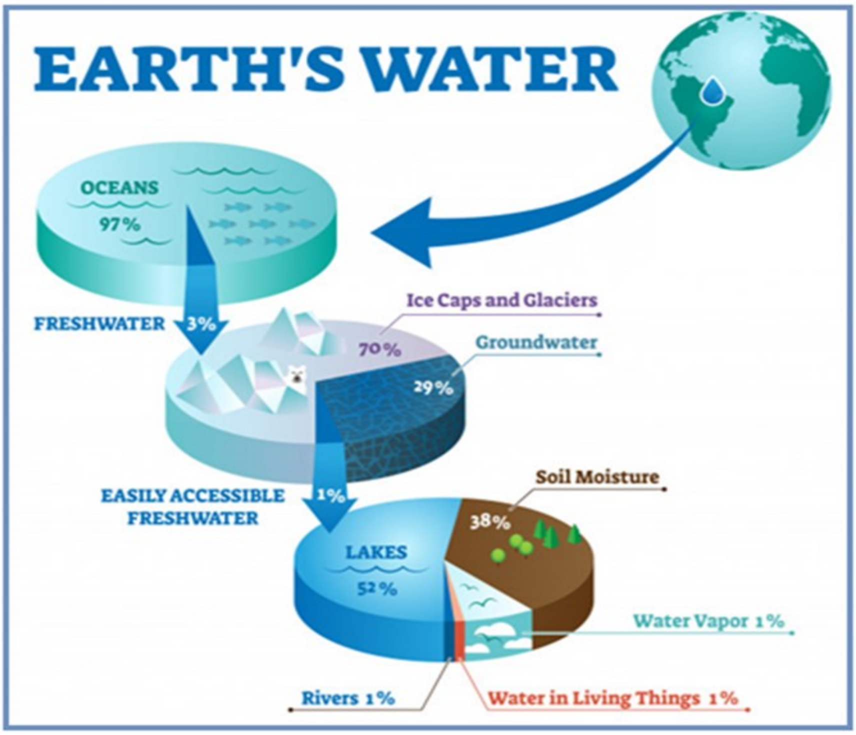


Figure (1-2): Distribution of Earth Water

https://www.freepik.com/premium-vector/earths-water-illustration_6124879.htm

The basic hydrologic equation that is applied either on a global or regional scale is:

$$\mathbf{I - O = \Delta S}$$

Where: I = inflow, O = outflow & ΔS = change in storage

Inflow (I):

1. Precipitation.
2. Import: *defined as* water channeled into a given area.
3. Groundwater inflow from adjoining areas.

Outflow (O):

1. Surface runoff outflow.
2. Export*: defined as* water channeled out of the same area.
3. Evaporation.
4. Transpiration.

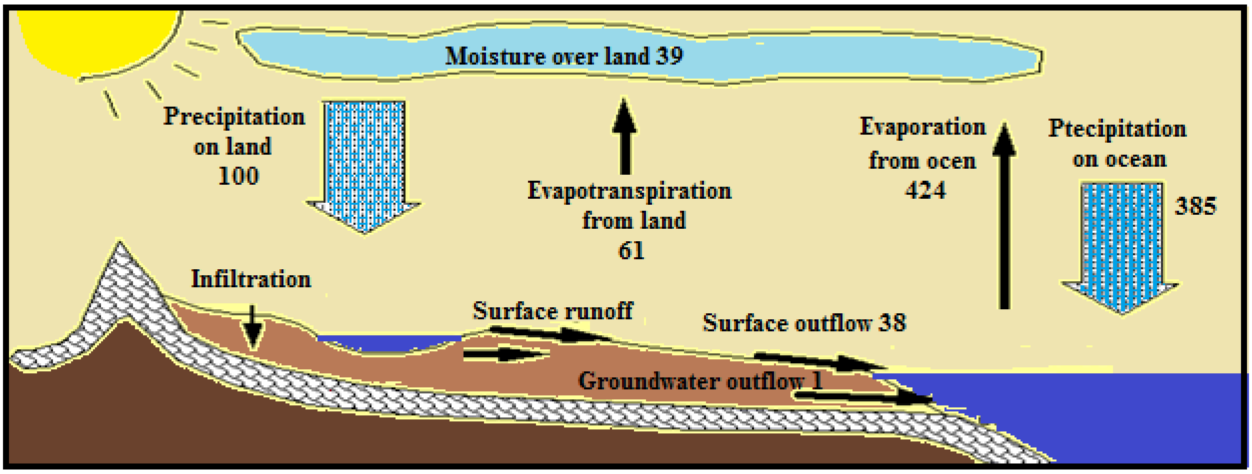
Change in Storage (ΔS):

This occurs as a change in:

1. Groundwater.
2. Soil moisture.
3. Surface reservoir water and depression storage.
4. Detention Storage.

$\Delta S = I - O$ **OR** $\Delta S = P - R - ET - F$ **OR** $ET + F = P - R - \Delta S$

Example (1-1): *Global Water Balance*



1) In the atmosphere:

Precipitation (P) = Evapo-transpiration (ET)

100 + 385 = 61 + 424

2) On land:

P = Evapo-transpiration (ET) + Surface runoff (R) + Groundwater outflow

100 = 61 + 38 + 1

3) Over oceans and seas:

Ocean precipitation + Surface runoff + Groundwater outflow = Evaporation (E)

385 + 38 + 1 = 424

Surface Water: Lakes – Ponds – Reservoirs – Rivers, Streams, Irrigation Canals, as shown in Figures (1-3), (1-4), (1-5), and (1-6).

Figure (1-3): Lakes

Figure (1-4): Ponds

https://www.slideshare.net/gauravhtandon1/environmental-engineeringi

Figure (1-5): Rivers

Figure (1-6): Streams

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Ground Water: Springs – Shallow Wells – Deep Wells, as shown in Figures (1-7), (1-8), (1-9), (1-10), and (1-11).

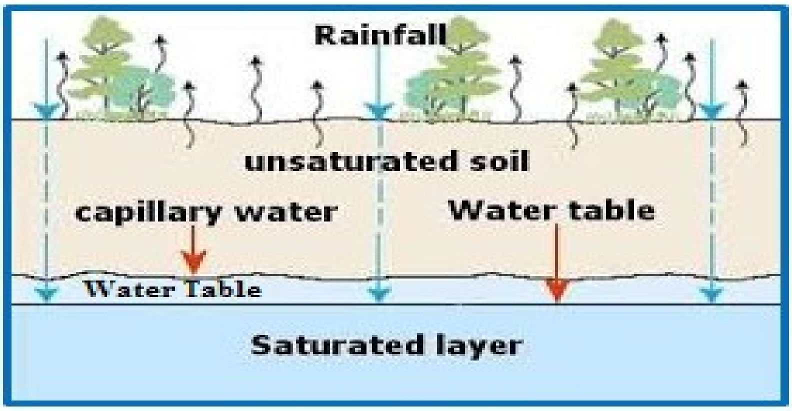


Figure (1-7): Ground Water Table

https://www.michigan.gov/documents/deq/Water_Well_Manual_2013_437334_7.pdf

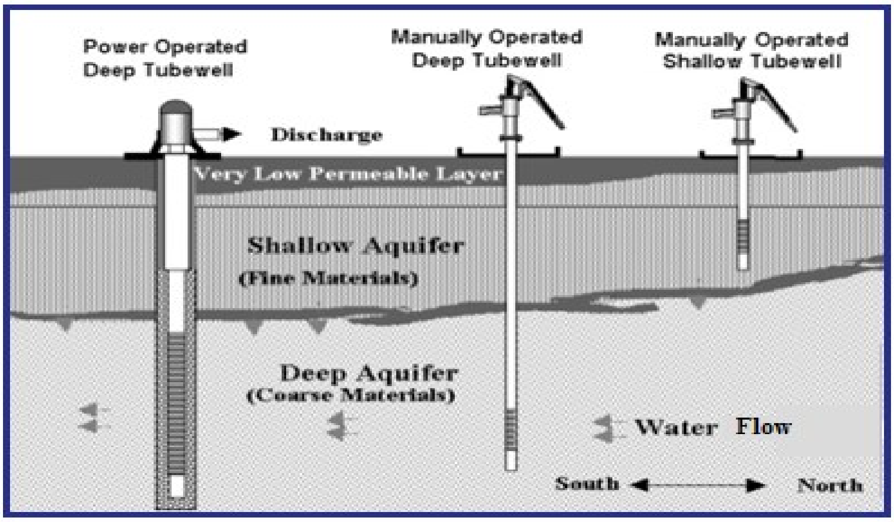


Figure (1-8): Shallow and Deep Wells

https://www.slideshare.net/gauravhtandon1/environmental-engineeringi

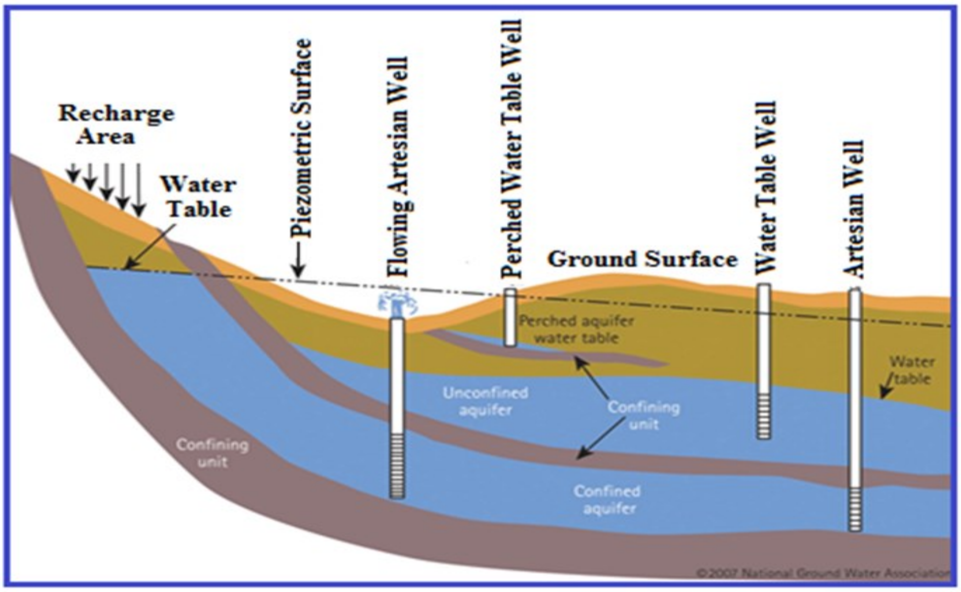


Figure (1-9): Aquifers and Wells

https://www.waternz.org.nz/Story?Action=View&Story_id=238

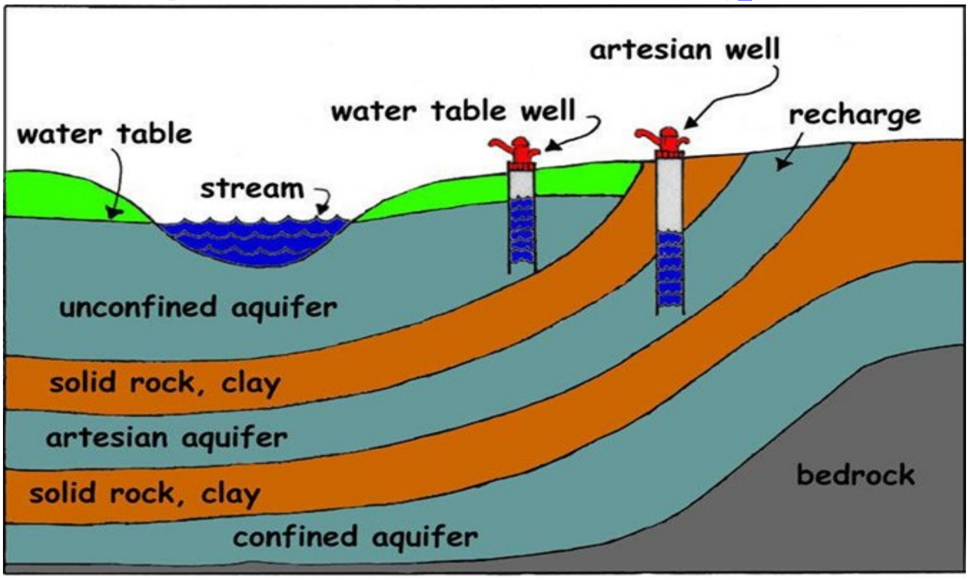


Figure (1-10): Artesian and Water Table Wells

https://www.kpcnews.com/heraldrepublican/article_b2d76196-06dd-52a4-a799-a51cba02353e.html

Figure (1-11): Wells

https://phys.org/news/2015-12-tropical-groundwater-resources-resilient-climate.html

A ***Catchment*** is a portion of the earth's surface that collects runoff and concentrates it at its furthest downstream point, referred to as the catchment outlet.
Generally, a ***watershed*** is used to describe a small catchment (stream watershed), whereas a ***basin*** is reserved for large catchments (river basins).

Example (1-2):
Four inches of runoff resulted from a storm on a drainage area of 50 mi^2.
What is the amount of this runoff in cubic meters?

Solution

$$R = 4 \text{ x } \{2.54 / 100\} \text{ x } 50 \text{ x } \{(1.609)^2 \text{ x } (1000)^2\} = 13.15 \text{ x } 10^6 \text{ m}^3$$

Example (1-3):
In the year 2020, a catchment with an area of 2500 km^2 received 1.3 m of precipitation. The average rate of flow measured in a river draining the catchment was 30 m^3/s.

1) How much total river runoff occurred in the year (in m^3)?
2) What is the runoff coefficient?
3) How much water is lost due to the combined effects of evaporation, transpiration, and infiltration (in m)?

Solution

1) Total runoff volume = number of seconds in a year x average flow rate
= (365x24x60x60) x 30 = 9.4608 x10^8 m^3

2) Runoff coefficient = Runoff volume / precipitation volume
= (9.4608 x10^8) / {1.3 x (2500 x 10^6)} = 0.29 = 29 %

3) $\Delta S = I - O$

$\Delta S = P - R - ET - F$

$ET + F = P - R - \Delta S$

Assume, $\Delta S = 0$ (no change in storage)

$ET + F = P - R$

$P = \{1.3 \text{ x } (2500 \text{ x } 10^6)\} = 3.25 \text{ x } 10^9 \text{ m}^3$

$R = 9.4608 \text{ x} 10^8 \text{ m}^3$ (total runoff volume)

$ET + F = P - R$ $= 3.25 \text{ x } 10^9 - 9.4608 \text{ x} 10^8 = 2.30392 \text{ x } 10^9 \text{ m}^3$

$= (2.30392 \text{ x } 10^9) / (2500 \text{ x } 10^6) = 0.92 \text{ m}$

Example (1-4):

In the year 2020, a 10,000 mi^2 watershed received 20 inches of precipitation. The average rate of flow measured in the river draining the area was 6,000 cfs.

Calculate the combined amounts of water evaporated and transpired from the region during this year?

Solution

$\Delta S = I - O$

$\Delta S = P - R - ET - F$

$ET + F = P - R - \Delta S$

Assume, $\Delta S = 0$ & $F = 0$

$ET = P - R$

$$R = \frac{6000 \times \{(12)^3 \times 3600 \times 24 \times 365\}}{10000 \times \{(1760)^2 \times (3)^2 \times (12)^2\}} = 8.14 \text{ in / year}$$

$ET = 20 - 8.14 = 11.86$ in / year

Example (1-5):

A vertical wall reservoir has an area of 500 acres. During a day, the inflow was 100 cfs and the evapotranspiration was one inch.

1) Is water stored in the reservoir?
2) If yes, calculate the stored water?

Solution

$\Delta S = I - O$

$\Delta S = P - R - ET - F$

$P = Q$ & $R = 0$ Assume, $F = 0$

$\Delta S = Q - ET$

$Q = 100 \times (12)^3 = 172800 \times \{3600 \times 24\} = 1.49 \times 10^{10}$ in^3 / day

$$= \frac{1.49 \times 10^{10}}{500 \times 4047 \times (3.28)^2 \times (12)^2} = 4.76 \text{ in}$$

1) $Q > ET$

$\therefore$ Water is stored in the reservoir

2) $\Delta S = 4.76 - 1 = 3.76$ in

1-2 Irrigation:

Irrigation is providing the soil artificially with water to achieve the required moisture for the plants' growth. This process is needed for both arid regions, where no rainfall, and semi-arid regions, where the available rainfall is not sufficient for the plants' growth.

Irrigation science is allocating water from its different sources, conveying water through irrigation channels to the required areas, and distributing water according to the various kinds of soils and plants. Storing water may be needed in some cases according to the balance between the available water and the requirements of the plants (amounts and times).

To detect the suitable kinds of crops and both amounts and rates of irrigation water, many factors must be studied concerning the soil, meteorology, and hydrology.

- Soil science includes texture, thickness, depth to the impermeable layers, salinity and alkalinity, porosity, and topography of the ground surface.

- Meteorology science studies the phenomena of the weather such as temperature, relative humidity, speed, and direction of the wind.

- Hydrology science includes studying in and out operations for all different surface and underground sources of water.

It must be noted that the science of hydraulics is essential in all irrigation works. It guarantees the proper motion of water according to the required rates and levels.

1-3 The Soil:

Components of the soil are different from one site to another, and sometimes are different in the same site. However, the soil consists of solid particles with irregular shapes and different sizes. To identify various types of soil, the solid particles are assumed to be found as regular spheres with different sizes. Table (1-1) shows the classification of soil particles into groups according to the diameter of the particles.

A mechanical analysis can be made for a soil sample to detect the ratios of different groups of particles. Ratios are determined according to the weights concerning the total weight of the soil sample. The soil type can be found using a soil texture triangle, as shown in Figure (1-12).

The Group	Diameter of the Particles (mm)
Gravel	> 1
Coarse Sand	1 - 0.5
Medium Sand	0.50 - 0.25
Smooth Sand	0.25 - 0.10
Very Smooth Sand	0.10 - 0.05
Silt	0.05 - 0.005
Clay	< 0.005

Table (1-1): Classification of Soil Particles.

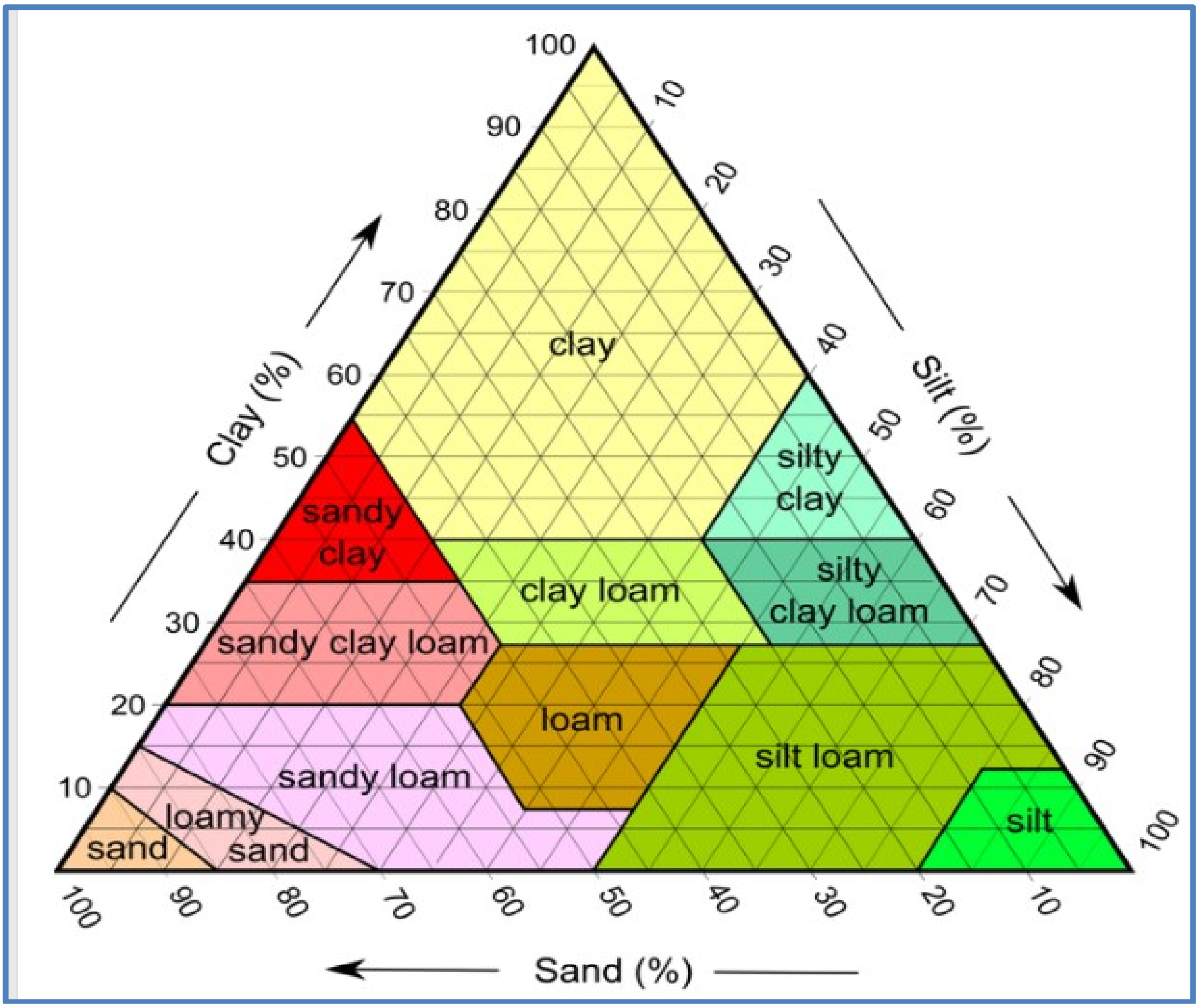


Figure (1-12): Soil Texture Triangle

https://thinkingcountry.com/2016/11/30/soil-texture-sand-silt-and-clay/

Example (1-6):

From the Soil Texture Triangle:

1) Find the soil texture for the combination of 10% sand, 85% silt, 5% clay?
2) State the soil texture for the combination of 40% sand, 30% silt?

Solution

1) Silt. 2) Clay loam.

The volume of the solid particles for any soil does not represent the volume of the soil, where there are voids (or pore spaces) between these particles. For a soil profile, as shown in Figure (1-13), the voids between the solid particles are occupied by both the air and the water. When the voids of the soil are fully occupied by only the water, then the soil is called saturated soil. The air-water balance represents the ratio between the air and the water that existed in the voids of the soil.

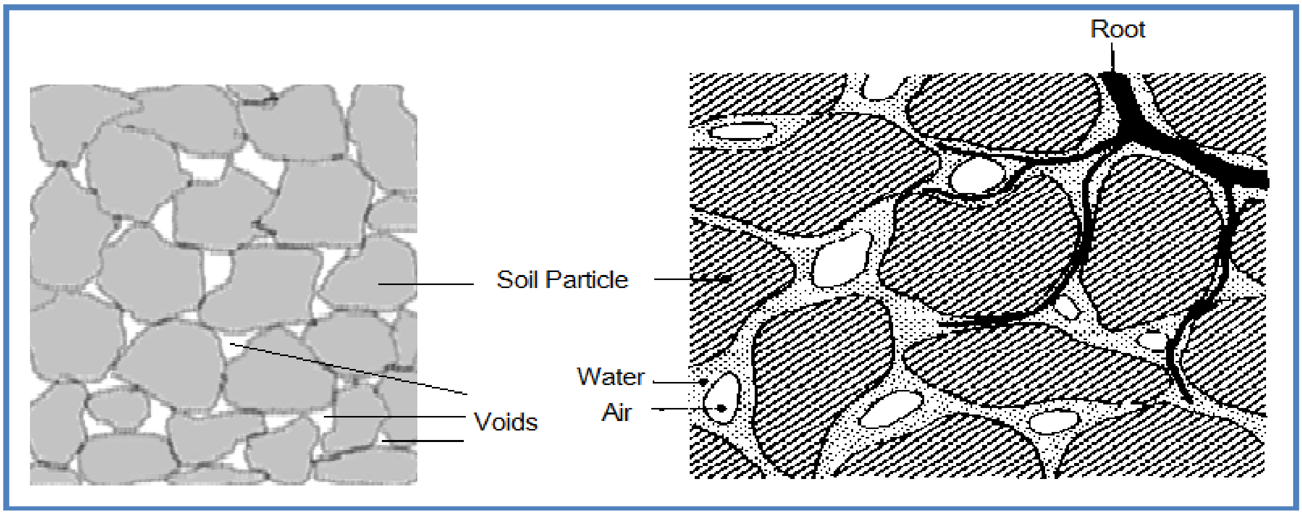


Figure (1-13): Soil Profile

1-4 <u>Water in Soil:</u>

When water is added to the ground surface either by artificial irrigation (or rainfall), a part of the water penetrates the ground surface to the pore spaces of the soil. Water moves downward due to the gravitational force.

The upper layers of the soil hold a fraction of the water due to the hygroscopic property of the solid particles and the surface tension force. The hygroscopic property of the solid particles of the soil is that these particles allocate moisture (water) from the atmosphere which contains water vapor.

If water is still added to the ground surface, the pore spaces of the upper layers of the soil are filled with water completely. Consequently, these layers become saturated.

Adding more water, water motion will occur in the lower layers of the soil.

The root zone, where the roots of plants grow, includes the upper layers of the soil, as shown in Figure (1-14). From the agricultural point of view, water in the root zone is important to get maximum crop yields.

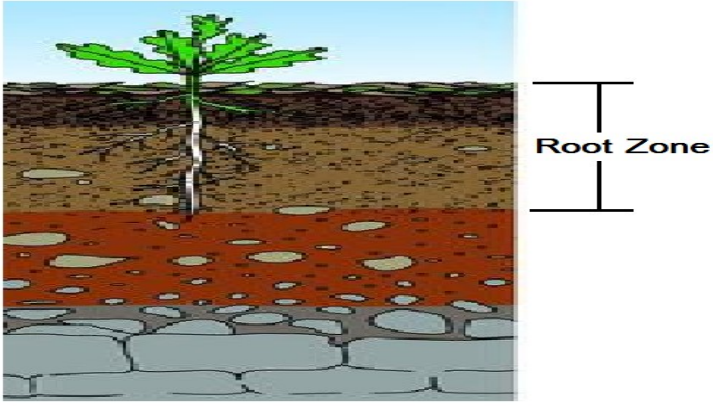


Figure (1-14): The Root Zone

♦ As shown in Figure (1-15), water in the soil can be divided into three forms:

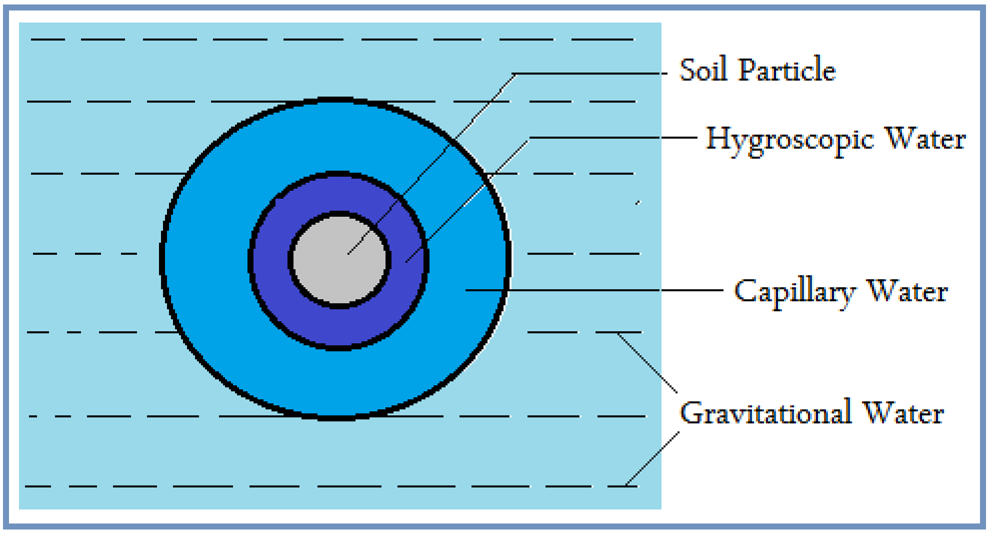


Figure (1-15): Forms of Water in the Soil

1) Hygroscopic Water:

It is a thin film of water around the soil particle. It is held to the soil particle by a great force that prevents water to move in any direction.

Thus, this form of water is unavailable to the plants.

2) Capillary Water:

It is a thick film of water around the soil particle next to the hygroscopic film. It is held to the soil particle by the force of surface tension. This water moves in all directions forming capillary zones. In the capillary zone, the air-water balance can be achieved where both air and water are found together. Thus, the roots of plants can breathe and grow, where the bacteria can grow and transport the essential elements from the soil to the roots.

3) Gravitational Water:

It includes water outside the hygroscopic and the capillary films. This form of water occupies the pore spaces of the soil, especially the big voids, and it moves downward due to the gravitational force.

When the quantity of the gravitational water increases, the upper layers of the soil (root zone) become saturated. For saturated soil, the pore spaces are filled only by water and there will be no air. The roots of plants cannot find air and the plants die.

1-5 Drainage:

It is removing the excess gravitational water from the root zone of the soil to achieve the air-water balance and to permit the plants to use well the capillary water.

It is obvious that the root zone of the soil, which represents the upper layers of the soil in which the roots of plants live, must not reach the saturation case. So, the drainage process must be employed.

1-6 Soil Moisture Coefficients:

These coefficients define the limits for the moisture contents in the soil according to the different forms of water.

These coefficients may be called also the “Soil Constants”.

Water content can be quantified on both a gravimetric (g water/g soil) and volumetric (cm^3 water/ cm^3 soil) basis. The volumetric expression of water content is used most often. Since 1 gram of water is equal to 1 cm^3 of water, the weight of the water can easily be determined, and immediately its volume is known.

1) Hygroscopic Coefficient:

It is the maximum moisture content that the soil can take from a surrounding atmosphere of a certain relative humidity. This coefficient is approximately 0.5 - 2 % for sandy soils, 4 - 9 % for silt soils, and 11 % for clayey soils.

2) Wilting Point:

It is the moisture content in the soil that the plant cannot adsorb. The wilting point can be determined by measuring the moisture left in a soil sample after being exposed to a force = 15 atmospheric pressure in a centrifugal instrument.

However, the wilting point is about 1 - 3 % for sandy soils, 6 - 13 % for silt soils, and 16 % for clayey soils.

3) Field Capacity:

It is the maximum moisture content that the soil can keep after being drained, which occurs 1-3 days after irrigation. The field capacity can be determined by measuring the moisture left in a soil sample after being exposed to a force = 1/3 atmospheric pressure in a centrifugal instrument.

At the field capacity, the films of the capillary water have the maximum thickness. So, this is the best case for the plants' growth where the air-water balance is well achieved.

But it must be noted that the soil can keep its field capacity only for a short time. That is because of the weather conditions, the soil properties, and the retention power by which the soil can keep the moisture. The sandy soils keep moisture less than the silt soils. Also, the silt soils keep moisture less than the clayey soils.

4) Maximum Water Capacity:

It is the moisture content when the soil is fully saturated (all the pore spaces of the soil are filled with water).

Figure (1-16) illustrates the main soil moisture coefficients.

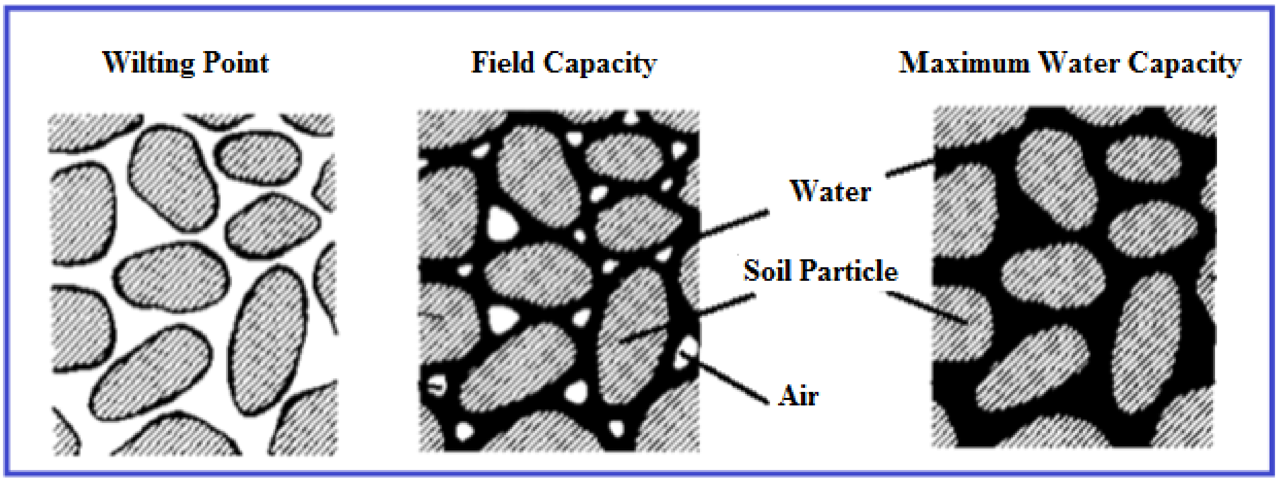


Figure (1-16): Soil Moisture Coefficients

1-7 <u>Classification of Water in the Soil according to Plants' Usage:</u>

1) Excess Water:

It is the moisture content more than the field capacity of the soil. This water percolates to the deep layers of the soil (below the root zone) where the plant cannot use.

2) Total Available Water:

It is the moisture content in the range between the field capacity and the wilting point. The plant can use this water in general.

3) Readily Available Water:

Practically, the wilting point has not to be reached to avoid difficulties in the plants' growth. So, the readily available water is assigned to be equal to 2/3 - 3/4 of the total available water.

4) Unavailable Water:

It is the moisture content less than the wilting point.

Figure (1-17) illustrates a schematic diagram for the classification of water in the soil according to the plants' usage, and Figure (1-18) shows the main soil constants.

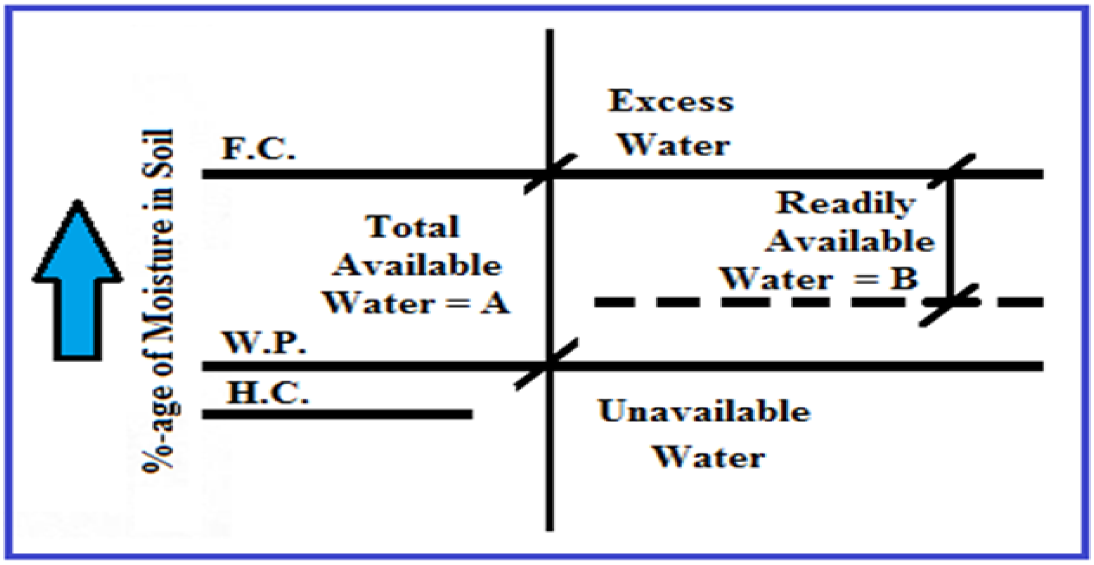


Figure (1-17): Classification of Water in the Soil according to the Plant's Usage

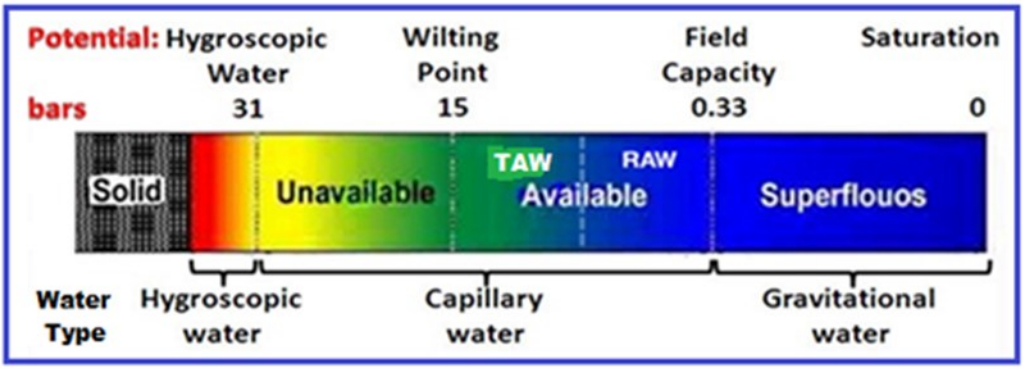


Figure (1-18): Main Soil Moisture Constants

1-8 Consumptive Use:

It is the quantity of water required, in a certain period, for the plant's growth in addition to the losses due to the transpiration and evaporation processes.
The transpiration is losing water through the leaves of the plant, while the evaporation is losing water from the soil cultivated by the plant.

The consumptive use is expressed as a volume of water or an equivalent depth of water. For irrigation science, in general, quantities of water are expressed as either volumes or equivalent depths.
The rainfall, for example, in an area is said to be 1.5 mm/day. This depth represents a quantity of water, which can also be expressed *as follows:*
For an area of one feddan, the common unit for areas in Egypt:
The quantity of water from the rainfall = (1.5/1000) x 4200 = 6.3 m^3/Fed/day

- One feddan is equal to 4200 m^2.
- One acre is equal to 4000 m^2.
- One hectare is equal to 10,000 m^2.

The following equation is employed to calculate ***the consumptive use (C)*** in each one irrigation process per feddan (unit area).

$$C = 4200 \text{ x } R \text{ x } \frac{\gamma_s}{\gamma_w} \text{ x } RAW$$

Where,	C	: The consumptive use, m^3/Fed.
	4200	: 1 Feddan = 4200 m^2.
	R	: Effective root depth, m.
	γ_s	: Specific weight of the soil, t/ m^3.
	γ_w	: Specific weight of the water, γ_w = 1 t/m^3.
	RAW	: Readily available water, % - age ratio.

The maximum period, in days, between irrigation processes **(P_{max})** can then be calculated *as follows:*

$$P_{max} = \frac{C}{F}$$

Where, F : The field irrigation requirements, m^3/Fed/day.

***The field irrigation requirements* (F)** is the quantity of water required daily including the field losses per feddan. The field losses include the water lost due to surface run-off and deep percolation.

$$F = \frac{D - r_e}{1 - L_f}$$

Where, D : The daily consumptive use, m^3/Fed/day.

r_e : The quantity of effective rainfall, m^3/Fed/day.

L_f : The field losses, % - age ratio.

For arid regions, there is no rainfall.
For semi-arid regions, the quantity of rainfall is small.
However, the quantity of effective rainfall is assumed to be zero if it is not given in the problems.

It must be noted that giving fewer quantities of water in each irrigation process with fewer periods between irrigation processes, will decrease the field losses and consequently will increase the efficiency of the field irrigation.

***The field water duty* (F.W.D.)** is the quantity of water applied to the field and it is expressed as m^3/Fed/day.

$$FWD = \frac{F \times P_{max}}{\text{On Interval}}$$

Where On-interval is the number of days in which irrigation is permitted by the water that exists in the canals.

The irrigation water reaches the field from the main source of water through a network of canals. So, there will be losses due to conveying water from the main source to the field.

The conveyance losses include seepage of water from the bed and the sides of the canals, evaporation of water from the surfaces of the canals, and transpiration by plants and weeds along the canals.

These losses are considered when calculating the water duty for the canals *as follows:*

D.C.W.D. = F.W.D. x 1.10

B.C.W.D. = F.W.D. x 1.15

M.C.W.D. = F.W.D. x 1.20

Where, D.C.W.D.: Distributary canal water duty.
B.C.W.D.: Branch canal water duty.
M.C.W.D.: Main canal water duty.

Example (1-7):

An area of clayey soil has 1.2 t/m^3 specific weight, 36 % field capacity and 20 % wilting point. This area is cultivated by cotton that requires a quantity of water of 24 m^3/day for each one feddan in July when its effective root depth is 90 cm.

1) If the field losses are 40 %, determine the field irrigation requirements?
2) Calculate the maximum period between irrigation processes?
3) If the on-interval is 5 days, determine the water duties for the field and the distributor canal?
4) Explain in detail how to increase the efficiency of the irrigation process?

Solution

Given:

γ_s = 1.2 t/m^3	F.C. = 0.36
W.P. = 0.20	D = 24 m^3/fed/day
R = 90 cm = 0.9 m	r_e = 0 (as it is not given)
L_f = 0.40	On-interval = 5 days

Required:

1) F?
2) P_{max}?
3) F.W.D. & D.C.W.D.?
4) How can the efficiency of irrigation process be increased?

Solution:

1) $F = \frac{D - r_e}{1 - L_f}$ $F = \frac{24-0}{1-0.4}$ = 40 m^3/Fed/day

2) $P_{max} = \frac{C}{F}$

$C = 4200 \text{ x } R \text{ x } \frac{\gamma_s}{\gamma_w} \text{ x } RAW$

RAW = = (2/3 - 3/4) x (F.C. - W.P.) = (3/4) x (0.36 - 0.20) = 0.12

Assume $\gamma_W = 1$ t/m^3

$C = 4200 \text{ x } 0.9 \text{ x } \frac{1.2}{1} \text{ x } 0.12 = 544.3$ m^3/Fed

$P_{max} = \frac{544.3}{40} = 13.6 \approx 13$ days

3) FWD $= \frac{F \text{ x } P_{max}}{\text{On Interval}} = \frac{40 \text{ x } 13}{5} = 104$ m^3/Fed/day

D.C.W.D. = F.W.D. x 1.10

D.C.W.D. = 104 x 1.1 = 114.4 m^3/fed/day

4) Discussion.

1-9 <u>Crop Rotation:</u>

It is the sequence of different crops cultivated in the land during a specific period.

The objectives of the crop rotation are as follows:

1) Maintaining the land suitable for being cultivated. That is by keeping a balance between the different food elements in the soil. Each crop needs a specific kind of food element in the soil. Some crops leave in the soil some food elements which are useful for other crops.
2) Optimum usage of the soil and the subsoil. That is by cultivating the crops of short roots after the crops of tall roots, and so on.
3) Giving sufficient time for land service. That is by choosing the crops such that there will be enough time between collecting the old crop and cultivating the new crop.
4) Rehabilitating some lands by leaching them from salts. That is by cultivating these lands with rice.
5) Improving the properties of some lands and providing them with natural organic fertilizers. That is by cultivating these lands with clover.

The kinds of crop rotation are as follows:

1) Two-turn rotation, where the crop is cultivated every two years.
2) Three-turn rotation, where the crop is cultivated every three years.
3) Special rotation, where the main objective is to leach and improve the properties of the lands required to be reclaimed.

1-10 Irrigation Rotation:

Water is discharged in the distributor canals for a specific period called "working period" or "on-interval". Then, water is prevented from being discharged in these canals for another period called "closing period" or "off-interval". The sum of the two periods is called "the length of the irrigation rotation".

The objectives of the irrigation rotation are as follows:

1) Protecting the lands beside the distributor canals from continuous seepage of water. That is because the distributor canals in the off-intervals act as drains that collect the excess water percolated to these lands during the on-intervals.
2) Helping the irrigation engineer to supervise different areas in sequent periods, which leads to achieving the required distribution of water among the different canals.
3) Helping the farmer to irrigate the land in the on-interval, and to do the required agricultural processes in the off-interval.
4) Decreasing the dimensions required for the sections of the canals. So, the cost is decreased.
5) Decreasing the losses, where the water does not exist in the canals for long periods.

Two factors must be considered in the irrigation rotation:

a) The on-interval must be sufficient for allowing water to fill the distributor canals and to reach the designed levels. It must be also sufficient for allowing the farmers to irrigate the land.

b) The maximum period between the irrigation processes detects the length of the irrigation rotation. This maximum period depends on the soil moisture coefficients of the soil and the kind of the cultivated crop, as discussed previously. If several crops are cultivated, then the crop of minimum P_{max} will detect the length of the irrigation rotation.

The irrigation rotation can be classified according to:

1) Period of the year at which the irrigation rotation is executed:

1. Summer irrigation rotation: It is done from the half of April either till the half of August if three turn rotation (6 and 12 days, for cotton and sharaki) or till the half of September if two-turn rotation (4 and 4 days, for rice, cotton, and sharaki).

2. Nile irrigation rotation: It is done from the half of August till the end of November. It may be either three-turn rotation (5 and 10 days, for cotton) or two-turn rotation (4 and 4 days, for rice).

3. Winter irrigation rotation: It is done from the end of November till the half of March. It is usually three turn rotation (6 and 12 days). It includes January where no water for irrigation is discharged. Establishing the required irrigation constructions, maintenance, and cleaning of the canals are well executed during this month.

4. Spring irrigation rotation: It is done from the half of March till the half of April. It is usually three turn rotation (5 and 10 days).

2) The number of turns:

First, for planning an irrigation network, it must be noted that any canal is represented by a continuous line. This line has the symbol (H.R.) at its beginning to represent the head regulator (H.R.) necessary for distributing the water, as shown in Figures (1-19). Also, each canal must end at a suitable drain (a dashed line) through a tail escape (T.E.) with the symbol (T.E.). That is to dispose safely of any excess water from the canal into the drain, as shown in Figure (1-20).

Figure (1-19): Head Regulator

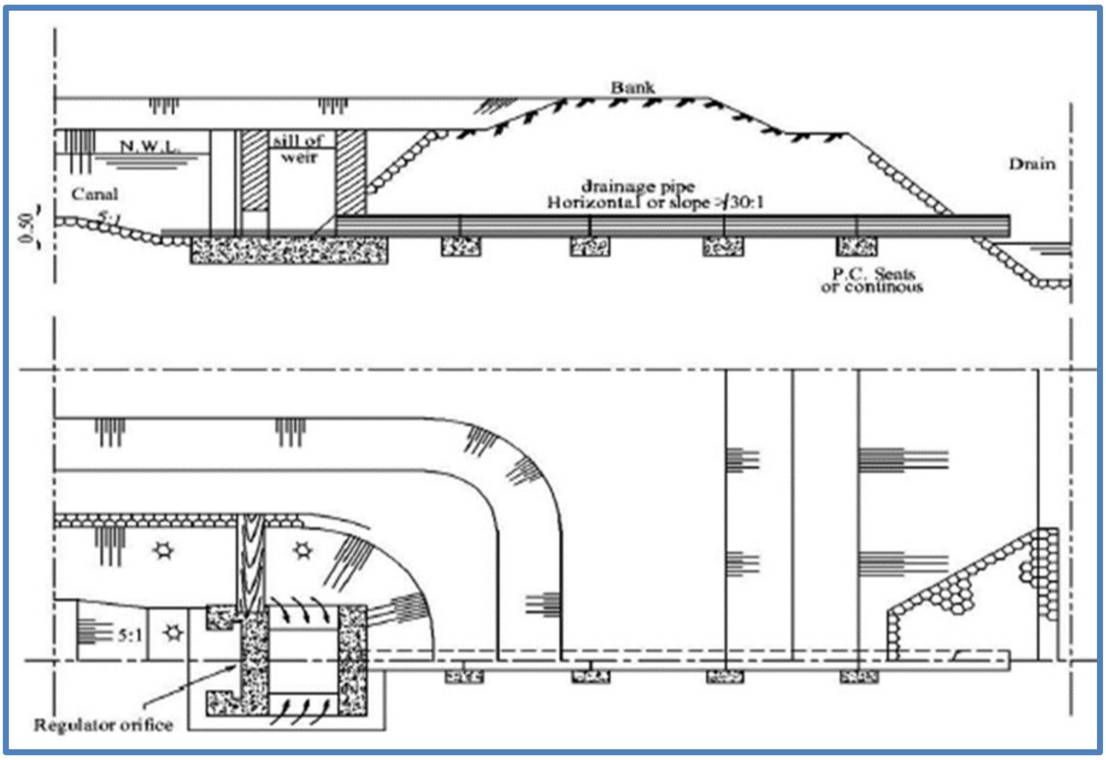


Figure (1-20): Tail Escape

1. <u>*Two-turn irrigation rotation:*</u>

The distributary canals are divided into two turns A and B of the almost equal area served. One intermediate regulator (I.R.) or partial regulator (P.R.), as shown in Figures (1-21) and (1-22), is constructed on the branch canal at the location that divides the total area served into the two turns A and B, as shown in Figure (1-23).

Figure (1-21): Partial (Intermediate) Regulator

Figure (1-22): Partial (Intermediate) Regulator

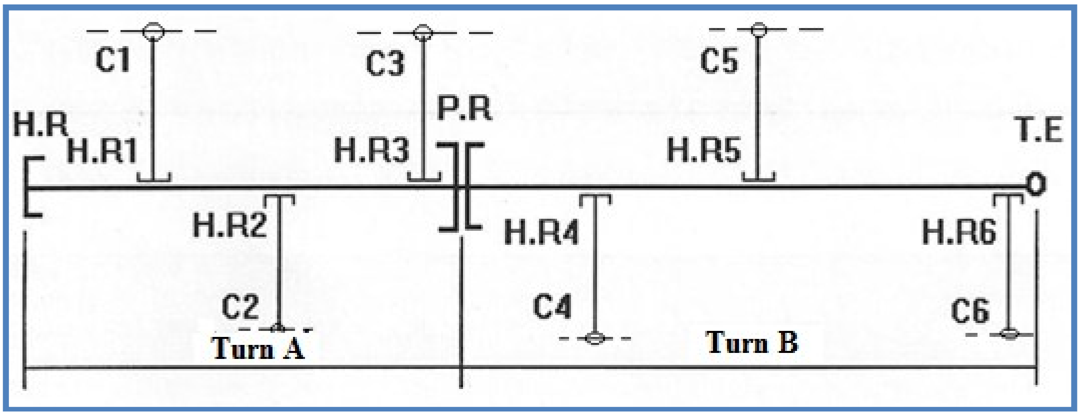


Figure (1-23): Two-Turn Irrigation Rotation

At the beginning of the two-turn rotation, the P.R. is closed to keep the water required for group A. The head regulators H.R.1, H.R.2, and H.R.3 are opened for passing the water into the distributary canals C1, C2, and C3. This process continues during the first interval, as shown in Figure (1-24).

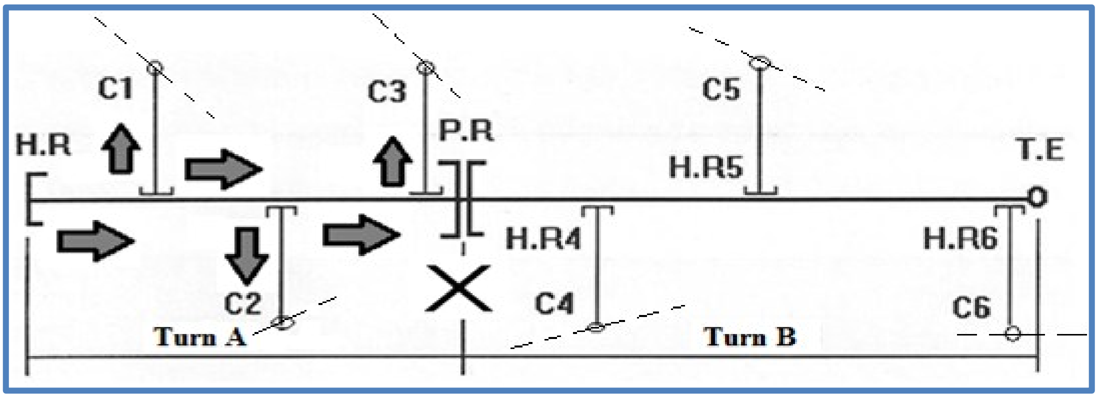


Figure (1-23): Turn A of Two-Turn Irrigation Rotation

It must be noted that the two-turn rotation is composed of two equal intervals. The first interval is on-interval for the distributary canals of group A, and it is off-interval for the distributary canals of group B.
Similarly, the second interval is off-interval for the distributary canals of group A, and it is on-interval for the distributary canals of group B.

However, for the second interval, the P.R. is opened to pass the water required for group B. The head regulators H.R.1, H.R.2, and H.R.3 are closed to pass no water, while the other head regulators H.R.4, H.R.5, and H.R.6 are opened for passing the water into the distributor canals C4, C5, and C6, as shown in Figure (1-25).

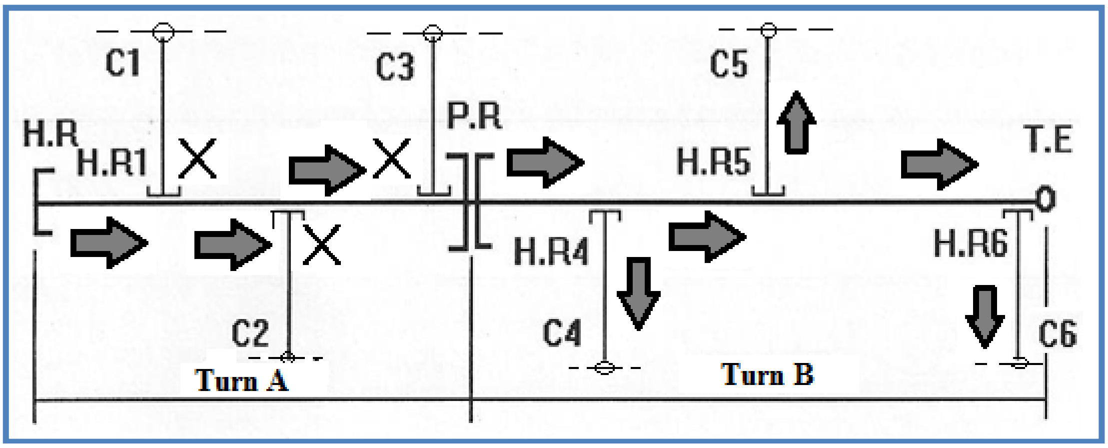


Figure (1-25): Turn B of Two-Turn Irrigation Rotation

Thus, the two-turn irrigation rotation continues according to this sequence.

2. ***Three-turn irrigation rotation:***

The distributary canals are divided into three groups A, B, and C of the almost equal area served. Two partial regulators (P.R.1 and P.R.2) are constructed on the branch canal at the two locations that divide the total area served into the three groups A, B, and C, as shown in Figure (1-26).

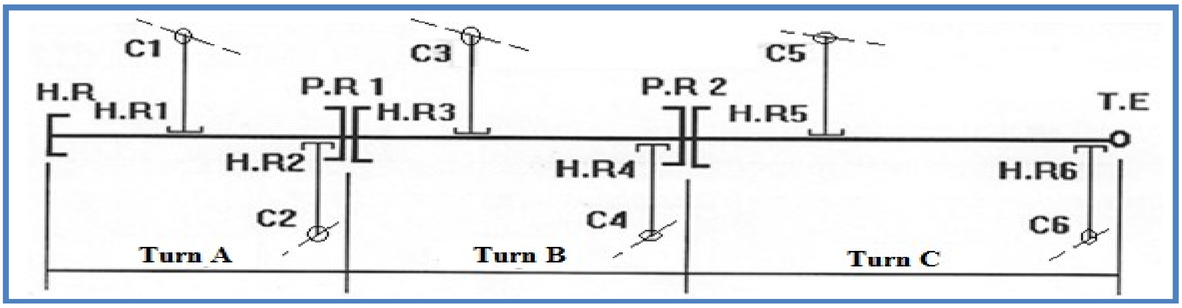


Figure (1-26): Three-Turn Irrigation Rotation

It must be noted that the three-turn irrigation rotation is composed of three intervals of time. For the first interval, the P.R.1 is closed to keep the water required for group A. The head regulators H.R.1 and H.R.2 are opened for passing the water into the distributary canals C1 and C2. Thus, group A is irrigated, as shown in Figure (1-27).

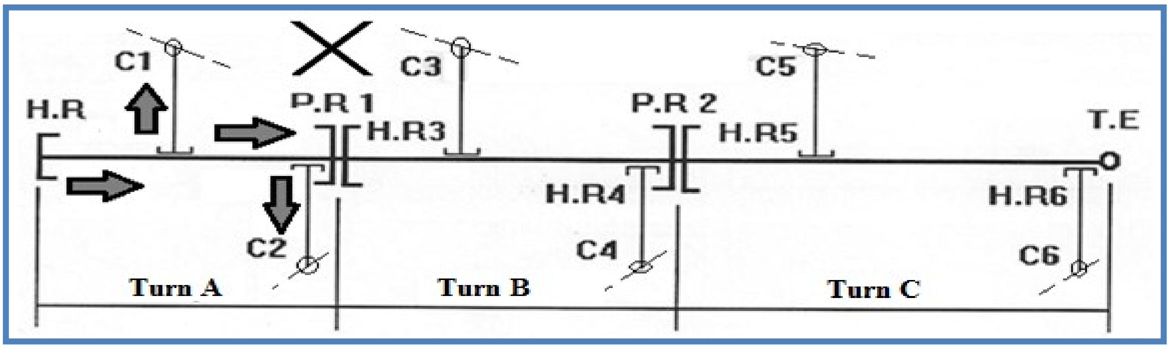


Figure (1-27): Turn A of Three-Turn Irrigation Rotation

Similarly, for the second interval, H.R.1, H.R.2, and P.R.2 are closed, while H.R.3, H.R.4, and P.R.1 are opened. Thus, group B is irrigated, as in Figure (1-28).

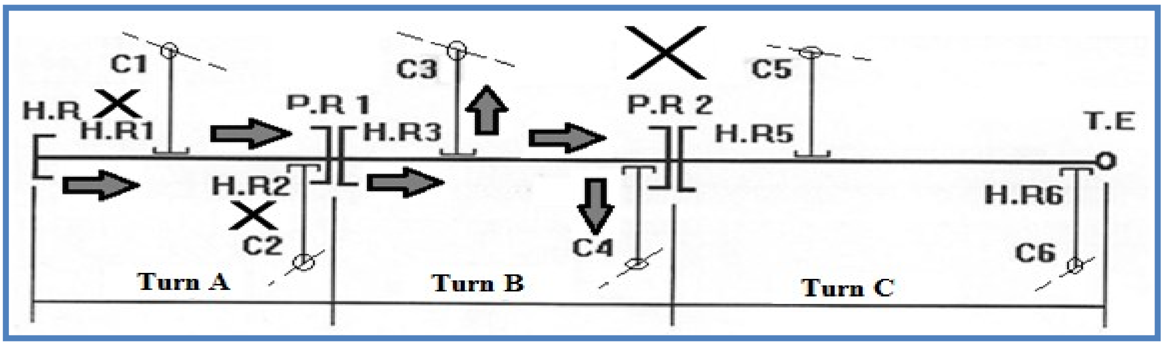


Figure (1-28): Turn B of Three-Turn Irrigation Rotation

Following the same sequence, for the third interval, H.R.1, H.R.2, H.R.3, and H.R.4 are closed, while H.R.5, H.R.6, P.R.1, and P.R.2 are opened. Thus, group C is irrigated, as shown in Figure (1-29).

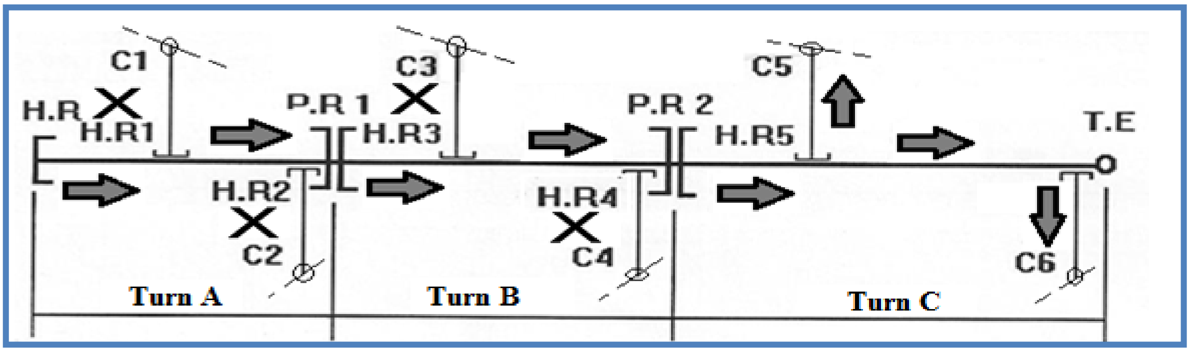


Figure (1-29): Turn C of Three-Turn Irrigation Rotation

Thus, the three-turn irrigation rotation continues in the same manner.

Example (1-8):

A branch canal of 25 km length serves an area of 48,400 feddan and has 6 distributary canals *as follows:*

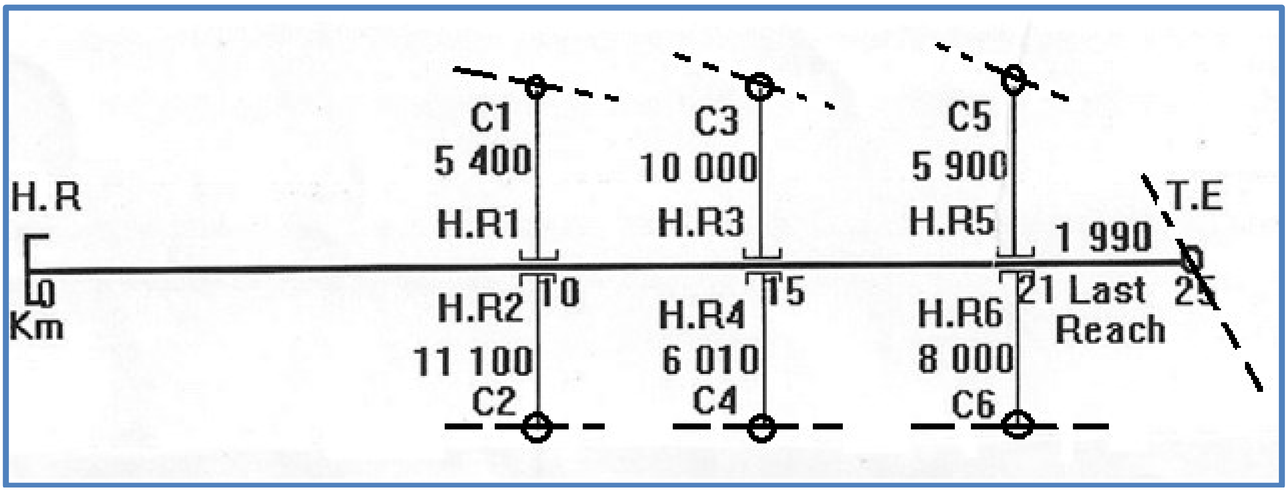
Canal	Km	Location	Area Served, Fed
C 1	10.0	Left	5,400
C 2	10.0	Right	11,100
C 3	15.0	Left	10,000
C 4	15.0	Right	6,010
C 5	21.0	Left	5,900
C 6	21.0	Right	8,000

It is required to draw a diagram for the branch canal with its distributary canals indicating the locations of suggested constructions and showing the area served for each turn *in the cases of:*

1) Two-turn irrigation rotation?
2) Three-turn irrigation rotation?

Solution:

The sum of area served for the 6 distributary canals =
5,400 + 11,100 + 10,000 + 6,010 + 5,900 + 8,000 = 46,410 Fed
∴ The area served by direct irrigation after km 21.00 =
48,400 – 46,410 = 1,990 Fed

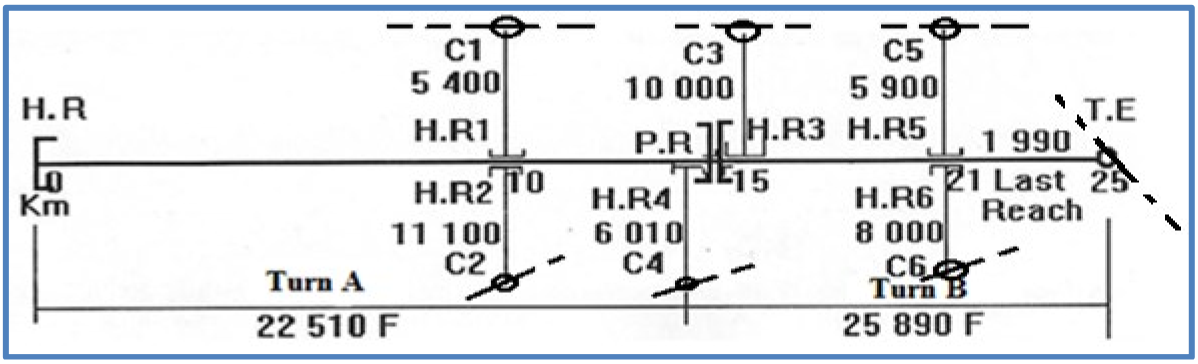


1) Two-turn irrigation rotation:

Average required area served for each turn = 48,400 / 2 = 24,200 Fed

∴ For the first turn, take group A = C1 + C2 + C4 = 22,510 Fed

& For the second turn, take group B = C3 + C5 + C6 + L.R. = 25,890 Fed



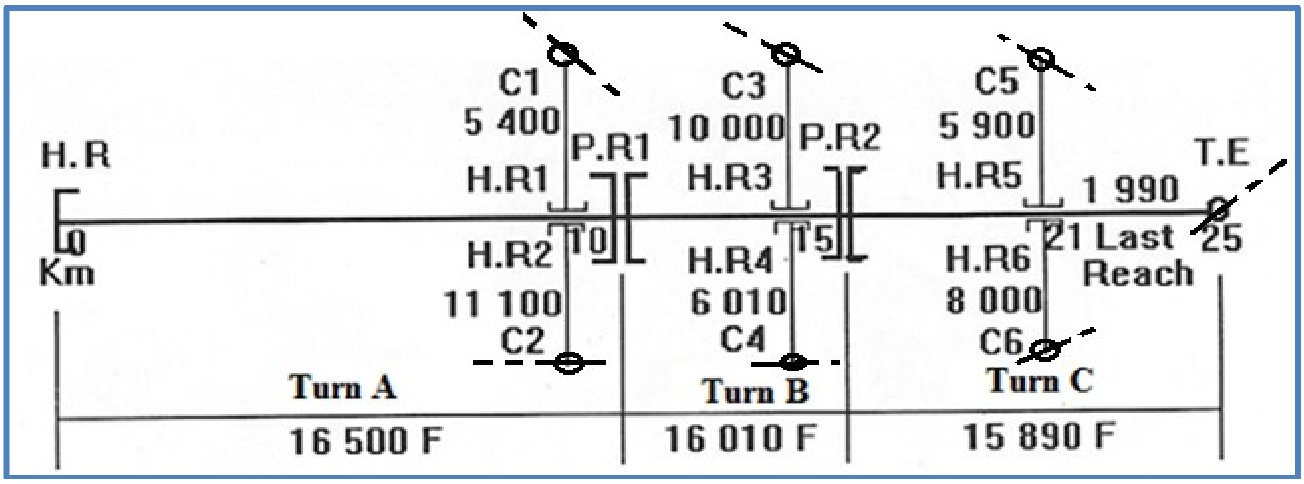
2) Three-turn irrigation rotation:

Average required area served for each turn = 48,400 / 3 = 16,133.3 Fed

∴ For the first turn, take group A = C1 + C2 = 16,500 Fed

& For the second turn, take group B = C3 + C4 = 16,010 Fed

& For the third turn, take group C = C5 + C6 + L.R. = 15,890 Fed



1-11 Water Duty and the Discharge:

The water duty is defined as the quantity of water applied to the field. It depends mainly on the kind of crop, where each crop requires a specific quantity of water for its growth and it must be irrigated each specific period.

- Each one feddan cultivated by rice requires a quantity of water of 420 m^3/ Fed/irrigation, and it must be irrigated every 8 days.

- For cotton, summer crops (such as maize), and wheat; the required quantity of water is 350 m^3/Fed/irrigation, and the period between irrigation processes has not to exceed 18 days.

- For fallow irrigation or sharaki (preparing the land for cultivating maize), the required quantity of water is 760 m^3/Fed/one irrigation, and the sharaki ends within about 36 days.

So, in the case of rice, a two-turn irrigation rotation (4 and 4 days) must be followed. While in the case of cotton, a three-turn irrigation rotation (6 and 12 days) can be followed.

The water duty is first calculated for the field (F.W.D.) according to the kinds of cultivated crops. Then, the water duty for the different grades of canals can be calculated as discussed previously.

Consequently, the discharge (Q) passing through the canals can be determined *using the following relation:*

Q = W.D. x Area Served

Where, Q: The discharge. & W.D.: The water duty.

Example (1-9):

A diversion canal serves an area of 20 km x 21 km and by two main canals A and B. The main canal A serves 60 % of the total area, and its area served is cultivated *as follows:* 40 % cotton, 50 % sharaki (prepared for cultivating maize), and the rest 10 % are used for public services.

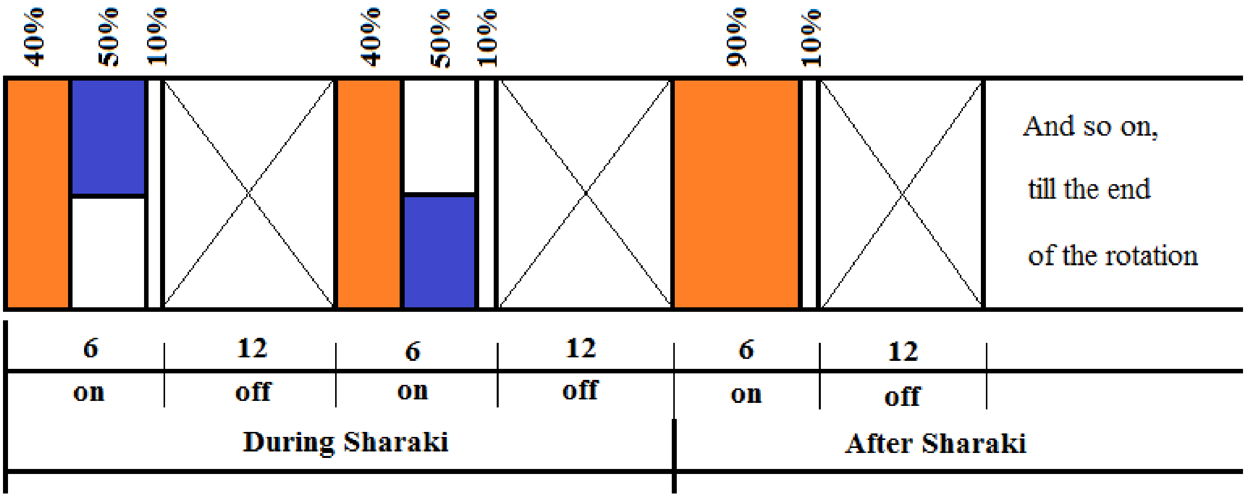
The main canal B serves 40 % of the total area, and its area served is cultivated *as follows:* 25 % rice, 30 % cotton, 35 % sharaki (prepared for cultivating maize), and the rest 10 % are used for public services.

1) Suggest suitable irrigation rotations for the two main canals A and B?
2) Sketch a diagram for each main canal showing the details of performing the irrigation rotation?
3) Determine the maximum and the minimum discharges passing in the diversion canal?

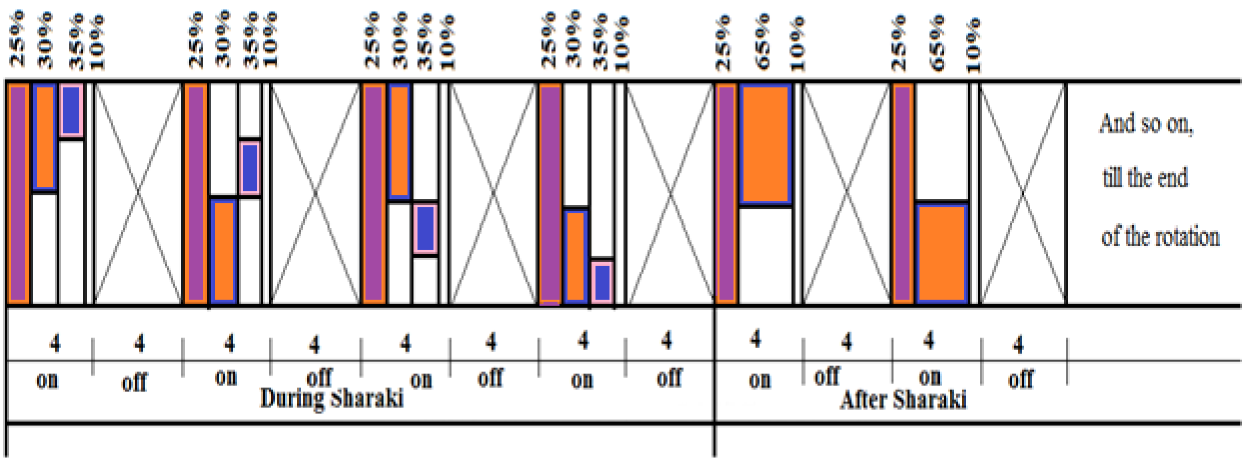
Solution

1) For the main canal A, use a three-turn irrigation rotation (6 and 12 days).
For the main canal B, use a two-turn irrigation rotation (4 and 4 days).

2) **For the main canal A:**



For the main canal B:



3) The total area served = $(20 * 21 * 10^6) / 4200 = 100,000$ Fed

$\therefore$ The area served for M.C.$_A$ = (60 / 100) x 100,000 = 60,000 Fed

& The area served for M.C.$_B$ = 40,000 Fed

For the main canal A:

F.W.D. $_{DSh}$ = {(40/100) * (350/6)} + {(50/100) * (760/6) * (1/2)} = 55 m^3/Fed/day

F.W.D. $_{Ash}$ = {(90/100) * (350/6)} = 52.5 m^3/Fed/day

Max M.C.W.D.$_A$ = 55 * 1.2 = 66 m^3/Fed/day

Min M.C.W.D.$_A$ = 52.5 * 1.2 = 63 m^3/Fed/day

Assume the main canal A distributes the irrigation water into 3 equal areas.

Q_{Amax} = 66 * (60,000 / 3) = 1,320,000 m^3/day

$\therefore Q_{Amax}$ = 1,320,000 / (24 * 60 * 60) = 15.28 m^3/sec

Q_{Amin} = 63 * (60,000 / 3) = 1,260,000 m^3/day

$\therefore Q_{Amin}$ = 1,260,000 / (24 * 60 * 60) = 14.58 m^3/sec

For the main canal B:

F.W.D.$_{DSh}$ = {(25/100) * (420/4)} + {(30/100) * (350/4) * (1/2)}
+ {(35/100) * (760/4) * (1/4)}
= 56 m^3/Fed/day

F.W.D.$_{Ash}$ ={(25/100) * (420/4)}+{(65/100) * (350/4) * (1/2)}
= 54.7 m^3/Fed/day

Max M.C.W.D.$_B$ = 56 * 1.2 = 67.2 m^3/Fed/day

Min M.C.W.D.$_B$ = 54.7 * 1.2 = 65.3 m^3/Fed/day

Assume the main canal B distributes the irrigation water into 2 equal areas.

Q_{Bmax} = 67.2 * (40,000 / 2) = 1,344,000 m^3/day
= 1,344,000 / (24 * 60 * 60) = 15.56 m^3/sec

Q_{Bmin} = 65.3 * (40,000 / 2) = 1,306,000 m^3/day

$= 1,306,000 / (24 * 60 * 60) = 15.12\ m^3/sec$

For the diversion canal:

$Q_{max} = Q_{Amax} + Q_{Bmax} = 15.28 + 15.56 = 30.84\ m^3/sec$

$Q_{min} = Q_{Amin} + Q_{Bmin} = 14.58 + 15.12 = 29.70\ m^3/sec$

1-12 Drainage Factor:

The drainage factor (D.F.) can be defined as the quantity of excess water that has to be disposed of to maintain the air-water balance in the root zone of the plant.

The drainage factor may be a ratio of the field water duty.

It can be assumed to be:

50 % of the field water duty for Lower Egypt,
40 % of the field water duty for Middle Egypt,
30 % of the field water duty for Upper Egypt.

The discharge (Q) passing through the drains can be determined *using the following relation:*

Q = D.F. x Area Served

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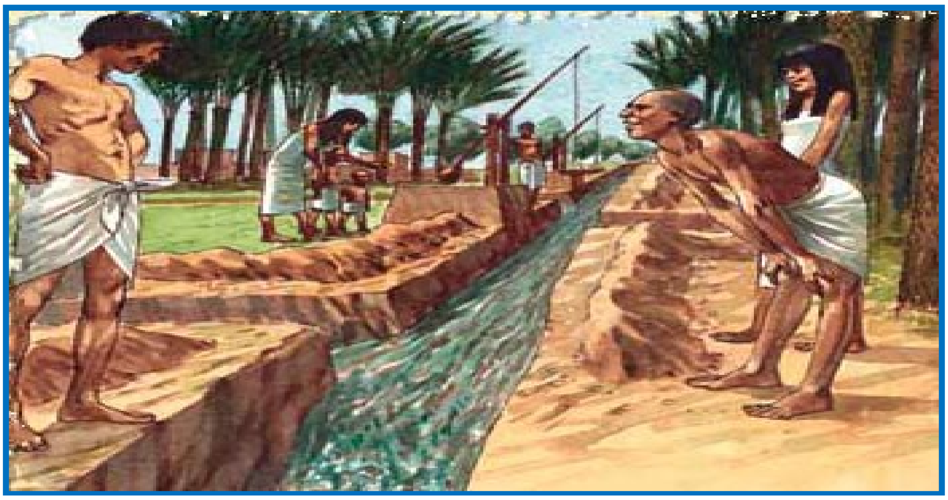
Chapter 2

Planning and Design of Irrigation and Drainage Networks



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Chapter 2

Planning and Design of Irrigation and Drainage Networks

2-1 Irrigation Networks:

Water for irrigation is supplied to the field from the main source through different grades of canals, which form an irrigation network. The various grades of canals are ranked in descending order *as follows:*

1. Diversion canal.
2. Main canal.
3. Branch canal.
4. Distributor canal.

Table (2-1) illustrates the average water slope, the area served, and the length for the different grades of canals.

Table (2-1): Grades of Canals

Grade of Canal	Water Slope (i), cm/km	Area Served, Feddans	Length, km
Diversion	3 - 5	> 200,000	> 50
Main	5 - 8	200,000 – 20,000	50 - 15
Branch	8 - 15	20,000 – 10,000	15 -10
Distributor	10 - 25	< 10,000	< 10

For planning an irrigation network, it has to be noted that any canal is represented by a continuous line. This line has the symbol (H.R.) at its beginning represents a head regulator (H.R.) necessary for distributing the water. Also, each canal has to end at a suitable drain (a dashed line) through a tail escape (T.E.) with the symbol (T.E.). That is to dispose safely of any excess water from the canal into the drain.

2-2 Drainage Networks:

Excess water is drained from the field to the location at which it is to be disposed of through different grades of drains, which form a drainage network. The various grades of canals are ranked in ascending order *as follows:*

1. Minor drain.
2. Branch drain.
3. Main drain.
4. District drain.

Table (2-2) illustrates the water slope, the area served, and the length for the different grades of drains.

Table (2-2): Grades of Drains

Grade of Drain	Water Slope (i), cm/km	Area Served, Feddans	Length, km
Minor	15 - 30	< 10,000	< 10
Branch	10 - 15	10,000 – 20,000	10 - 15
Main	7 - 10	20,000 – 200,000	15 - 50
District	3 - 5	> 200,000	> 50

For planning a drainage network, it has to be noted that any drain is represented by a dashed line. Each dashed line representing a drain has to deliver its water to another suitable drain with the symbol (- - →). Conveying water continues till the district drain disposes the water to a river, a lake, or the sea through its outfall.
However, Figure (2-1) shows planning for irrigation and drainage networks.

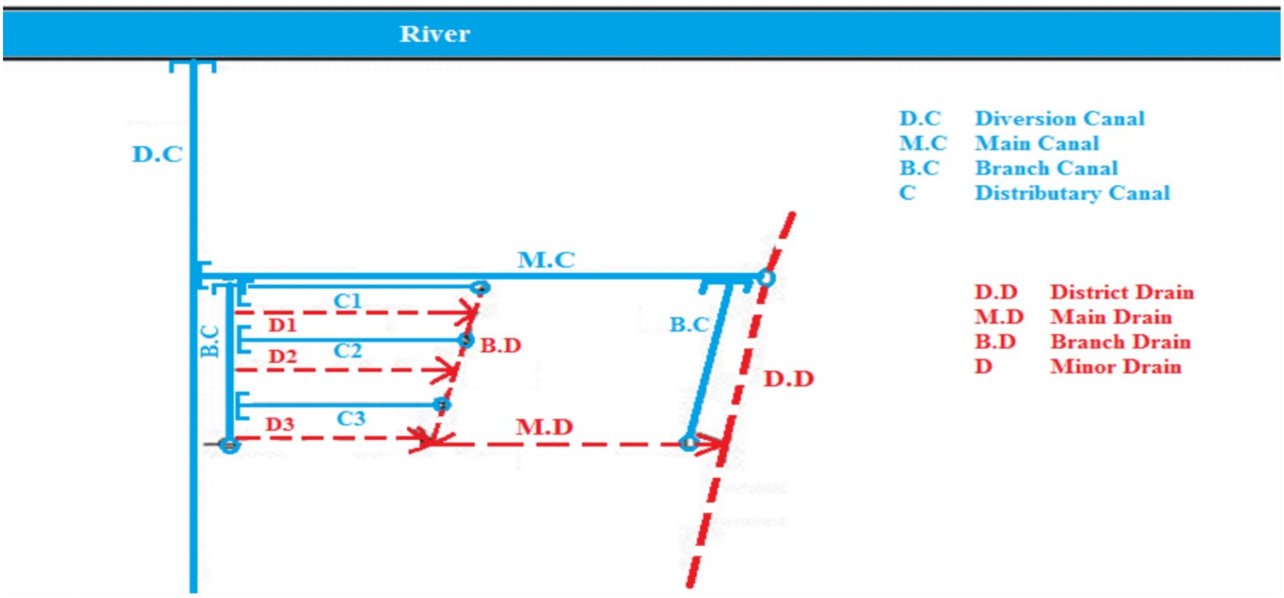


Figure (2-1): Irrigation and Drainage Networks

The main source of water in Egypt is the Nile River, which is one of the largest rivers in the world with a length of approximately 6,700 km, its basin area is about 3 million km^2, and it is shared by 10 countries, as shown in Figure (2-2).

Figure (2-2): Nile River Basin

Ministry of Water Resources and Irrigation, 2005. "National Water Resources Plan for Egypt – 2017".

The major control structures on the Nile River in Egypt are shown in Figure (2-3), while irrigation canals and drains in the Delta of Egypt are shown in Figures (2-4) and (2-5).

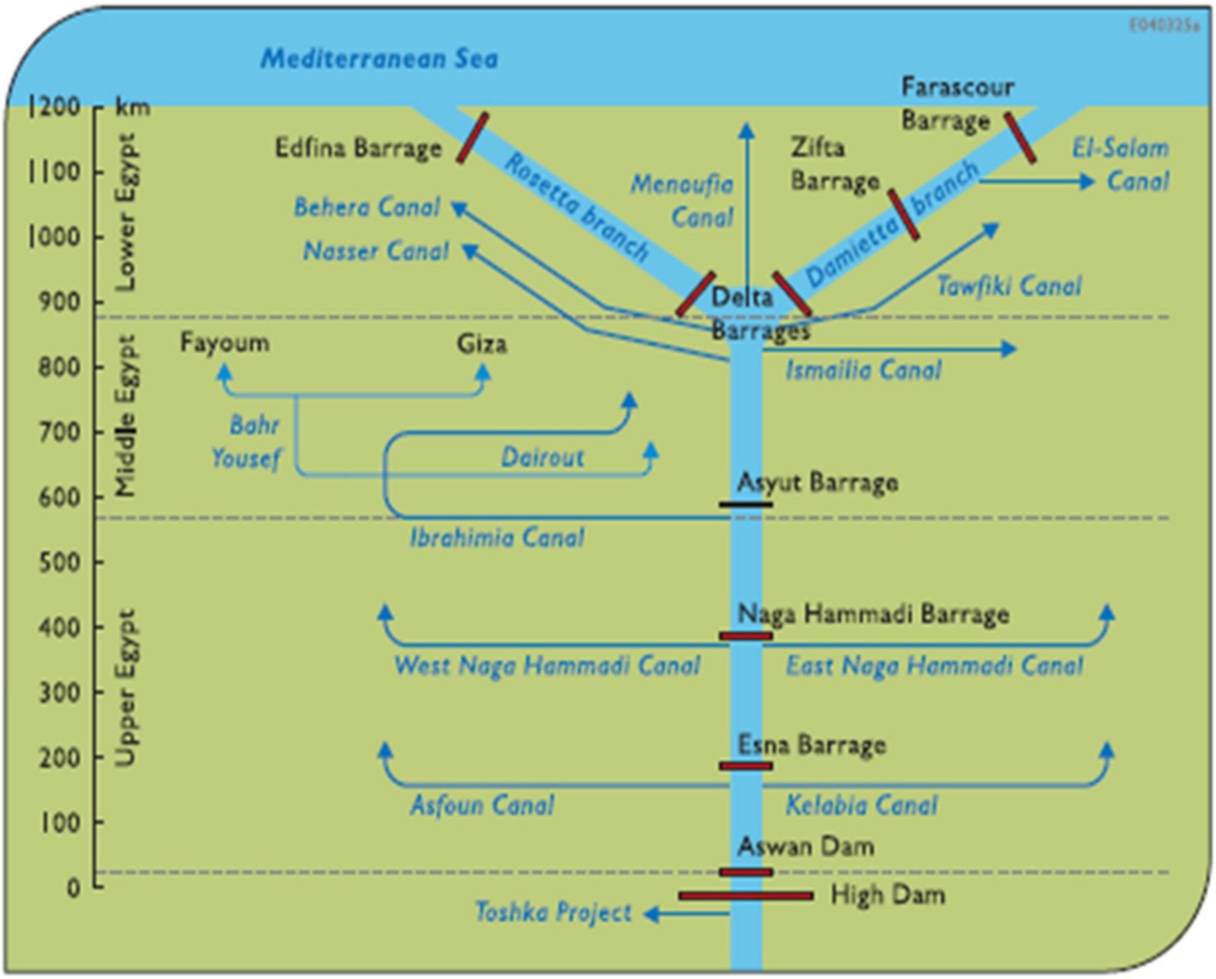


Figure (2-3): Major Control Structures on the Nile River in Egypt

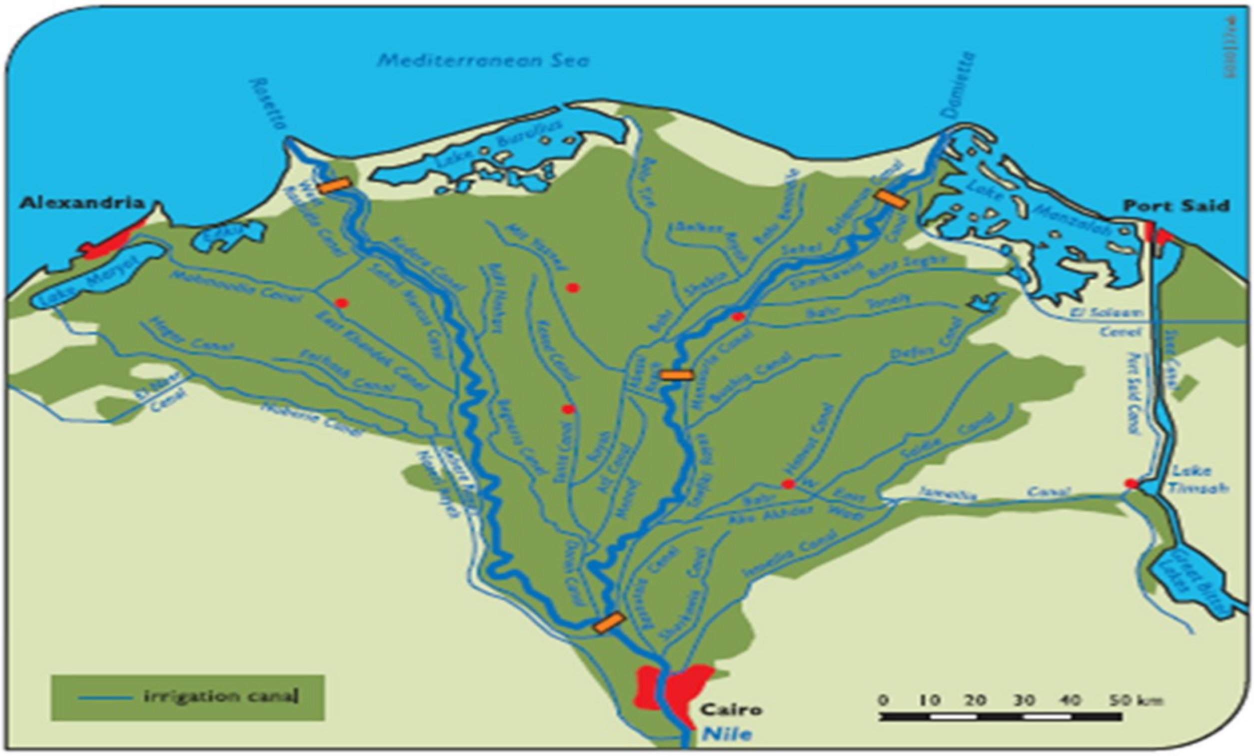


Figure (2-4): Irrigation Canals in the Delta, Egypt

Figure (2-5): Drains in the Delta, Egypt

2-3 <u>Planning of Irrigation and Drainage Networks:</u>

In general, each canal has to cover all the area served required to be irrigated with the shortest possible length. The irrigation canals are preferred to be planned at the high locations such that the water is over the area served. That is to enable water to reach the cultivated land by gravity.

On the other side, each drain has to cover all the area served required to be drained with the shortest possible length. The drains are preferred to be planned at the low locations such that the excess water is disposed of from the cultivated land by gravity.

However, the planning of both the irrigation and the drainage networks depends on the topography of the ground surface. This topography is illustrated by the contour maps, on which the planning is done.

There are two main types of the topography of the ground surface as follows:

1) Corrugated Topography:

As possible as the engineer can, the canals are planned to run on ridges; while the drains are planned to run in depressions. If some canals or drains will not follow this condition, priority is given to the channels of the longest path. Ridges for canals and depressions for drains are shown in Figure (2-6).

Figure (2-7) shows planning for the irrigation and drainage networks in the case of corrugated topography.

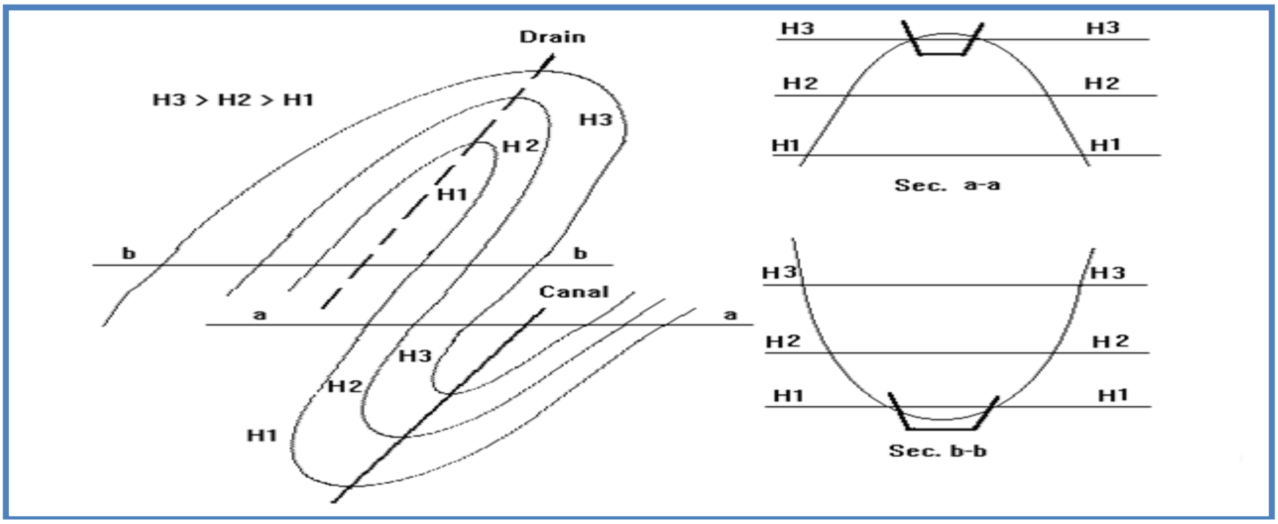


Figure (2-6): Ridges for Canals and Depressions for Drains

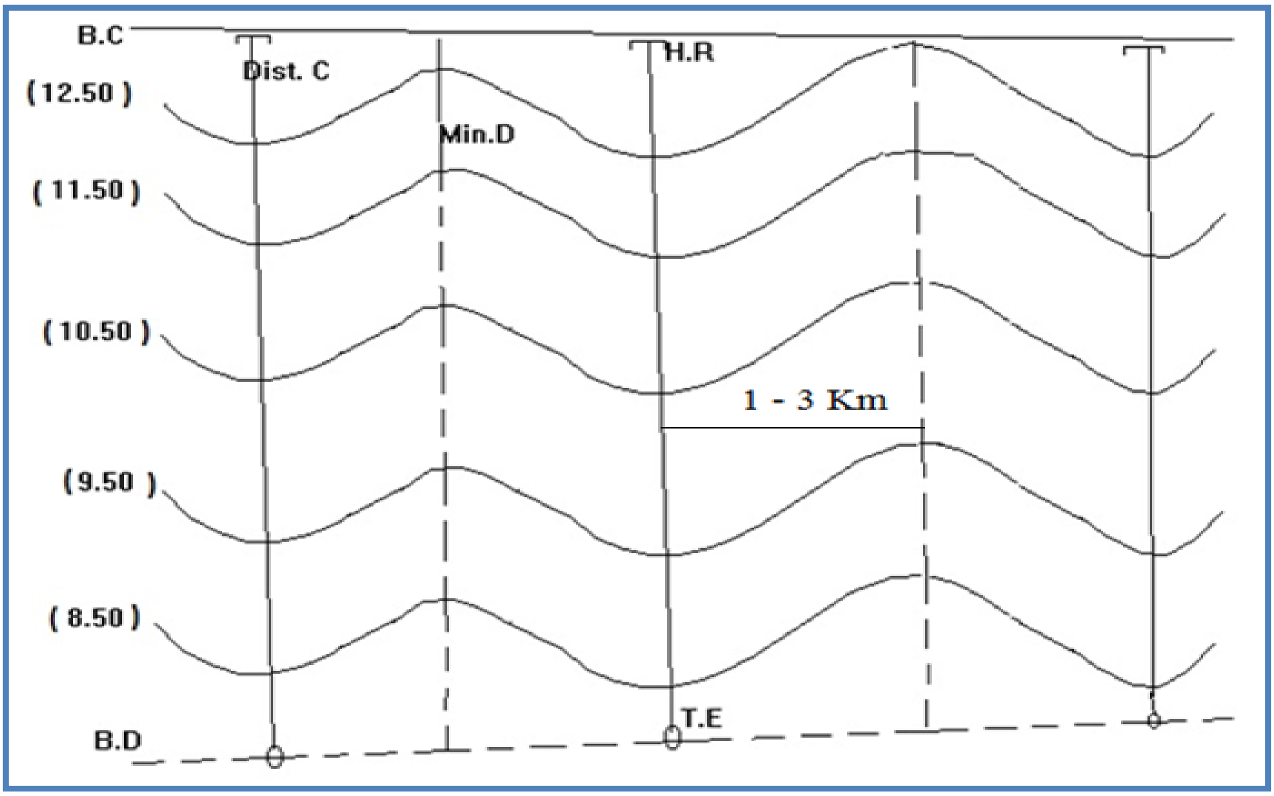


Figure (2-7): Planning for Corrugated Topography

2) Sloping Topography:

When the contour lines are parallel, this is the case that the land is sloping in one direction. The planning of the irrigation and drainage networks depends on the magnitude of the ground slope (S) *as follows:*

a) Flat Slope ($S \leq 7$ cm/km)

Both the canals and the drains are planned almost perpendicular to the contour lines. Each canal or drain serves the two sides along with it, as shown in Figure (2-8 /a).

b) Medium Slope ($7 \leq S \leq 20$ cm/km)

Both the canals and the drains are planned inclined to the contour lines. Each canal or drain serves only one side along with it, as shown in Figure (2-8 /b).

c) Steep Slope ($S \geq 20$ cm/km)

Both the canals and the drains are planned almost parallel to the contour lines. Each canal or drain serves only one side along with it, as shown in Figure (2-8 /c).

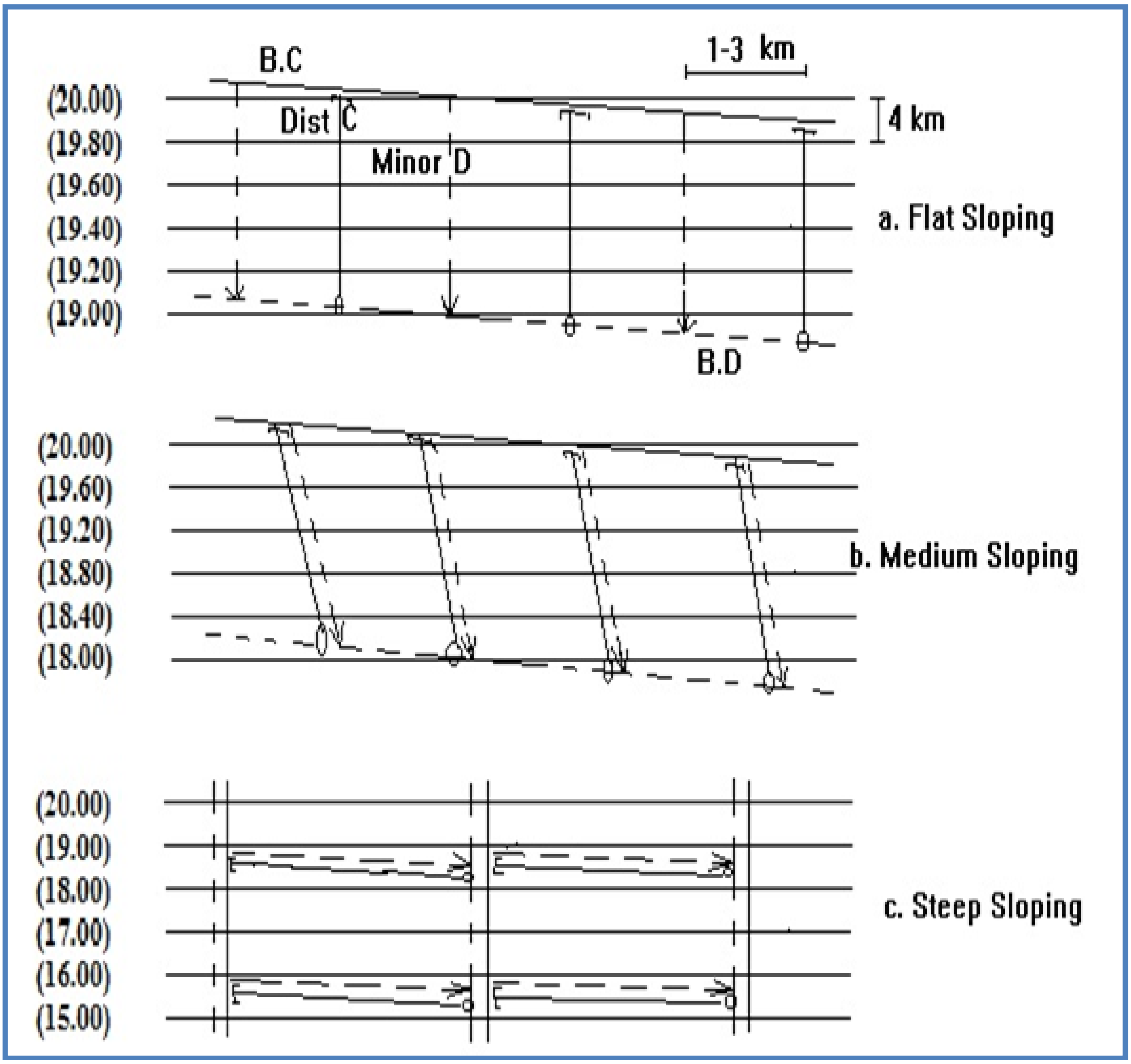


Figure (2-8): Planning for Sloping Topography

Note: ***Correct planning has to:***

1) Follow the planning rules concerning the contour map.
2) Serve all the areas for both irrigation and drainage.
3) Have a service distance not more than 3 km for irrigation and drainage.
4) Maintain general rules for both irrigation and drainage processes.

Exercise (2-1):

Check the planning for the irrigation and drainage networks required to serve the illustrated area in figure (2-9)?

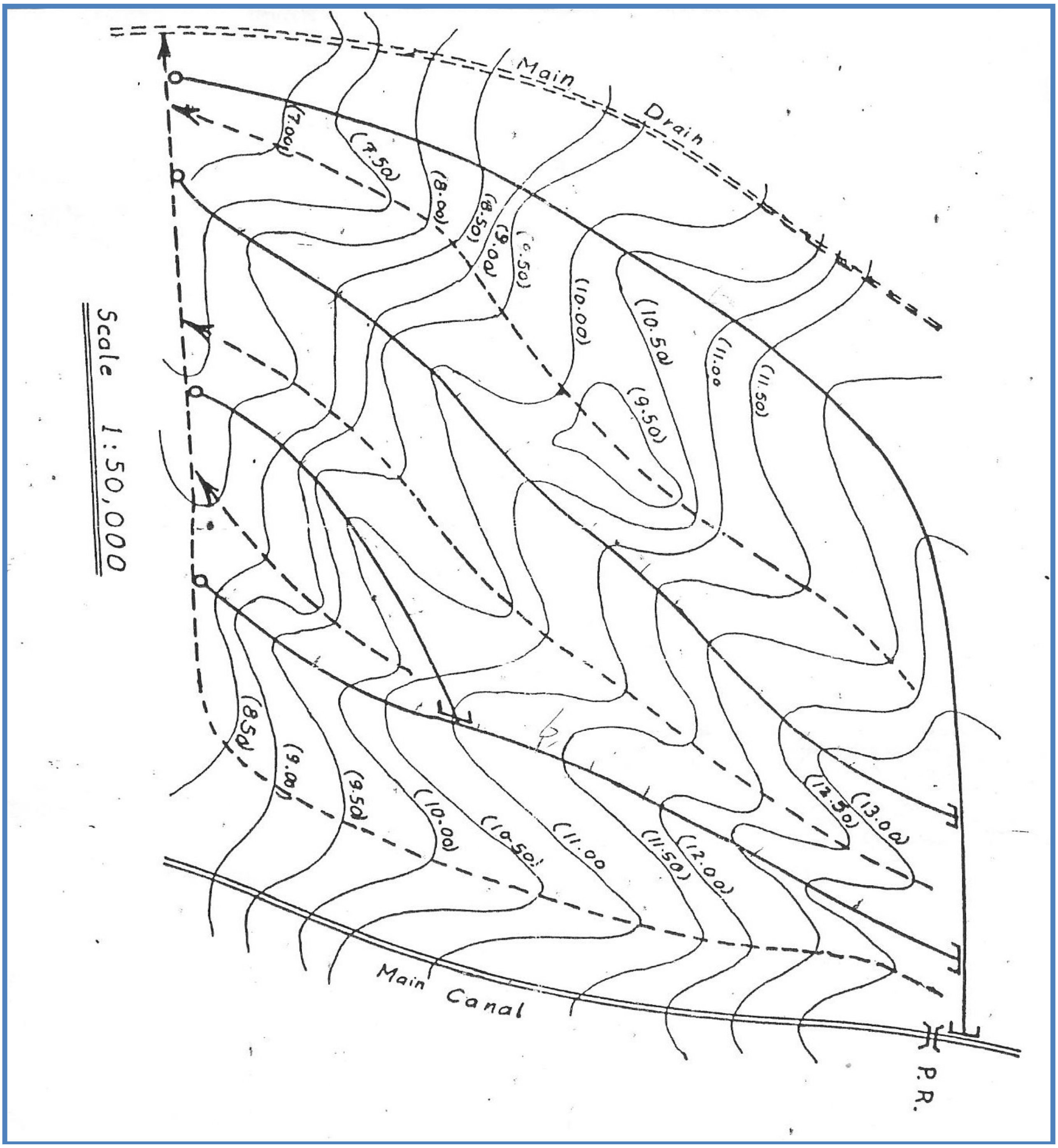


Figure (2-9): Contour Map for Exercise 2-1

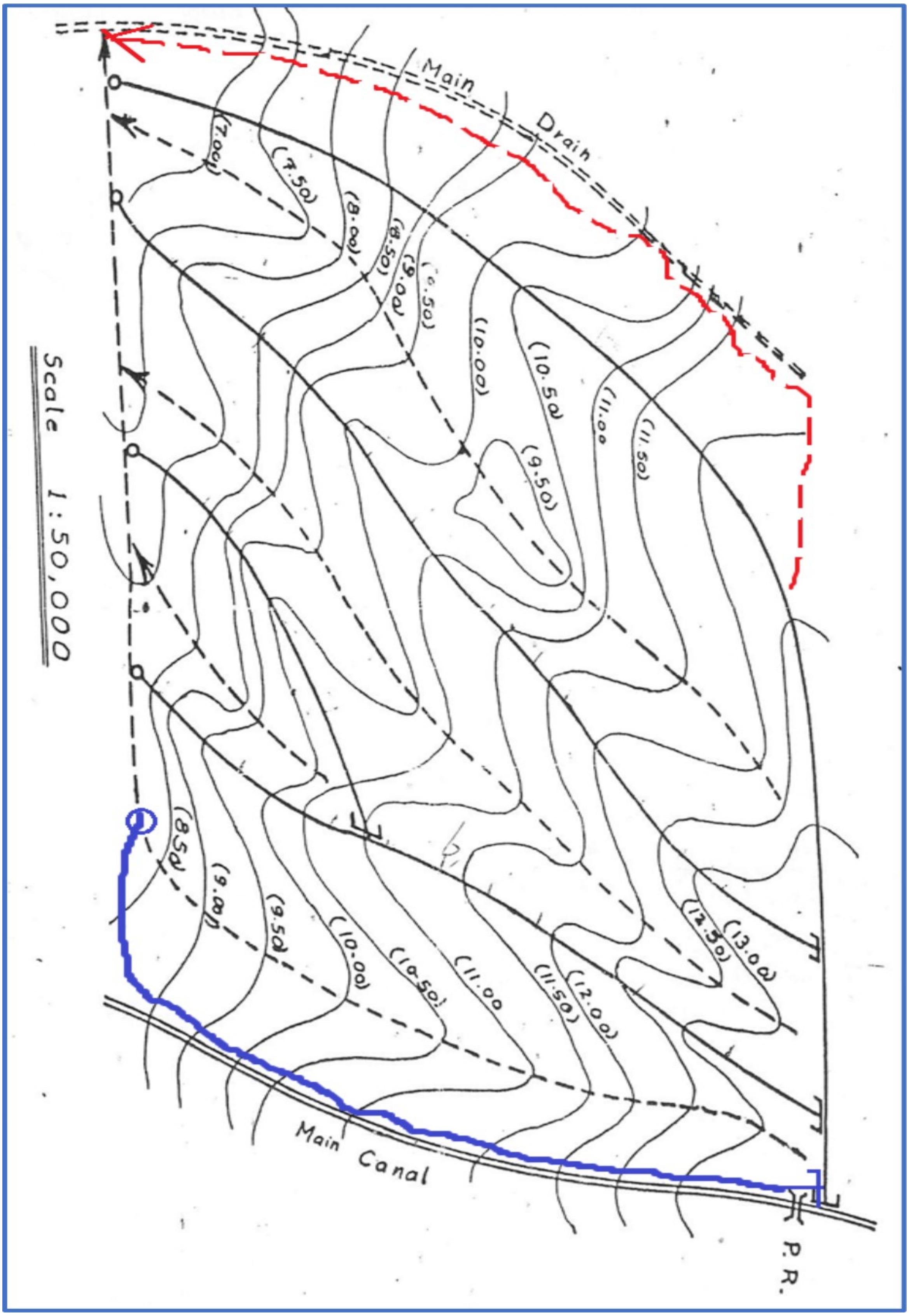


Figure (2-10): A Solution for Exercise 2-1

Exercise (2-2):

An area of 7,500 feddan is sloping from the north to the south, as shown in Figure (2-11). This area is bounded by the main canal at the north at the contour (10.00), a main drain at the south at the contour (8.50), and two roads at both the east and the west.

1) Sketch a plan for the irrigation and drainage networks to serve this area?
2) Determine the horizontal distance (x) between the two roads if the vertical distance between the main canal and the main drain (y) is 6 km?

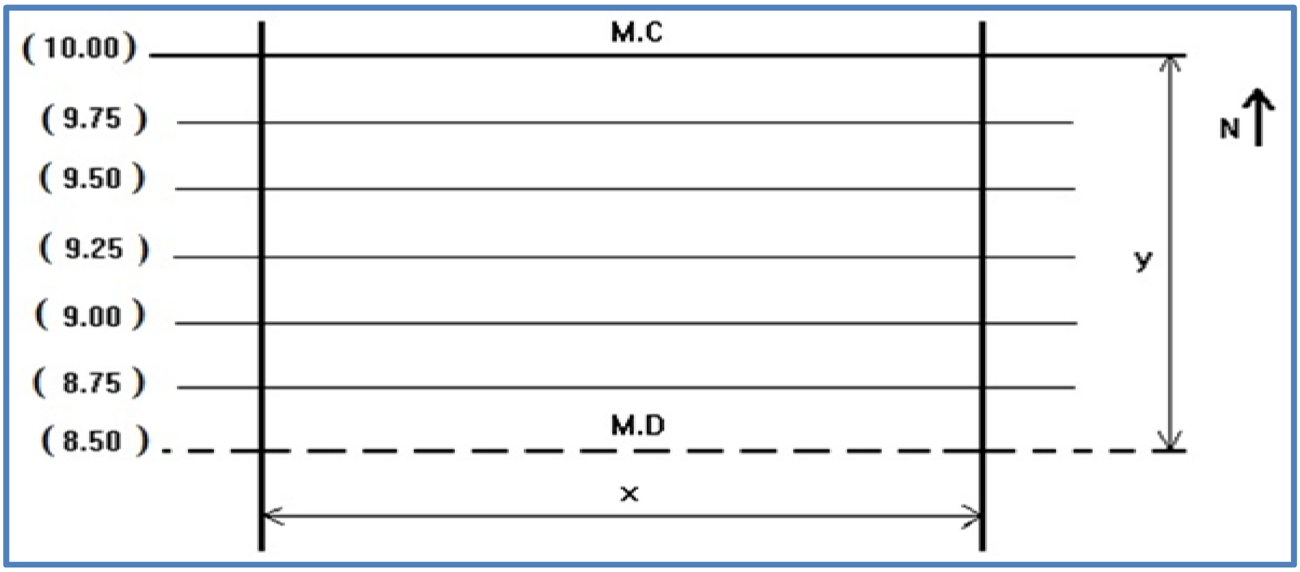


Figure (2-11): Contour Map for Exercise 2-2

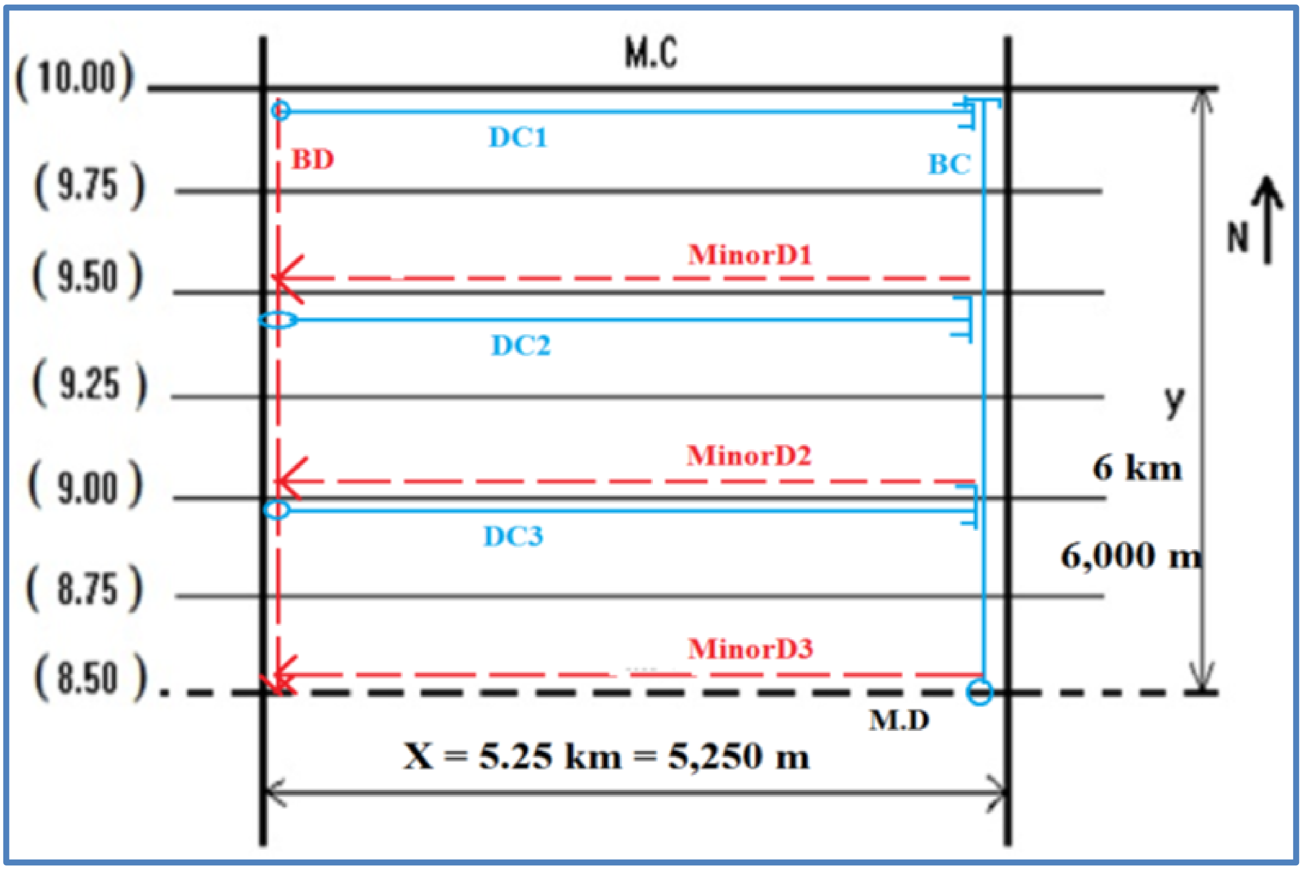


Figure (2-12): A Solution for Exercise 2-2

2-4 Synoptic Diagram:

The synoptic diagram is a complete longitudinal section for either the irrigation or the drainage networks on one drawing sheet. It includes only two lines; one line represents the average land levels, while the other line represents the waterline. These two lines are tabulated and drawn with a suitable vertical scale. Also, the length in kilometers of the channel is tabulated and drawn with a suitable horizontal scale.

2-4-1 Synoptic Diagram for Irrigation Networks:

The synoptic diagram for the canals is constructed in an ascending order, where the distributor canals are executed first. The zero kilometer of the canal is at its head regulator.

The following steps summarize the procedure used for drawing the synoptic diagram for the canals:

a) The branch canal and its distributor canals:

1. Complete longitudinal sections for the branch canal and its distributor canals, according to the planned irrigation network on the contour map, are drawn on one drawing sheet, as shown in Figure (2-13).

2. The line representing the land levels (L.L.) is drawn for each canal according to the contour map, as shown in Figure (2-14).

3. The water lines (W.L.) for the distributor canals are drawn according to the type of irrigation system.
   For free irrigation, water levels have to be 25 cm above the average land level.
   For lift irrigation, water levels have to be 50 cm below the average land level.
   The slope of the waterline (i) depends on the ground slope (S) as illustrated in Table (2-1) previously.

The water lines for the two irrigation systems are shown in Figure (2-15, A and B). Figures (2-16) and (2-17) illustrate the water lines for the distributor canals according to the ground slope for both free and lift irrigation respectively.

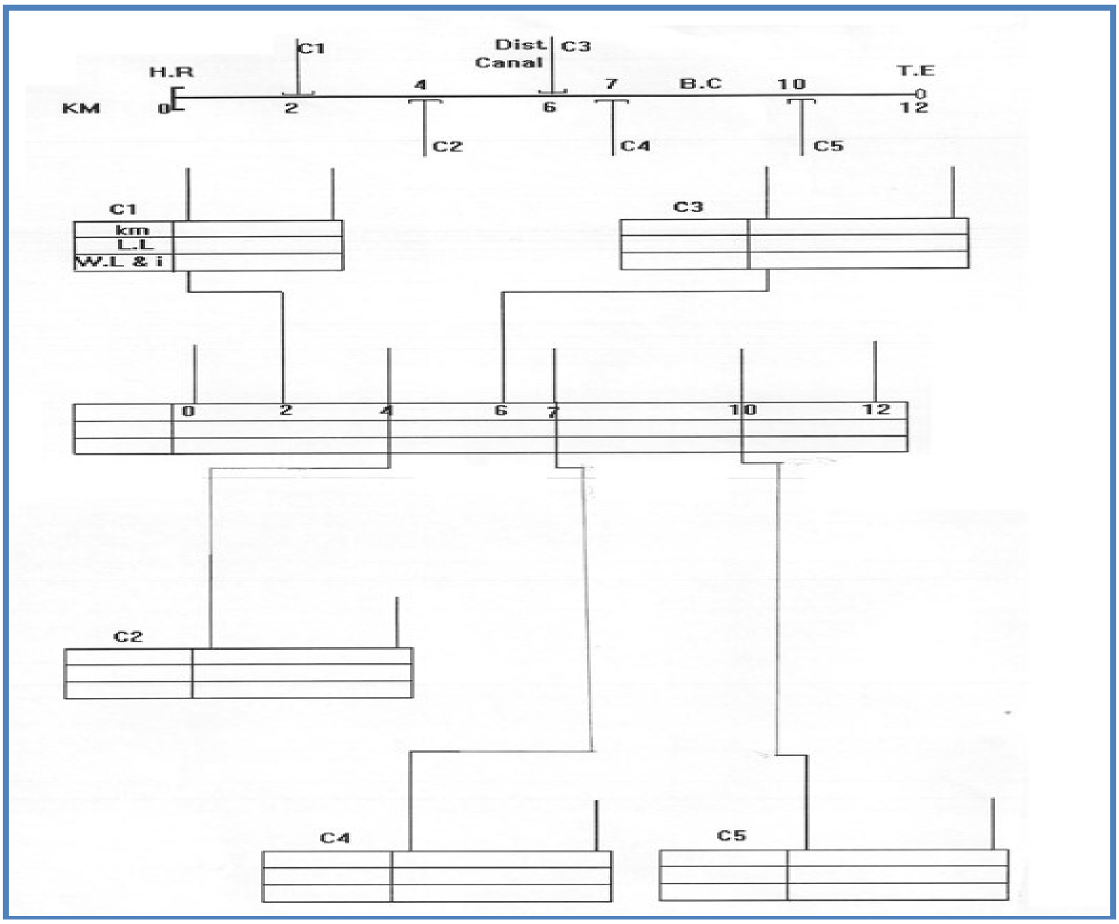


Figure (2-13): Longitudinal Section for Branch Canal and its Distributor Canals

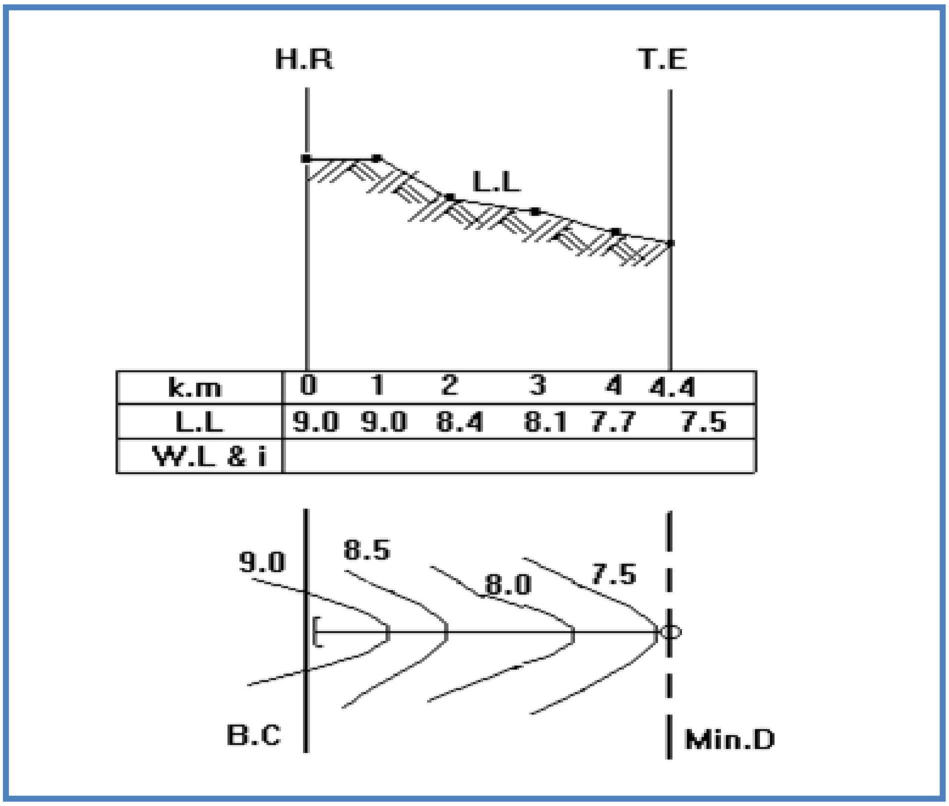


Figure (2-14): Land Levels for Canals

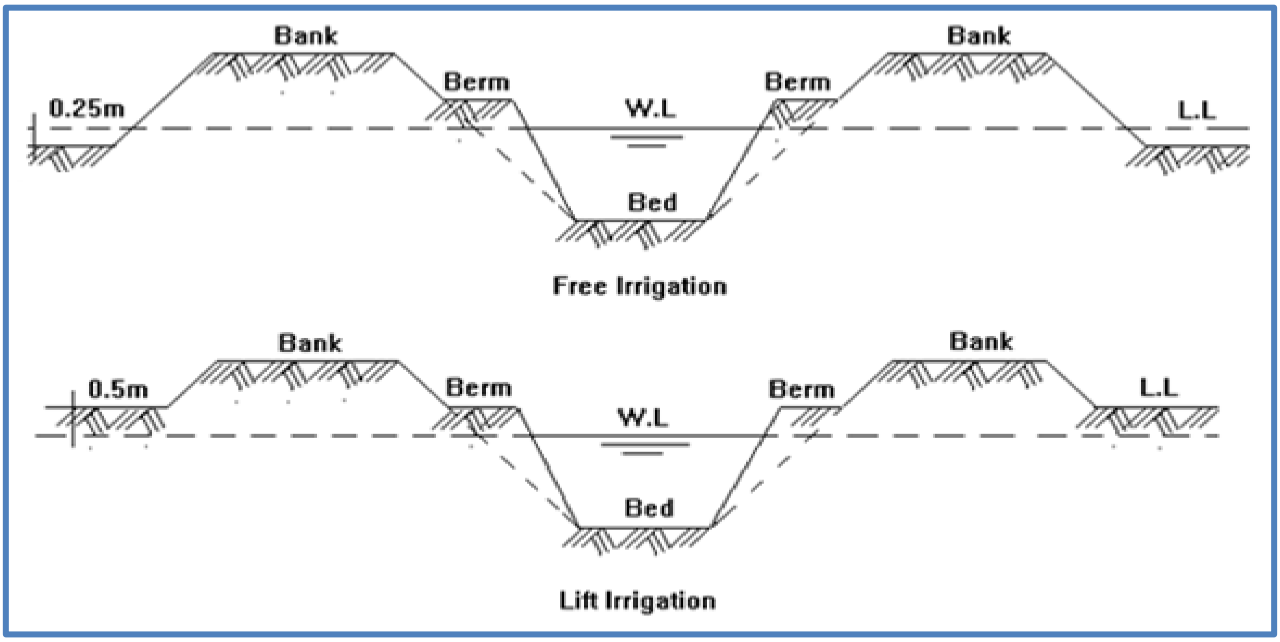


Figure (2-15): Water Line for the Irrigation Systems

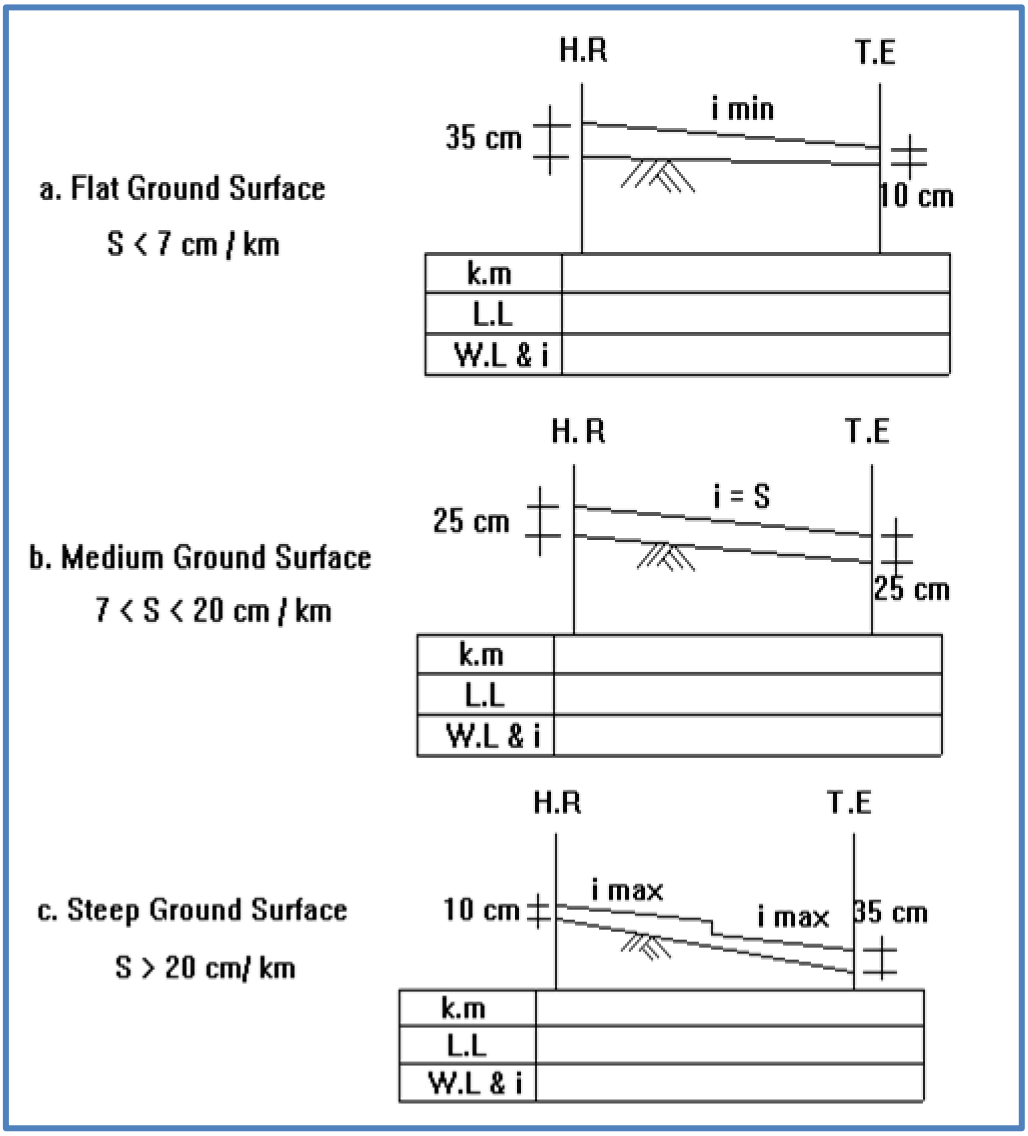


Figure (2-16): Water Line for the Distributor Canals for Free Irrigation

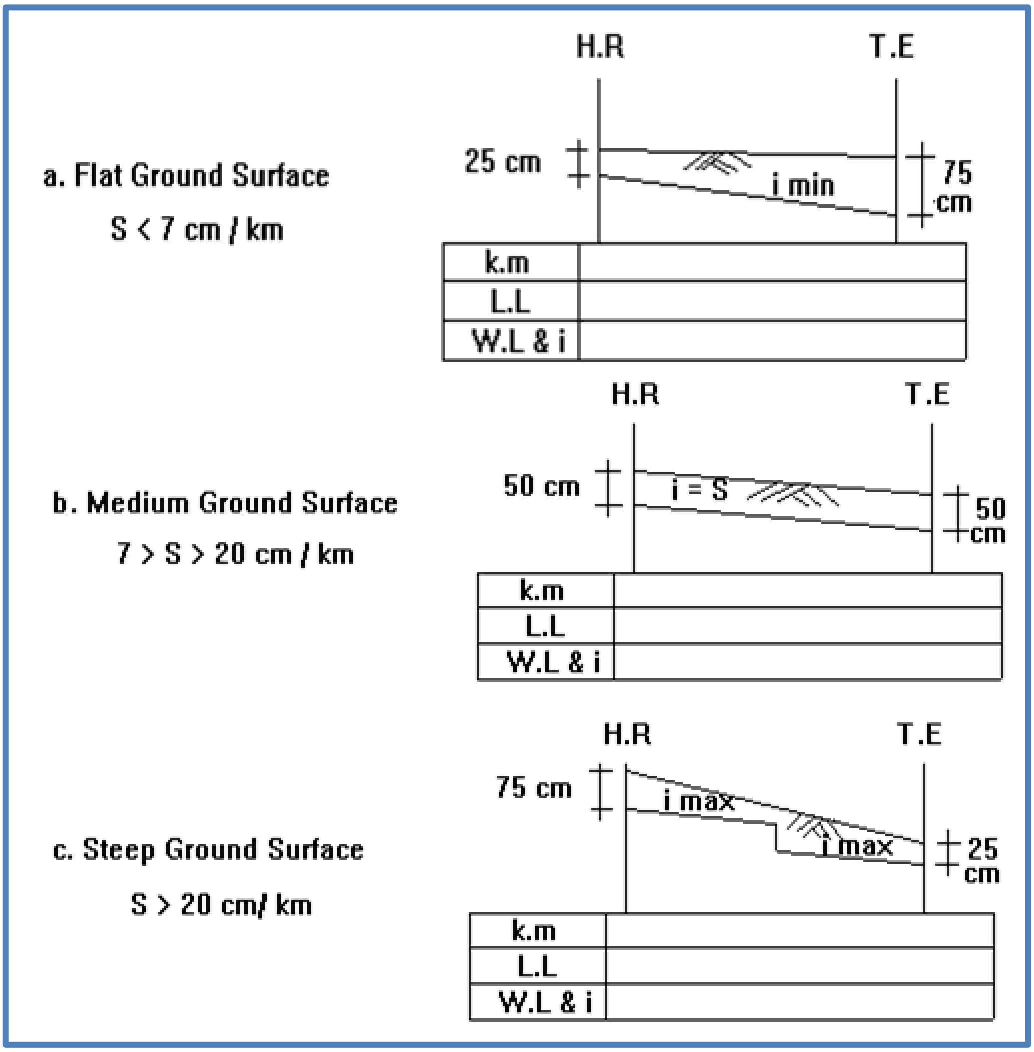


Figure (2-17): Water Line for the Distributor Canals for Lift Irrigation

4. The water levels at the intakes of the distributor canals are determined.

5. Then, the water levels upstream of each head regulator of every distributor canal are detected such that the head on each regulator ranges between 5 - 10 cm.

6. The water levels got from the previous step are transmitted and marked along the branch canal, according to the location of each distributor canal.

7. The water line for the branch canal is then determined and is drawn with a suitable scale, as shown in Figure (2-18).

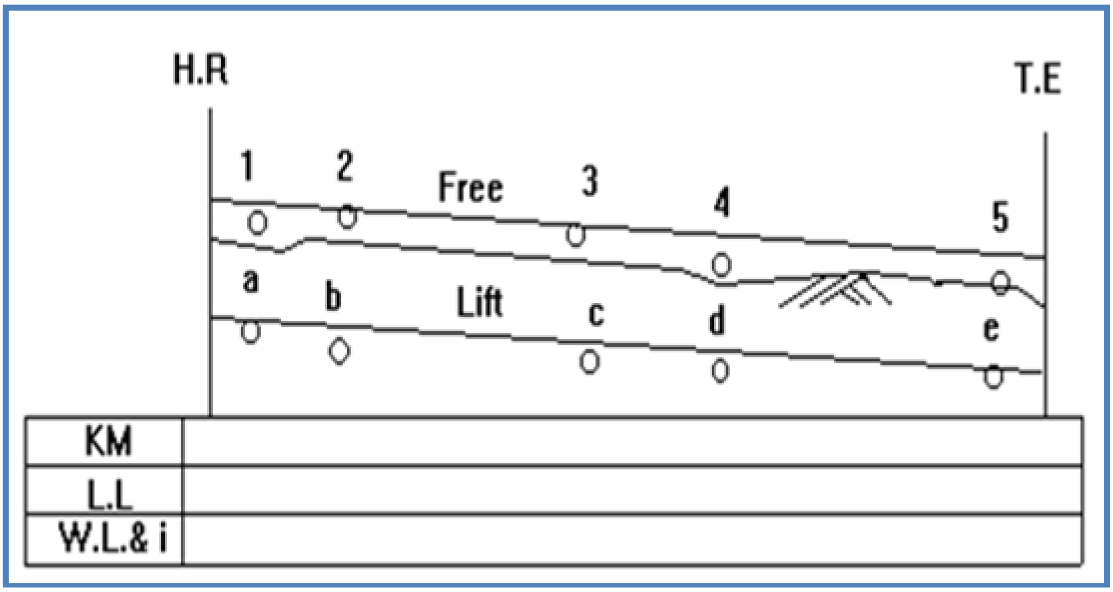


Figure (2-18): Water Lines for Branch Canals

b) The main canal and its branch canals:

Similarly, the water levels for the branch canals downstream their head regulators (their intakes) are determined. These levels have to be below the water levels of the main canal to avoid lifting water by pump stations.

c) The diversion canal and its main canals:

Following the same sequence, the water levels for the main canals downstream their head regulators (their intakes) are determined. These levels have to be below the water levels of the diversion canal; otherwise, pump stations have to be constructed to lift the water for the main canals.

♦ **General Remarks:**

1. The water levels at the end of all canals have to be determined. That is because each canal has to be connected to a suitable drain with a tail escape to control the water level in the canal (by disposing of any excess water from the canal).

2. The last reach of either the branch or the main canal is treated as a distributor canal when direct irrigation is allowed from this reach.

3. The slope of the water line can be increased in the flow direction at distances of 3 - 4 km if needed, as shown in Figure (2-19). It is preferred to change the slope of the water line at the constructions that exist along the canal.

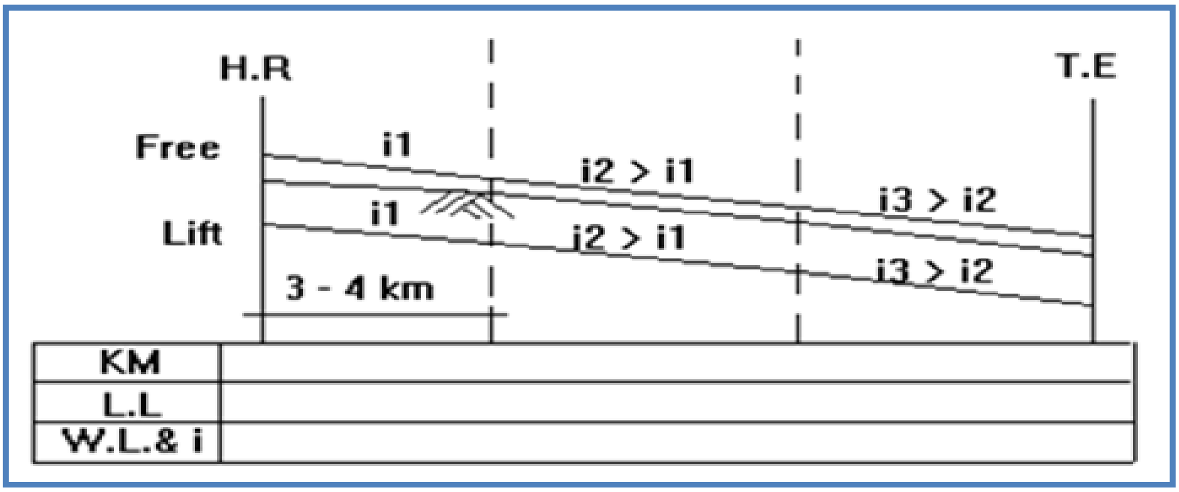


Figure (2-19): Changing the Slope of Water Lines for Canals

4. The height of the water required for the two types of irrigation systems is allowed to be decreased or increased in limited zones to use a constant slope for the water line for the distributor canals, as shown in Figure (2-20).

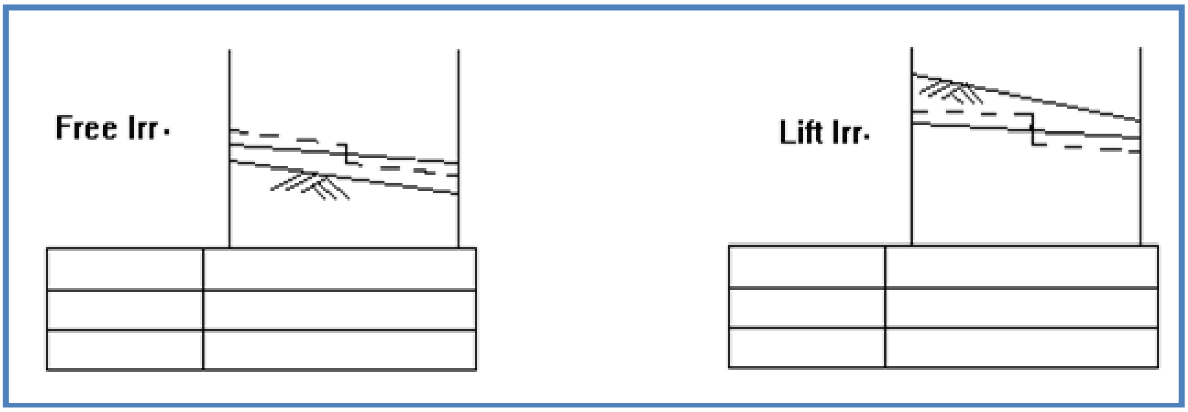


Figure (2-20): Allowable Heights for Irrigation Systems for Distributor Canals

5. It is allowed to change the followed type of irrigation system in limited zones to use a constant slope for the water line for the distributor canals, as shown in Figure (2-21).

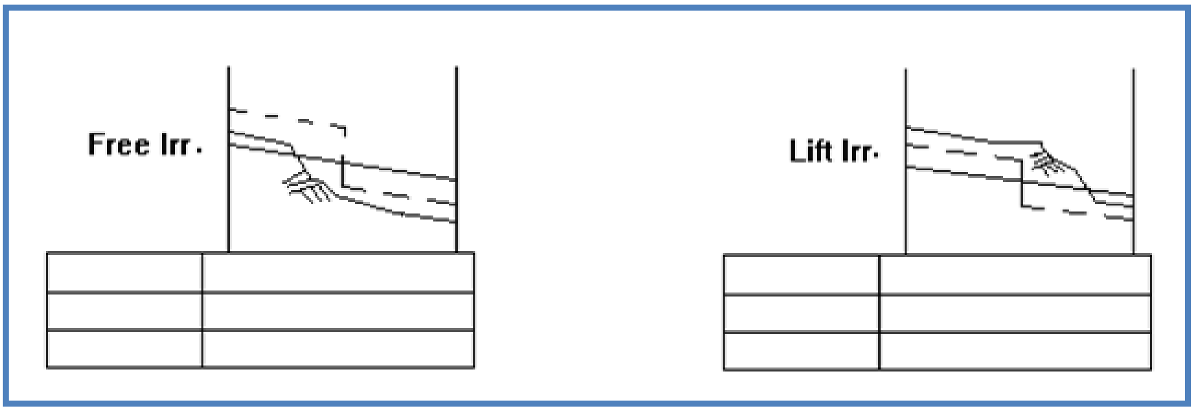


Figure (2-21): Allowable Changing for Irrigation Systems for Distributor Canals

6. The problem of drops in the water line for canals, if arises, can be solved, as shown in Figure (2-22), *as follows:*

   a) If the drop in the water line is less than 50 cm, a standing wave weir is used.

   b) If the drop in the water line is in the range of 50 - 150 cm, a clear overfall weir can be used.

   c) If the drop in the water line is greater than 150 cm, a regulator is to be used.

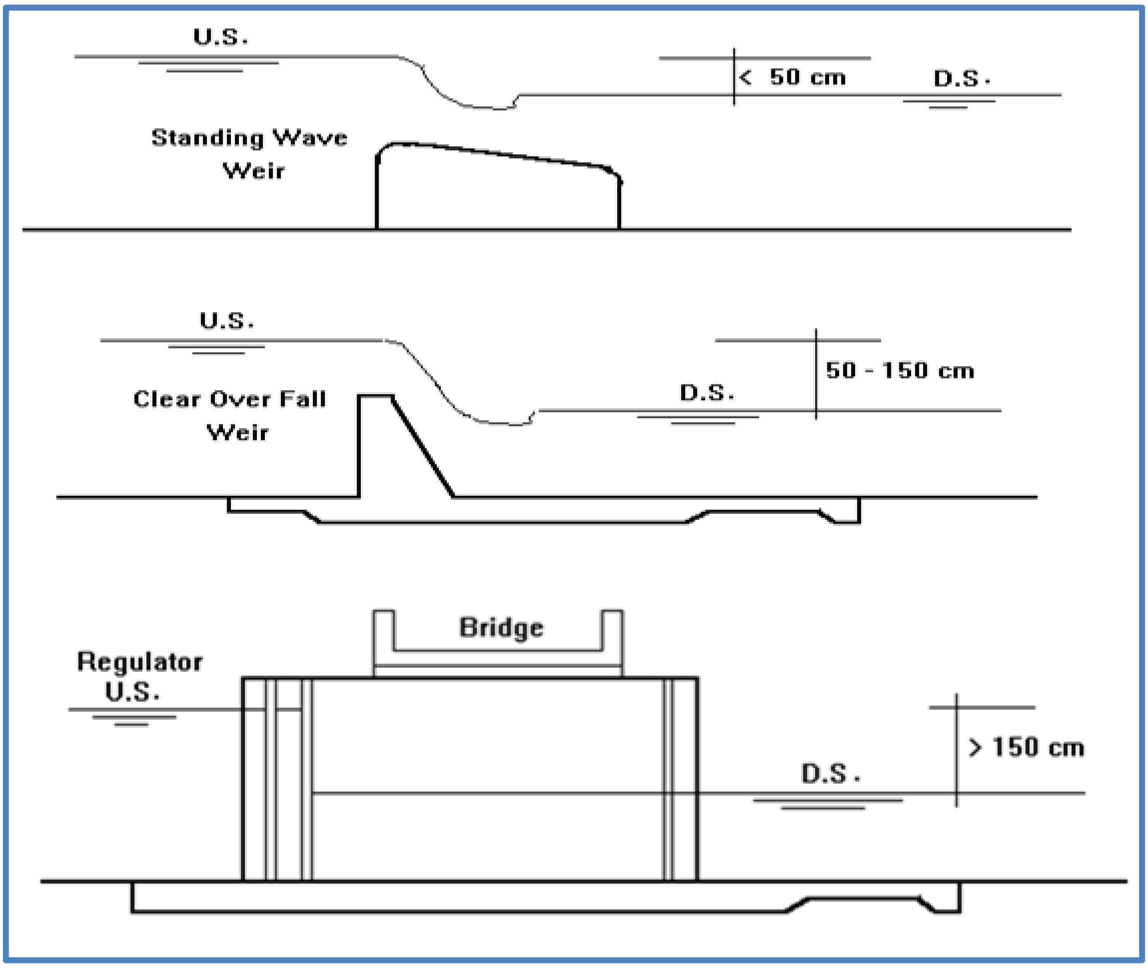


Figure (2-22): Drops in the Water Line for Canals

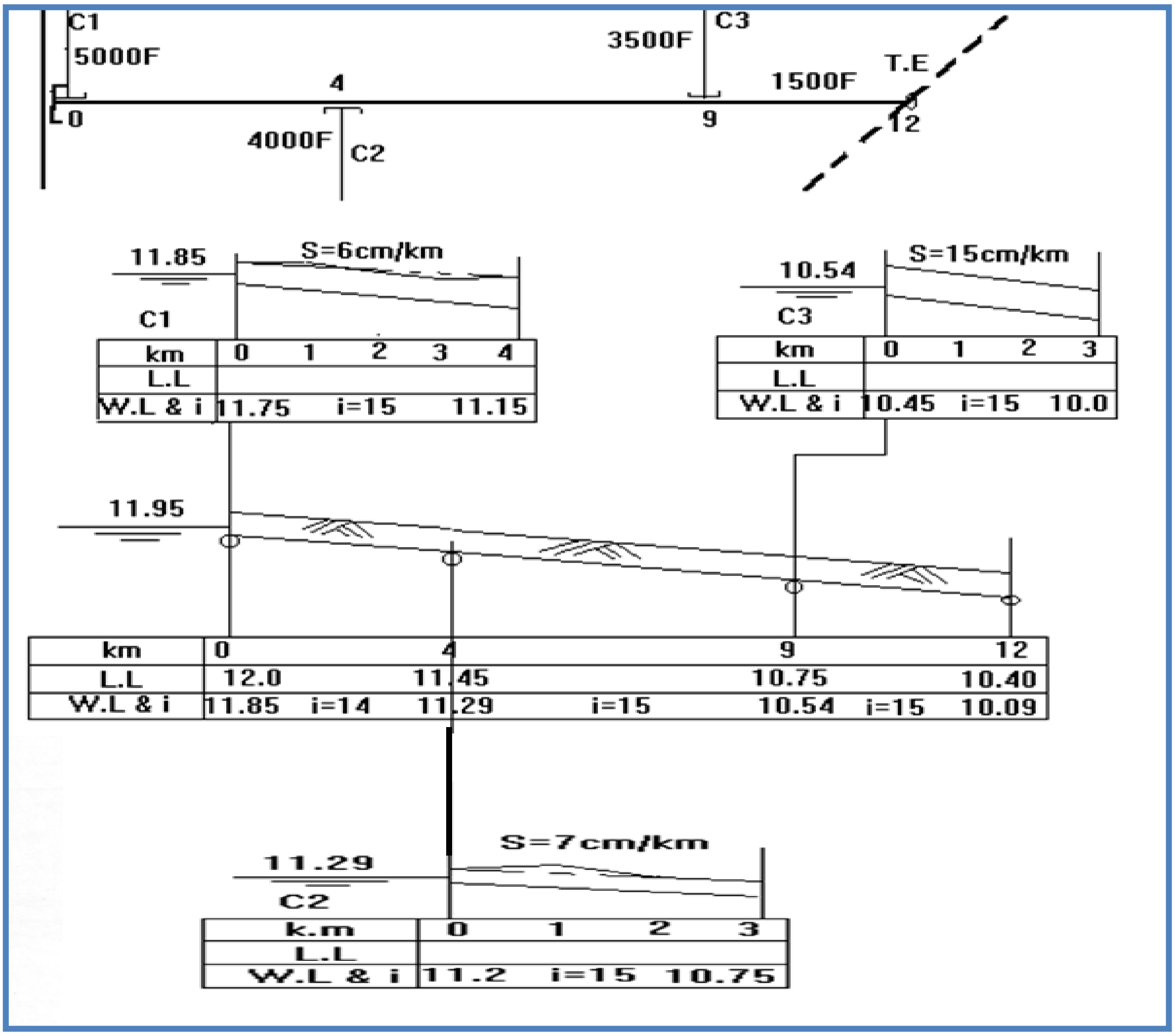
Example (2-1):

A branch canal has a length of 12.0 km, serves an area of 14,000 feddan, and feeds 3 distributor canals. The land level for the branch canal is (10.40) at the Km 12.0. The data for the branch canal and its distributor canal are given *in the following table:*

Distributor Canal	Location L: Left **R: Right**	Area Served, **Fed**	Land Levels for Distributor Canals at Km **0.0**	**1.0**	**2.0**	**3.0**	**4.0**
C 1	0.0, L	5,000	(12.00)	(12.00)	(11.80)	(11.70)	(11.75)
C 2	4.0, R	4,000	(11.45)	(11.55)	(11.35)	(11.25)	---
C 3	9.0, L	3,500	(10.75)	(10.60)	(10.45)	(10.30)	---

1) Sketch a plan for the branch canal and its distributor canals?
2) Draw the synoptic diagram for the branch canal and its distributor canals if lift irrigation is followed?

Solution: (*Note that this is a final solution*)



2-4-2 Synoptic Diagram for Drainage Networks:

The synoptic diagram for the drains is constructed in an ascending order, where the minor drains are executed first. The zero kilometer of the drain is at its outfall, as shown in Figure (2-23). The procedure used for drawing the synoptic diagram for the drains is similar to that used for the canals *except for the following considerations:*

a) For the minor drains:

1. The water line has to be 1.25 - 1.50 m below the average land level, as shown in Figure (2-24).
2. The slope of the waterline (i) depends on the ground slope (S) as illustrated in Table (2-2) previously.
3. The water level upstream the outfall of each minor drain has to be higher than the water level in the branch drain by 10 - 20 cm, as shown also in Figure (2-25).

b) For the branch drains:

1. The water line has to be 1.5 - 2.0 m below the average land level.
2. The water level upstream the outfall of each branch drain has to be higher than the water level of the main drain, otherwise, pump stations have to be constructed to lift the water.

c) For the main drains:

1. The water line has to be 2.0 - 2.5 m below the average land level.
2. The water level upstream the outfall of each main drain has to be higher than the water level of the district drain, otherwise, pump stations have to be constructed to lift the water, as shown in Figure (2-26).

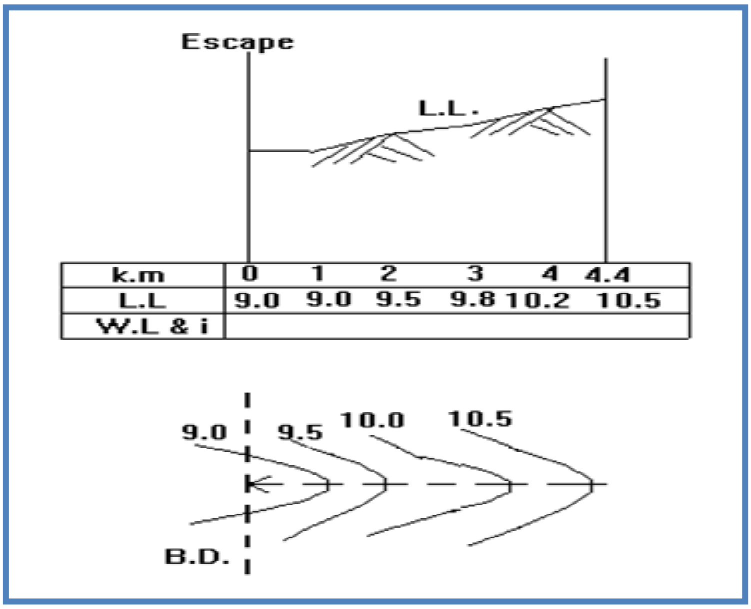


Figure (2-23): Land Levels for Drains

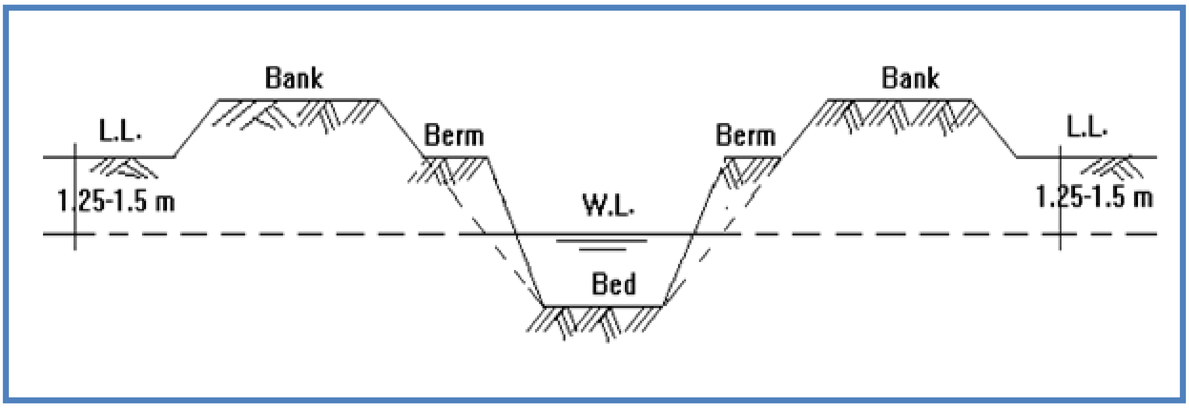


Figure (2-24): Water Line for the Minor Drains

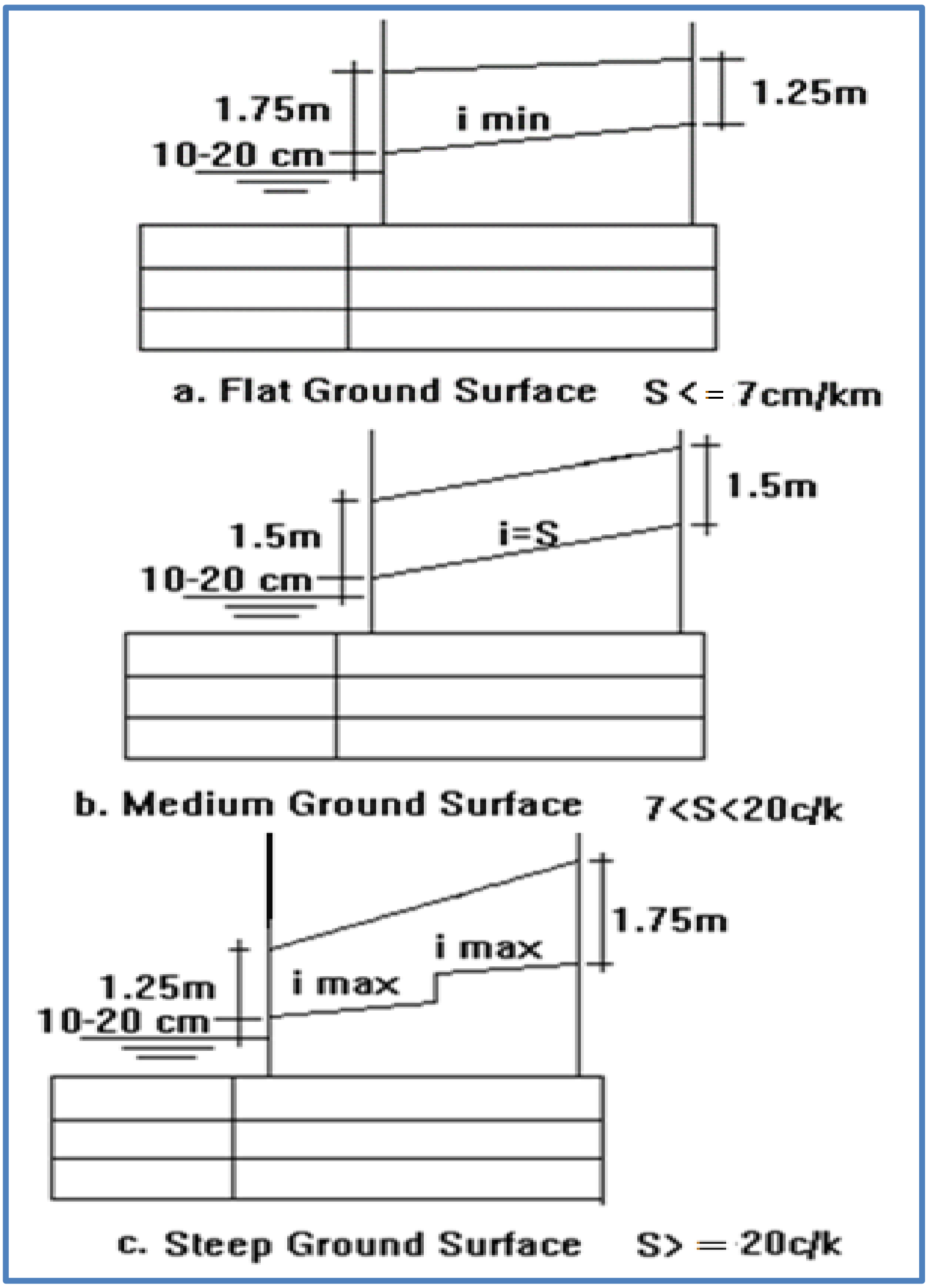


Figure (2-25): Longitudinal Water Line for the Minor Drains

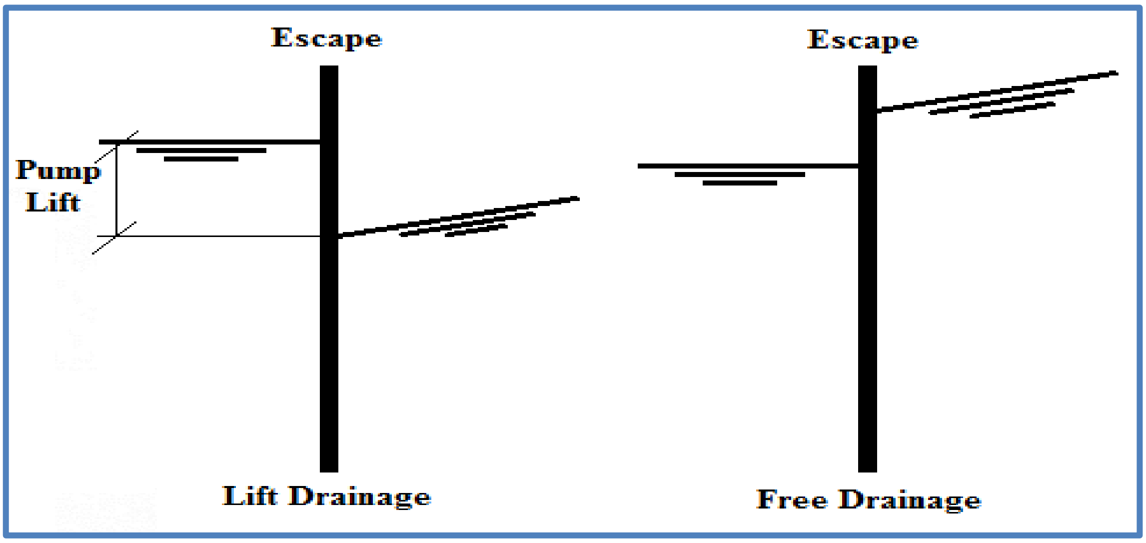


Figure (2-26): Drainage of the Main Drains into the District Drains

♦ **General Remarks:**

1. The slope of the water line can be decreased in the flow direction at distances of 3 - 4 km if needed, as shown in Figure (2-27).

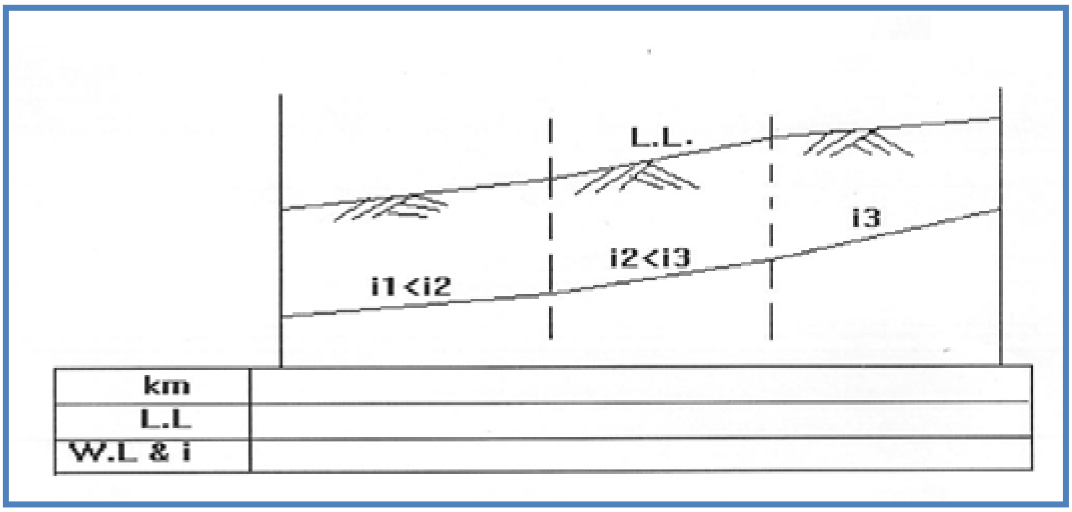


Figure (2-27): Changing the Slope of Water Line for Drains

2. The problem of drops in the water line for drains, if arises, can be solved, as shown in Figure (2-28), *as follows:*

a) If the drop in the water line is less than 50 cm, a sloping bed with pitching is used.

b) If the drop in the water line is greater than 50 cm, a clear over-fall weir is used.

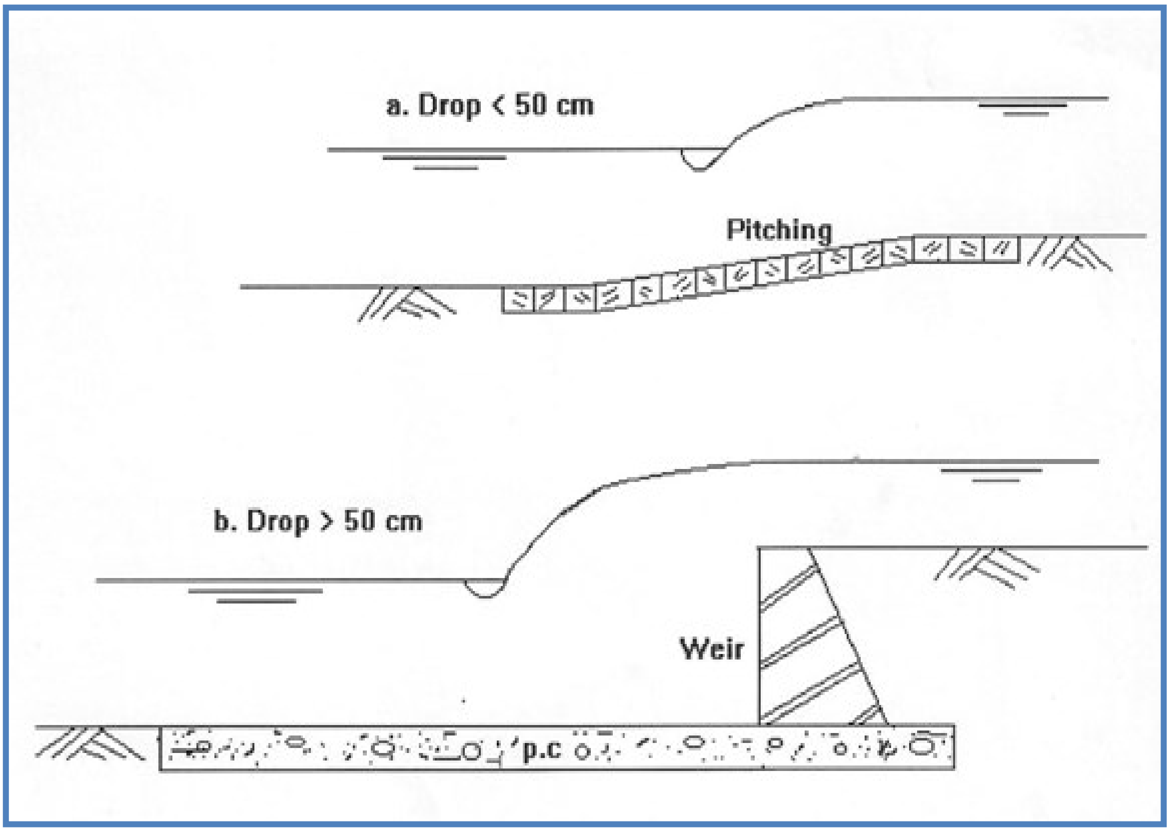


Figure (2-28): Drops in the Water Line for Drains

Example (2-2):

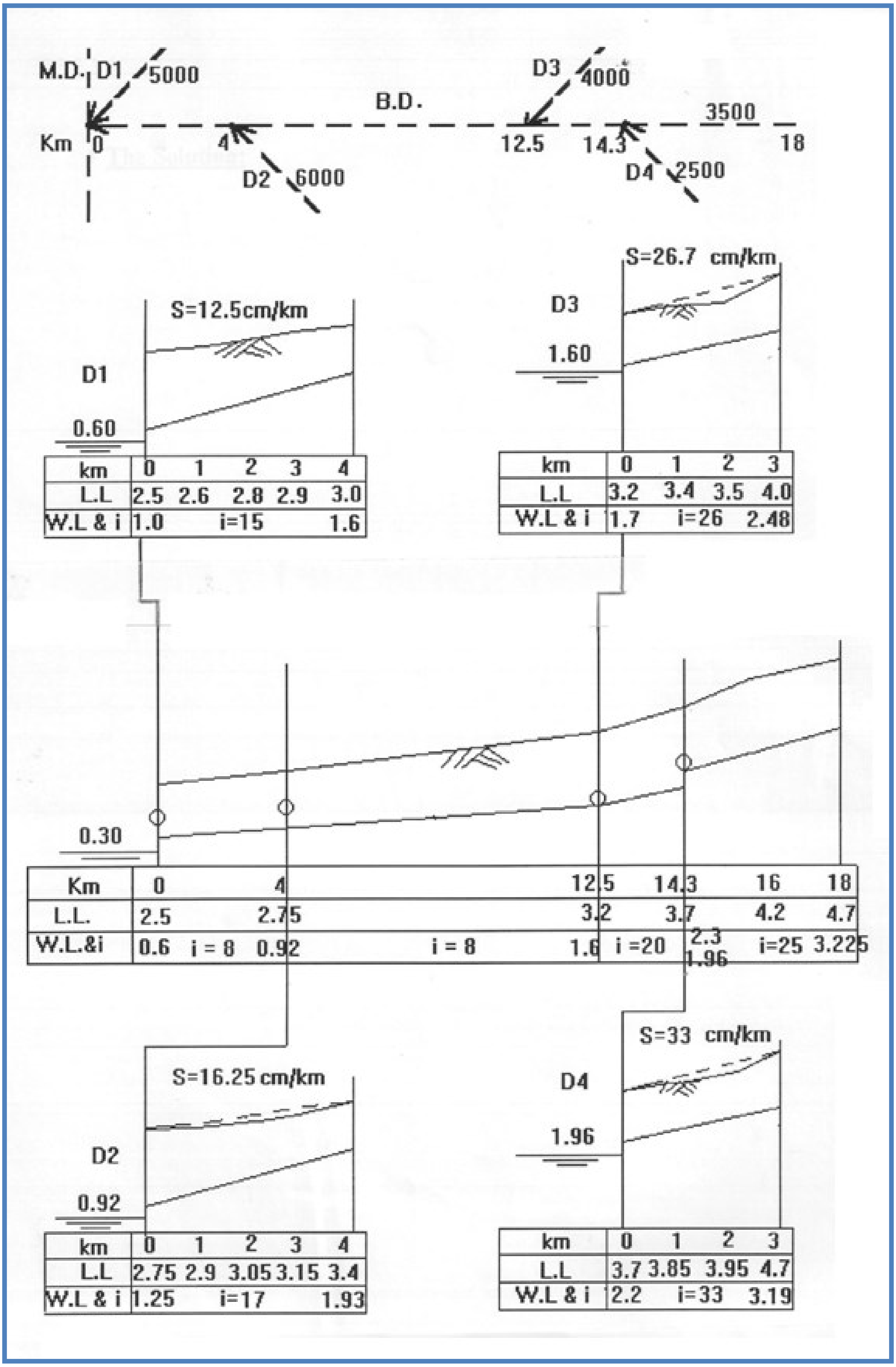
A branch drain has a length of 18.0 km, serves an area of 21,000 Feddan, and falls in the main drain having a water level of (0.30) m. This branch drain takes water from 4 minor drains. The data are given *in the following table:*

Minor Drain	Location L: Left R: Right	Area Served, Fed	Land Levels for Minor Drains at Km				
			0.0	1.0	2.0	3.0	4.0
D 1	0.0, L	5,000	(2.50)	(2.60)	(2.80)	(2.90)	(3.00)
D 2	4.0, R	6,000	(2.75)	(2.90)	(3.05)	(3.15)	(3.40)
D 3	12.5, L	4,000	(3.20)	(3.40)	(3.50)	(4.00)	---
D 4	14.3, R	2,500	(3.70)	(3.85)	(3.95)	(4.70)	---
---	16.0	---	(4.20)	---	---	---	---
---	18.0	---	(4.70)	---	---	---	---

1) Sketch a plan for the branch drain and its minor drains?

2) Draw the synoptic diagram for the branch drain and its minor drains?

Solution: (*Note that this is a final solution*)



2-5 The Area Served:

The area served is the area of the land that is either irrigated by a canal or drained by a drain. It is measured from the planned networks on the contour maps according to the scale and is then transformed into Feddans.

I- Canals:

For the irrigation canals, the area served decreases with the flow direction (same direction of increasing of Km marks).

The cross-sections of irrigation canals have to be chosen and designed at every change in the discharge.

When the irrigation rotations are used, the area served has to be increased by a compensation ratio. This compensation ratio ranges between 20 % and 40 % of the area served of the preceding turn.

Also, intermediate (partial) regulators are required to divide the total area served and to control the levels of the water.

Example (2-3):

A branch canal has a length of 15.0 km and serves an area of 25,000 feddan. This branch canal feeds six distributor canals *as follows:*

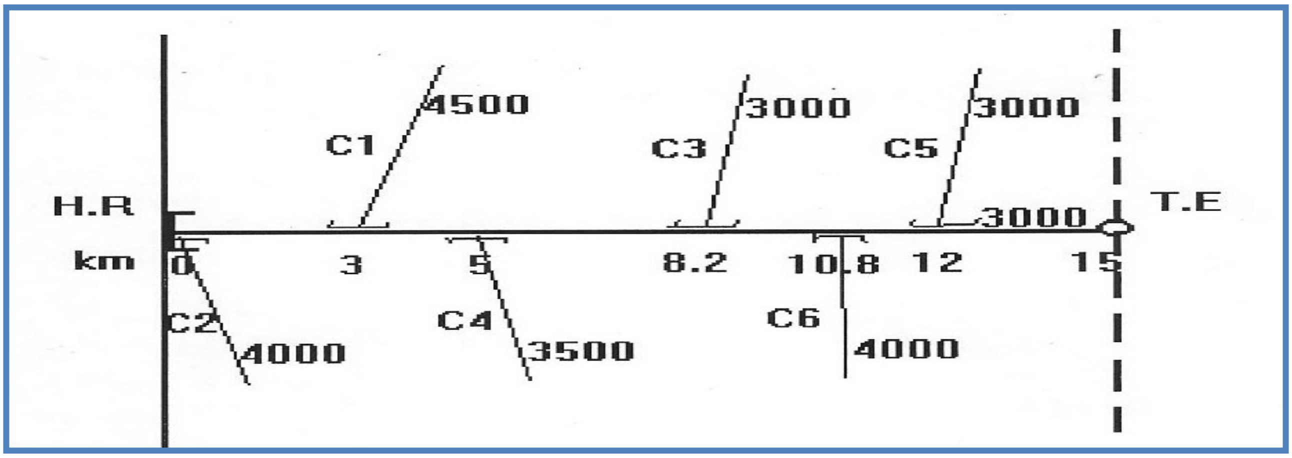
Distributor Canal	Location, Km	Area Served, Feddan
C 1	3.0, Left	4,500
C 2	0.0, Right	4,000
C 3	8.200, Left	3,000
C 4	5.0, Right	3,500
C 5	12.0, Left	3,000
C 6	10.800, Right	4,000

1) Sketch a plan for the branch canal and the distributor canals?
2) Choose the sections to be designed and determine the area served for the design?
3) If a two-turn irrigation rotation is used for the branch canal, re-solve (1) and (2) for this case assuming a compensation ratio of 30 %?

Solution:

1) Area served for the 6 distributor canals = 22,000 Feddans

For the last reach (after Km, 12.0 as a distributor canal):
∴ Area served = 25,000 – 22,000 = 3,000 Feddans

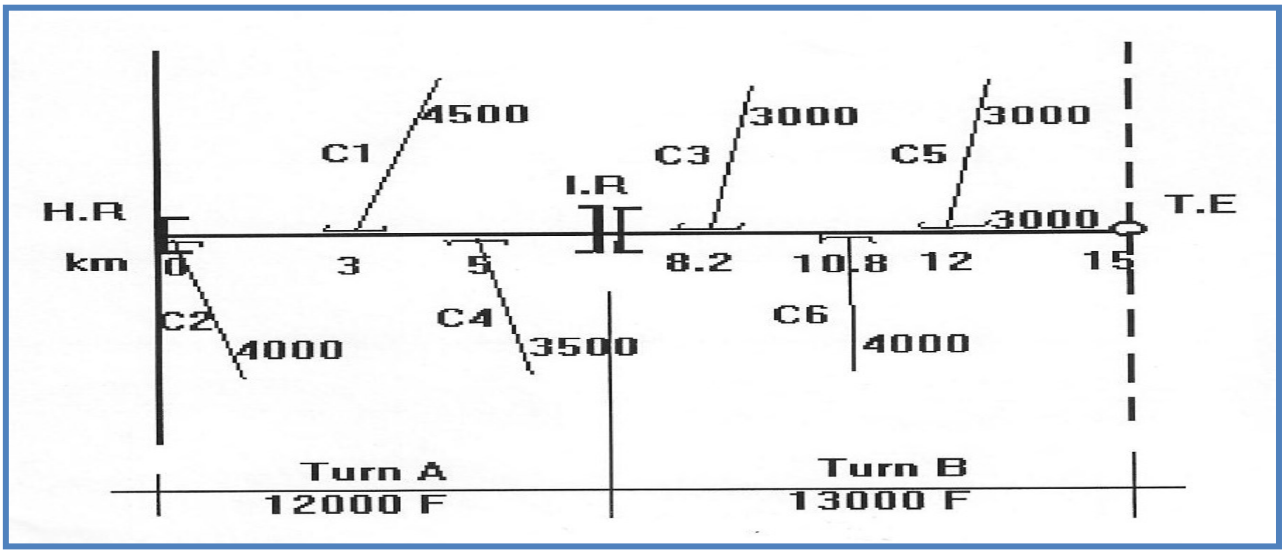


2) Case of no irrigation rotations:

Section	Location, Km	Area Served, Feddan
1	0.0	25,000 21,000
2	3.0	21,000 16,500
3	5.0	16,500 13,000
4	8.200	13,000 10,000
5	10.800	10,000 6,000
6	12.0	6,000 3,000

3) Case of two turn irrigation rotation:

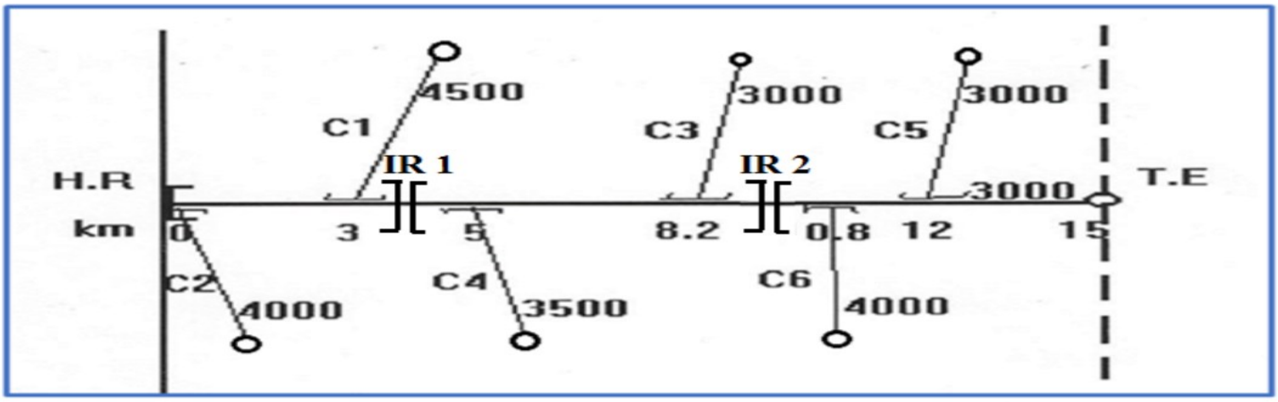
Average area served = 25,000 / 2 = 12,500 Feddans



Section	Location,	Area Served, Fed		AS + Comp., Fed		ASdesign,
	Km	A	B	A+0.3B	B+0.3A	Fed
1	0.0	12,000 8,000	13,000 13,000	15,900 11,900	16,600 15,400	16,600 15,400
2	3.0	8,000 3,500	13,000 13,000	11,900 7,400	15,400 14,050	15,400 14,050
3	5.0	3,500 ---	13,000 13,000	7,400 3,900	14,050 13,000	14,050 13,000
4	8.200	--- ---	13,000 10,000	3,900 3,000	13,000 10,000	13,000 10,000
5	10.800	--- ---	10,000 6,000	3,000 1,800	10,000 6,000	10,000 6,000
6	12.0	--- ---	6,000 3,000	1,800 900	6,000 3,000	6,000 3,000

Exercise:

Solve the last example when a three irrigation rotation is used for the branch canal?



Sec	Location Km	Area Served, Fed			AS + Comp., Fed			ASdesign Feddan
		Turn A	Turn B	Turn C	A+0.3C	B+0.3A	C+0.3B	

II- Drains:

For drains, the area served increases with the flow direction (opposite direction of increasing of Km marks).

The cross-sections of drains have to be chosen and designed at every change in the discharge.

Example (2-4):

A branch drain has a length of 13.0 km and serves an area of 22,000 Feddan. Five minor drains dispose their water into the branch drain *as follows:*

Minor Drain	Location, Km	Area Served, Feddan
D 1	1.0, Right	4,000
D 2	3.0, Left	4,000
D 3	5.0, Right	3,000
D 4	8.0, Left	4,500
D 5	10.600, Right	4,000

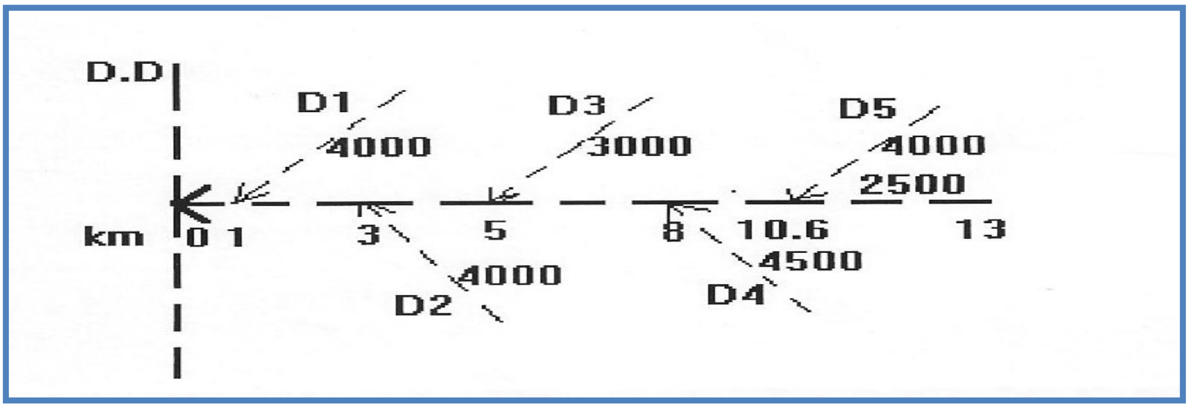
1) Sketch a plan for the branch drain and the minor drains?
2) Choose the sections to be designed and determine the area served for the design?

Solution:

1) Area served for the 5 minor drains = 19,500 Feddans

For the last reach (after Km, 10.600 as a minor drain):

∴ Area served = 22,000 – 19,500 = 2,500 Feddans



2)

Section	Location, Km	Area Served, Feddan
1	1.0	22,000 18,000
2	3.0	18,000 14,000
3	5.0	14,000 11,000
4	8.0	11,000 6,500
5	10.600	6,500 2,500

2-6 Design of Cross Sections:

The trapezoidal cross-section is the common and best shape for the irrigation and drainage networks, especially for the earth channels (canals and drains). As shown in Figure (2-29), **b** is the bed width and **y** is the water depth.

The sides of the trapezoidal section have the slope z:1. The slope z:1 depends on the type of the soil to keep the stability of the sides of the channels.

In general, the side slopes are:

1:1 for clayey soil,
3:2 for silt soils,
2:1 for sandy soils.

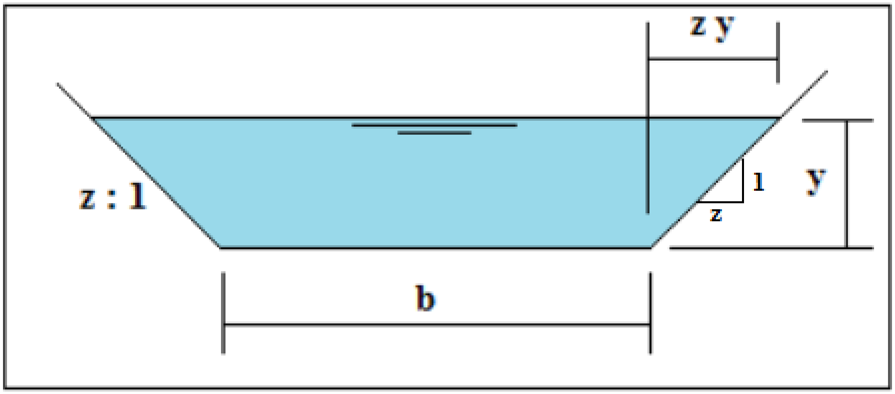


Figure (2-29): Trapezoidal Cross Section

From the science of hydraulics, the flow in the open channels is governed by two main equations *as follows:*

1) The continuity equation: **Q = A x v** .... (1)

Where, Q: the discharge, m^3/sec
A: the cross sectional area, m^2
v: the mean velocity of the flow, m/sec

2) The flow equation: **v = f (n, R, S)**

Where, n: the roughness coefficient.
R: the hydraulic mean radius, m & **R = A / P**
P: the wetted perimeter, m
S: the bed slope, cm/km

There are many hydraulic formulae to define the function relating the velocity to its parameters. The commonly used formula is the **Manning equation**, *which is:*

$$v = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} \quad \text{..........} \quad (2)$$

Thus, from the equations (1) and (2), we get:

$$\mathbf{Q = A * v = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A} \qquad \text{...} \quad (3)$$

This is the main equation that will be used to design the cross-sections of the irrigation and drainage networks.

Each parameter included in this equation is going to be discussed in the following items.

(1) The discharge (Q):

It is the volume of water passing through the section at a specific time.

Q = A.S. x W.D.

Where, Q : the discharge, m^3/sec

A.S. : the area served, Feddans.

W.D. : the water duty of the canal, m^3/Fed/sec

(2) The area (A):

It is the area of water in the trapezoidal cross-section.

$A = (b \times y) + 2 \times 1/2 \times (z\,y \times y)$

$\therefore A = b\,y + z\,y^2$

(3) The velocity (v):

For the earth channels, the maximum permissible velocity depends on the type of the soil and the nature of the flowing water. It is recommended that the velocity is 0.45 m/sec for sandy soil, 0.6 m/sec for silt soil, and 0.7 m/sec for clayey soil.

However, the velocity has to range between 0.3 and 0.9 m/sec for non-silting and non-scouring conditions.

The non-silting condition means that the velocity of the flow keeps the silts in suspension (does not permit them to fall reducing the area of the section).

While the non-scouring condition means that the velocity of the flow keeps the stability of the section (does not push particles from the bed and the sides to move away affecting the stability of the sides and increasing the area of the section).

(4) The roughness coefficient (n):

It is a unitless coefficient that depends on the hydraulic condition of the channel. The values for (1/n) are given in Table (2-3) for different canals and drains.

Table (2-3): Values of (1/n) for Canals and Drains

1/n	Hydraulic Condition of the Canal	1/n	Hydraulic Condition of the Drain
40	Canals of average conditions.	**33**	Drains of average conditions.
44	New earth canals.	**28**	Very weedy drains.
50	Masonry canals.		
60	Rough brick canals.		
70	Concrete-lined canals.		

(5) The hydraulic mean radius (R):

$$\mathbf{R = A / P}$$

For the trapezoidal cross section:

$$P = b + 2\ (y^2 + z^2\ y^2)^{\mathbf{1/2}}$$

$$\therefore\ P = b + 2\ y\ (1+z^2)^{\mathbf{1/2}}$$

$$R = \frac{b\ y + z\ y^2}{b + 2\ y\ \sqrt{1+z^2}}$$

(6) The bed slope (S):

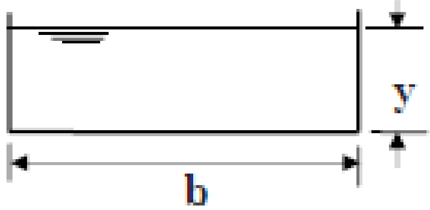
It is the slope of the bed of the canal and has the unit cm/km. The bed slope (S) is assumed to equal the slope of the waterline (i) of the canal to have a uniform flow. The value of (i) is got from the final synoptic diagram for the canal.

Thus, to design the cross-sections of the irrigation canals, both the bed width (b) and the water depth (y) have to be determined. The Manning equation, equation no. (3), is one equation with the two variables (b) and (y). So, another equation relating both (b) and (y) is required to get the design values for (b) and (y).

2-7 Best Hydraulic Sections:

The best hydraulic section of an open channel is the section that provides a maximum discharge for a given cross-sectional area (through the least wetted perimeter).

Rectangular cross-section



$$P = 2y + \frac{A}{y}$$

$$\frac{dP}{dy} = 0$$

$$\therefore b = 2\ y$$

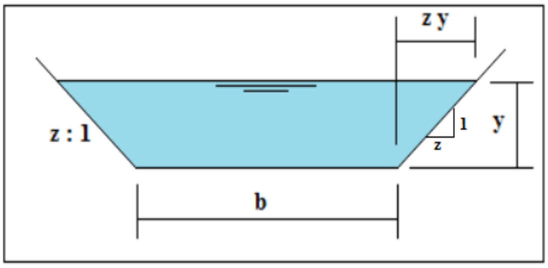
<u>*Trapezoidal cross-section*</u>

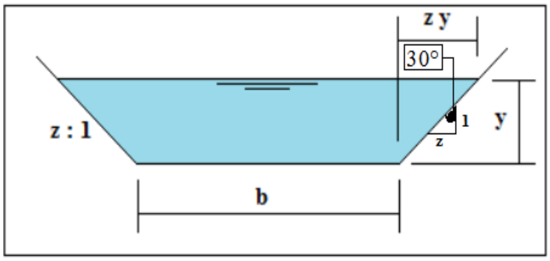
$$P = \frac{A}{y} - zy + 2y\sqrt{1+z^2}$$

$$\frac{\partial P}{\partial y} = 0$$

$$\frac{\partial P}{\partial z} = 0$$

$$\therefore b = 2\,\frac{\sqrt{3}\,y}{3}$$





The disadvantage of the best hydraulic section is that the water depth (y) is relatively high value concerning the bed width (b), which means more required excavation and consequently more cost.

2-7-1 Excel Design for the Best Hydraulic Sections

As a spreadsheet, Microsoft Excel software is employed to obtain the required best hydraulic sections for trapezoidal open channels (a published paper by Dr. Alaa El-Hazek, 2012[1]).

The design sheet (method) and the paper can be downloaded from Dr. Alaa El-Hazek pages on Benha University Site OR Research Gate Site.

Steps for using Excel Design

1- Select the sheet with the required z (z = 1 OR 1.5 OR 2).

2- Enter the data:

Section Number
Water Surface Slope "i" (cm/km)
Bed Slope "$S = i$" (m/m)
Discharge "Q" (m^3/sec)
1 / Manning Coefficient "$1/n$"

[1] Alaa N. El-Hazek (2012). "Best Hydraulic Sections for Open Channels employing Spread Sheets". VII - International Conference on Environmental Hydrology with 1st Symposium on Environmental Impacts on the Nile Water Resources, Cairo, Egypt.

3- Get the answers:

Water Depth "y" (m)	
Bed Width "b" (m)	

4- Modify b to the nearest 0.5 m and get the modified solution.

Modified Bed Width "b_m" (m)	
Modified Water Depth "y_m" *(m)*	

<u>Velocity Option</u>

5- Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec)

Modified Water Depth "y_m" (m)	
Modified Bed Width "b_m" (m)	

Appendix A includes 6 Excel sheets for z = 1, 1.5, and 2.
3 sheets without the velocity option (Steps 1 till 4) and 3 sheets with the velocity option (Steps 1 till 5).
Also, Excel Design is applied for solving two design examples for canals and drains.

2-8 <u>Non-Silting Non-Scouring Sections:</u>

2-8-1 <u>Cross Sections for Irrigation Networks:</u>

Manning equation is to be used with one of *<u>the following Buckley equations:</u>*

$$y = \frac{(i+8)^2 * b}{650} \qquad \text{for } y \le 1.62 \text{ m} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

$$y = 0.1\left(\frac{i}{2} + 4\right) b^{\frac{1}{2}} \qquad \text{for } y > 1.62 \text{ m} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

<u>Where,</u> i : cm/km

The value of the bed width (b) must be modified to the nearest 0.1 OR 0.5 m (b_m). So, the corresponding modified value for the water depth (y_m) is calculated <u>*as follows:*</u>

$$A_{calculated} = A_m$$

$$\therefore \; b\,y + z\,y^2 = b_m\,y_m + z\,y_m^2$$

2-8-2 Cross Sections for Drainage Networks:

Manning equation is to be used with one of *the following Buckley equations:*

For $i \leq 10$ cm./km.

$y = 0.96\ b$ for $b \leq 2$ m. .... (6)

$y = 1.5\ (b)^{1/3}$ for $b > 2$ m. .... (7)

For $i > 10$ cm./km.

$y = b$ for $b \leq 2$ m. .... (8)

$y = 1.75\ (b)^{1/3}$ for $b > 2$ m. .... (9)

The value of the bed width has to be modified, if needed, as for irrigation networks.

2-8-3 Design Charts and Design Equations for Non-Silting Non-Scouring Sections

For non-silting non-scouring trapezoidal earthen open channels, design charts and design equations are developed[2].

The paper and charts can be downloaded from Dr. Alaa El-Hazek page on Benha University Site OR Research Gate Site.

Graphical Design (via Design Charts[3])

For Canals: $1/n = 40$

1- Select the proper design chart according to z and expected y ($y \leq$ OR > 1.62 m).
2- On the chart, knowing Q get y according to i.
3- Substituting in b-y equation (4 OR 5 according to the value of y), b is determined.

For Drains: $1/n = 33$

1- Select the proper design chart according to z, i ($i \leq$ OR > 10 cm/km), and expected b ($b \leq$ OR > 2.0 m).

[2] Alaa Nabil El-Hazek (2019). "Design Charts and Design Equations for Trapezoidal Earthen Open Channels". Sumerianz Journal of Scientific Research, Vol. 2, No. 12, pp. 166-182

[3] Appendix B

2- On the chart, knowing Q get y according to i.
3- Substituting in b-y equation (6 OR 7 OR 8 OR 9 according to the values of i and b), b is determined.

Appendix B includes 31 design charts for canals and drains for z = 1, 1.5, and 2.

Also, design charts are used for solving two design examples.

Analytical Design (via Design Equations)

For canals (1/n = 40 and y ≤ 1.62 m)

For drains (1/n = 33 and b ≤ 2.0 m)

$$Q = C\,y^{2.666} \qquad \text{..........} \qquad (10)$$

1- C: according to z and i, from Table (2-4).
2- Knowing Q and C, get y.
3- Substituting in b-y equation (equation 4 for canals) – (equation 6 OR 8 for drains according to the values of i), b is determined.

For canals (1/n = 40 and y > 1.62 m)

For drains (1/n = 33 and b > 2.0 m)

$$Q = \alpha\,y^{\beta} \qquad \text{..........} \qquad (11)$$

1- α and β: according to z and i, from Table (2-5) for canals OR Table (2-6) for drains.
2- Knowing Q, α, and β, get y.
3- Substituting in b-y equation (equation 5 for canals) – (equation 7 OR 9 for drains according to the values of i), b is determined.

Table (2-4): Coefficient C for Design Equation 10

i, cm/km	Canals, 1/n = 40 and y ≤ 1.62 m			Drains, 1/n = 33 and b ≤ 2.0 m		
	z = 1.0	z = 1.5	z = 2.0	z = 1.0	z = 1.5	z = 2.0
8	0.9595	1.0927	1.2157	0.3931	0.5012	0.6032
9	---	---	---	0.4169	0.5316	0.6398
10	0.8763	1.0252	1.1635	0.4395	0.5603	0.6744
11	---	---	---	0.4492	0.5760	0.6958
12	0.8089	0.9716	1.1235	0.4692	0.6016	0.7267
14	0.7552	0.9302	1.0943	0.5068	0.6498	0.7850
16	0.7126	0.8987	1.0741	0.5418	0.6947	0.8392
18	0.6789	0.8752	1.0609	0.5747	0.7368	0.8901
20	0.6522	0.8580	1.0534	0.6057	0.7766	0.9382
22	0.6311	0.8457	1.0503	0.6353	0.8146	0.9840
24	0.6145	0.8375	1.0507	0.6636	0.8508	1.0278
26	0.6015	0.8325	1.0540	0.6906	0.8855	1.0697

Table (2-5): Coefficients α and β for Design Equation 11 (Canals)

i, cm/km	Canals, 1/n = 40 and y > 1.62 m					
	z = 1.0		z = 1.5		z = 2.0	
	α	β	α	β	α	β
3	0.7243	3.6606	0.8431	3.5930	0.8431	3.5859
5	0.6847	3.6449	0.8028	3.5882	0.8408	3.5465
7	0.6264	3.6263	0.7641	3.5572	0.8156	3.5026
9	0.5745	3.6030	0.7296	3.5209	0.7934	3.4555
10	0.5535	3.5874	0.7155	3.5017	0.7851	3.4317
12	0.5213	3.5470	0.6923	3.4644	0.7802	3.3747
14	0.4957	3.5078	0.6766	3.4261	0.7896	3.3058
16	0.4776	3.4653	0.6656	3.3918	0.7950	3.2548
18	0.4630	3.4274	0.6581	3.3615	0.8068	3.2027
20	0.4553	3.3816	0.6548	3.3323	0.8198	3.1574

Table (2-6): Coefficients α and β for Design Equation 11 (Drains)

i, cm/km	Drains, 1/n = 33 and b > 2.0 m					
	z = 1.0		z = 1.5		z = 2.0	
	α	β	α	β	α	β
3	0.0623	4.5644	0.0828	4.4144	0.1007	4.3181
4	0.0742	4.5432	0.1001	4.3829	0.1274	4.2553
5	0.0855	4.5217	0.1224	4.3193	0.1583	4.1807
6	0.0968	4.4980	0.1409	4.2830	0.1836	4.1396
7	0.1086	4.4707	0.1522	4.2830	0.2109	4.0942
8	0.1213	4.4385	0.1721	4.2421	0.2254	4.0942
9	0.1286	4.4385	0.1825	4.2421	0.2391	4.0942
10	0.1345	4.4429	0.1907	4.2460	0.2490	4.1000
11	0.1063	4.3399	0.1636	4.1130	0.2249	3.9518
12	0.1106	4.3412	0.1708	4.1130	0.2348	3.9523
14	0.1182	4.3510	0.1834	4.1167	0.2549	3.9492
16	0.1328	4.3070	0.2012	4.0929	0.2798	3.9250
18	0.1435	4.2889	0.2240	4.0490	0.3047	3.8989
20	0.1549	4.2647	0.2427	4.0212	0.3297	3.8740
22	0.1643	4.2538	0.2594	4.0030	0.3629	3.8264
24	0.1762	4.2275	0.2770	3.9802	0.3866	3.8089
26	0.1855	4.2161	0.2939	3.9611	0.4153	3.7772

Design equations are used for solving two design examples.

Example (2-5):

A canal serves an area of 7,000 Feddan, has a water duty of 50 m^3/Fed/day, and has a trapezoidal cross-section. The canal runs in silt soil.
Design the cross-section of the canal at km 0.0 where the water slope is 10 cm/km?

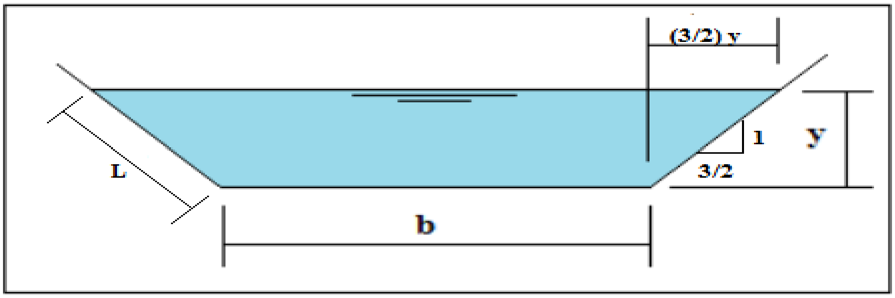
Solution:

A.S.= 7,000 Feddans W.D. = 50 m^3/Fed/day

Trapezoidal section. Silt soil $\therefore$ z : 1 = 3 : 2

i = 10 cm/km

$$Q = A.S. \times W.D. = \frac{7{,}000 * 50}{24 * 60 * 60} \qquad \therefore Q = 4.05 \ m^3/sec$$



$A = b\ y + 2 * (0.5 * y * 1.5\ y)$

$\therefore A = b\ y + 1.5\ y^2$

Assume, y < 1.62 m, *then:*

$$y = \frac{(i+8)^2 * b}{650} \qquad y = \frac{(10+8)^2 * b}{650} = 0.5\ b$$

$\therefore b = 2\ y$

$\therefore A = 2\ y^2 + 1.5\ y^2 = 3.5\ y^2$ & $P = b + 2\ (2.25\ y^2 + y^2)^{1/2}$

$\therefore P = 2\ y + 3.6\ y = 5.6\ y$

$$\therefore R = \frac{A}{P} = \frac{3.5\ y^2}{5.6\ y} = 0.625\ y$$

$$Q = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A$$

Assume, $S = i = 10 / 10^5 = 10^{-4}$ & $1 / n = 40$

$$4.051 = 40 * (0.625)^{\frac{2}{3}} * (y)^{\frac{2}{3}} * \ (10^{-4})^{\frac{1}{2}} * 3.5\ y^2$$

$\therefore y^{8/3} = 3.959$ $\therefore y = 1.675\ \ m > 1.62\ \ m$

<u>Thus, use the other equation:</u>

$$y = 0.1\ \left(\frac{i}{2} + \ 4\right) b^{\frac{1}{2}} = \ 0.1\ \left(\frac{10}{2} + \ 4\right) b^{\frac{1}{2}}$$

$\therefore y = 0.9\ b^{1/2}$ $\therefore y^2 = 0.81\ b$ $\therefore b = 1.23\ y^2$

$\therefore A = b\ y + 1.5\ y^2 = 1.23\ y^3 + 1.5\ y^2$

$\&\ P = b + 3.6\ y = 1.23\ y^2 + 3.6\ y$

$$Q = \frac{1}{n} * R^{\frac{2}{3}} * \ S^{\frac{1}{2}} * A \qquad Q = \frac{1}{n} * \frac{A^{\frac{5}{3}}}{P^{\frac{2}{3}}} * \ S^{\frac{1}{2}}$$

$$4.051 = 40 * \frac{(1.23\ y3 + 1.5\ y2)^{\frac{5}{3}}}{(1.23\ y2 + 3.6\ y)^{\frac{2}{3}}} * \ (10^{-4})^{\frac{1}{2}}$$

$$10.128 = \frac{(1.23\ y3 + 1.5\ y2)^{\frac{5}{3}}}{(1.23\ y2 + 3.6\ y)^{\frac{2}{3}}}$$

<u>Trial and Error:</u>

$y = 1.7$ $\rightarrow$ R.H.S. = 10.875

$y = 1.65$ $\rightarrow$ R.H.S. = 9.828

$y = 1.68$ $\rightarrow$ R.H.S. = 10.447

$\therefore y = 1.69\ m > 1.62\ m$ $\therefore$ O.K.

$\therefore b = 1.23\ y^2 = 3.51\ m$

Take $b_m = 3.5\ m$

$A_{\text{calculated}} = A_m$

$$\therefore b\,y + 1.5\,y^2 = b_m\,y_m + 1.5\,y_m^2$$

$$(3.51 * 1.69) + (1.5 * (1.69)^2) = 3.5\,y_m + 1.5\,y_m^2$$

$$1.5\,y_m^2 + 3.5\,y_m - 10.22 = 0 \qquad \therefore\ y_m^2 + 2.33\,y_m - 6.81 = 0$$

$$\therefore y_m = \frac{-2.33 \pm [(2.33)^2 - (4 * 1 * -6.81)]^{1/2}}{2 * 1} \qquad \therefore\ y_m = 1.7\ \text{m}$$

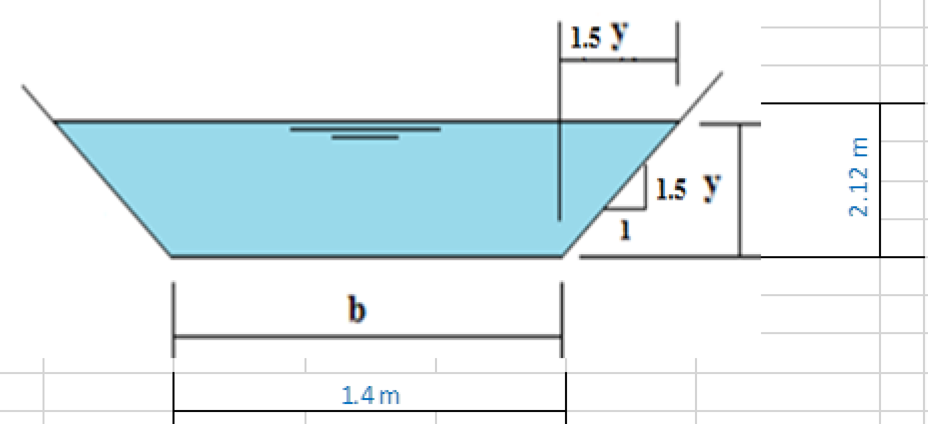
Steps for using Excel Design	***Excel Design[4]***
1- Select the sheet with the required z (z = 1 OR 1.5 OR 2).	$z = 1.5$
2- Enter the data: Section Number Water Surface Slope "i" (cm/km) Bed Slope "$S = i$" (m/m) Discharge "Q" (m^3/sec) 1 / Manning Coefficient "$1/n$"	Sec No: 1 $i = 10$ cm/km $S = i = 10^{-4}$ $Q = 4.05\ m^3/s$ $1/n = 40$
3- Get the answers: Water Depth "y" (m) Bed Width "b" (m)	$y = 2.14$ m $b = 1.31$ m
4- Modify b to the nearest 0.5 m and get the modified solution. Modified Bed Width "b_m" (m) Modified Water Depth "y_m" *(m)*	$b_m = 1.4$ m $y_m = 2.12$ m
Velocity Option 5- Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec) Modified Water Depth "y_m" (m) Modified Bed Width "b_m" (m)	$v = 0.42$ m/s OK

[4] Alaa N. El-Hazek (2012). "Best Hydraulic Sections for Open Channels employing Spread Sheets". VII - International Conference on Environmental Hydrology with 1st Symposium on Environmental Impacts on the Nile Water Resources, Cairo, Egypt.

Best Hydraulic Trapezoidal Sections for Open Channels

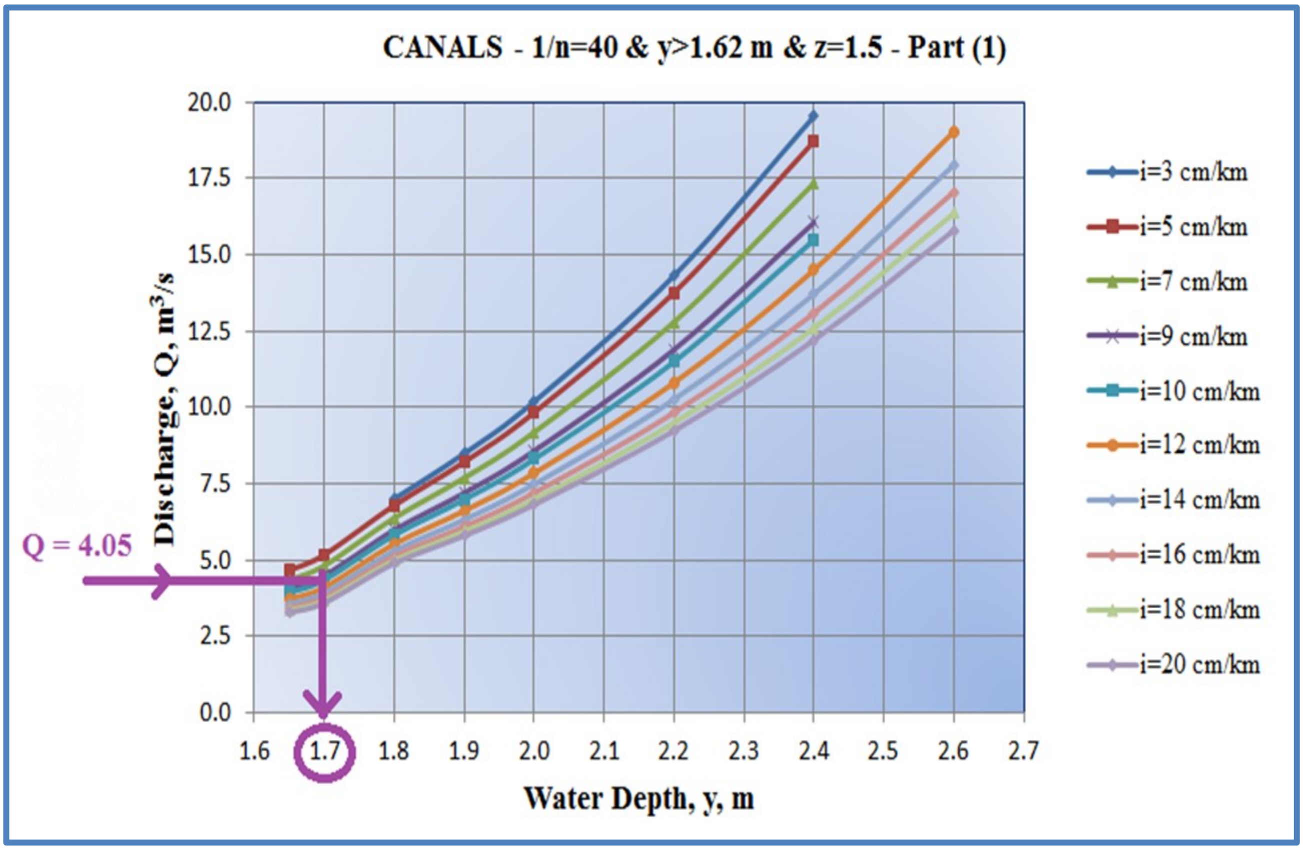
z = 1.5

$Q = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A$	Manning Equation
Section 1	Section Number
10	Water Surface Slope "i" (cm/km)
0.0001	Bed Slope "$S = i$" (m/m)
4.05	Discharge "Q" (m^3/sec)
40	1 / Manning Coefficient "$1/n$"
For Best Hydraulic Section	x' = T / 2 & z = 1.5 & b = 0.61 y
Basic Solution	
2.1414	Water Depth "y" (m)
1.3063	Bed Width "b" (m)
9.675757906	Cross Sectional Area "A" (m^2)
9.036780219	Wetted Perimeter "P" (m)
1.070708557	Hydraulic Radius "$R = A / P$" (m)
7.73051578	Top Width "T" (m)
Additional Solution for Modified Bed Width (to nearest 0.05 m)	
9.675757906	Cross Sectional Area "A" (m^2)
1.40	Modified Bed Width "b_m" (m)
2.12	Modified Water Depth "y_m" (m)
9.04	Modified Wetted Perimeter "P" (m)
1.07	Modified Hydraulic Radius "$R = A / P$" (m)
7.75	Top Width "T" (m)
OPTION: Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec)	
0.418571862	Velocity "v = Q / A" (m/sec)
	Modified Cross Sectional Area "A = Q / 0.9" (m^2)
	Modified Water Depth "y_m" (m)
	Modified Bed Width "b_m" (m)
	Modified Velocity "v" (m/sec)



Design Charts and Design Equations for Non-Silting Non-Scouring Sections[5]

Graphical Design (via Design Charts)



From the curve: $y = 1.7$ m

To get b:

$$\boldsymbol{y = 0.1\left(\frac{i}{2} + 4\right) b^{\frac{1}{2}}}$$

$y = 0.1\ (5 + 4)\ b^{1/2}$

$\therefore\ b = (1.7)^2 / 0.81 \approx 3.6$ m

Analytical Design (via Design Equations)

For canals (1/n = 40 and y > 1.62 m) $\boldsymbol{Q = \alpha\, y^{\beta}}$

α and β: from Table 2 according to z and i.

z = 1.5 and i = 10 cm/km

From Table (2-5), $\alpha = 0.7155$ $\beta = 3.5017$

$4.05 = 0.7155\ y^{3.5017}$

$y = (4.05/0.7155)^{1/3.5017} = 1.64$ m $\therefore b = (1.64)^2 / 0.81 = 3.3$ m

[5] Alaa Nabil El-Hazek (2019). “Design Charts and Design Equations for Trapezoidal Earthen Open Channels”. Sumerianz Journal of Scientific Research, Vol. 2, No. 12, pp. 166-182

Example (2-6):

A minor drain serves an area of 6,000 Feddan of clayey soil. It has a drainage factor of 25 m^3/Fed/day and its cross-section has the shape of a trapezoidal section.

Design the cross-section of the minor drain at its outfall where the water slope is 20 cm/km?

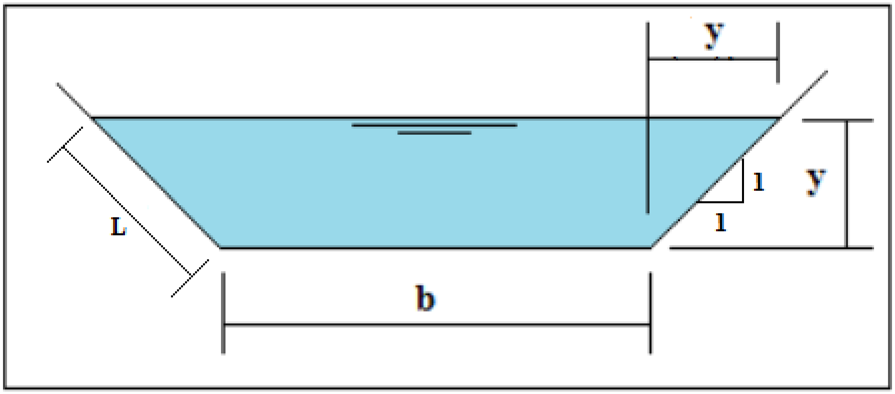
Solution:

A.S. = 6,000 Feddans   D.F. = 25 m^3/Fed/day

Trapezoidal section   Clayey soil $\therefore$ z : 1 = 1 : 1

i = 20 cm/km

$$Q = A.S. \times D.F. = \frac{6{,}000 * 25}{24 * 60 * 60} \qquad \therefore Q = 1.736 \; m^3/sec$$



$$A = b\,y + 2 * (0.5 * y * y)$$

$$\therefore A = b\,y + y^2$$

For i > 10 cm/km, assume b ≤ 2 m, *then:*

$$y = b$$

$$\therefore A = y^2 + y^2 = 2\,y^2$$

$$\& \; P = b + 2\,(y^2 + y^2)^{1/2}$$
$$\therefore P = y + 2.828\,y = 3.828\,y$$

$$\therefore R = \frac{A}{P} = \frac{2\,y^2}{3.828\,y} = 0.52\,y$$

$$Q = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A$$

Assume, $S = i = 20 / 10^{-5} = 2 * 10^{-4}$ & $1 / n = 33$

$$1.736 = 33 * (0.52)^{\frac{2}{3}} * y^{\frac{2}{3}} * (2 * 10^{-4})^{\frac{1}{2}} * 2\,y^2$$

$\therefore y^{8/3} = 2.876$ $\therefore y = 1.49$ m

$\therefore b = 1.49$ m < 2 m O.K.

Take $b_m = 1.5$ m

$A_{calculated} = A_m$

$\therefore b\,y + y^2 = b_m\,y_m + y_m^2$

$\therefore (1.49)^2 + (1.49)^2 = 1.5\,y_m + y_m^2$

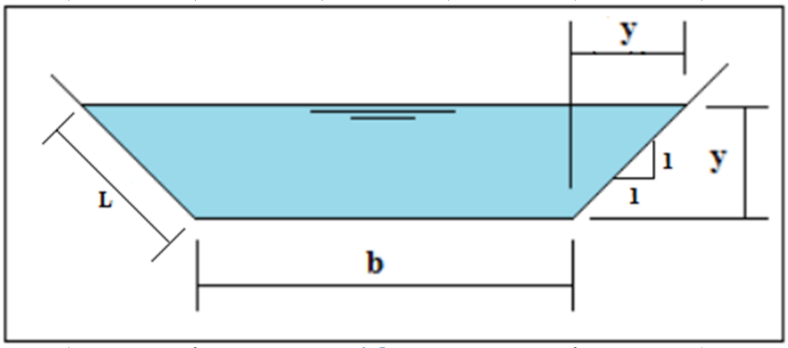
$y_m^2 + 1.5\,y_m - 4.44 = 0$

$$\therefore y_m = \frac{-1.5 \pm [(1.5)^2 - (4 * 1 * -4.44)]^{1/2}}{2 * 1} \qquad \therefore y_m = 1.49 \text{ m}$$

Steps for using Excel Design	***Excel Design[6]***
1- Select the sheet with the required z (z = 1 OR 1.5 OR 2).	z = 1
2- Enter the data: Section Number Water Surface Slope "i" (cm/km) Bed Slope "$S = i$" (m/m) Discharge "Q" (m^3/sec) 1 / Manning Coefficient "$1 / n$"	Sec No: 1 i = 20 cm/km $S = i = 2*10^{-4}$ Q = 1.736 m^3/s 1/n = 33
3- Get the answers: Water Depth "y" (m) Bed Width "b" (m)	y = 1.56 m b = 1.28 m
4- Modify b to nearest 0.5 m and get the modified solution. Modified Bed Width "b_m" (m) Modified Water Depth "y_m" (m)	b_m = 1.3 m y_m = 1.55 m
Velocity Option 5- Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec) Modified Water Depth "y_m" (m) Modified Bed Width "b_m" (m)	v = 0.39 m/s OK

[6]Alaa N. El-Hazek (2012). "Best Hydraulic Sections for Open Channels employing Spread Sheets". VII - International Conference on Environmental Hydrology with 1st Symposium on Environmental Impacts on the Nile Water Resources, Cairo, Egypt.

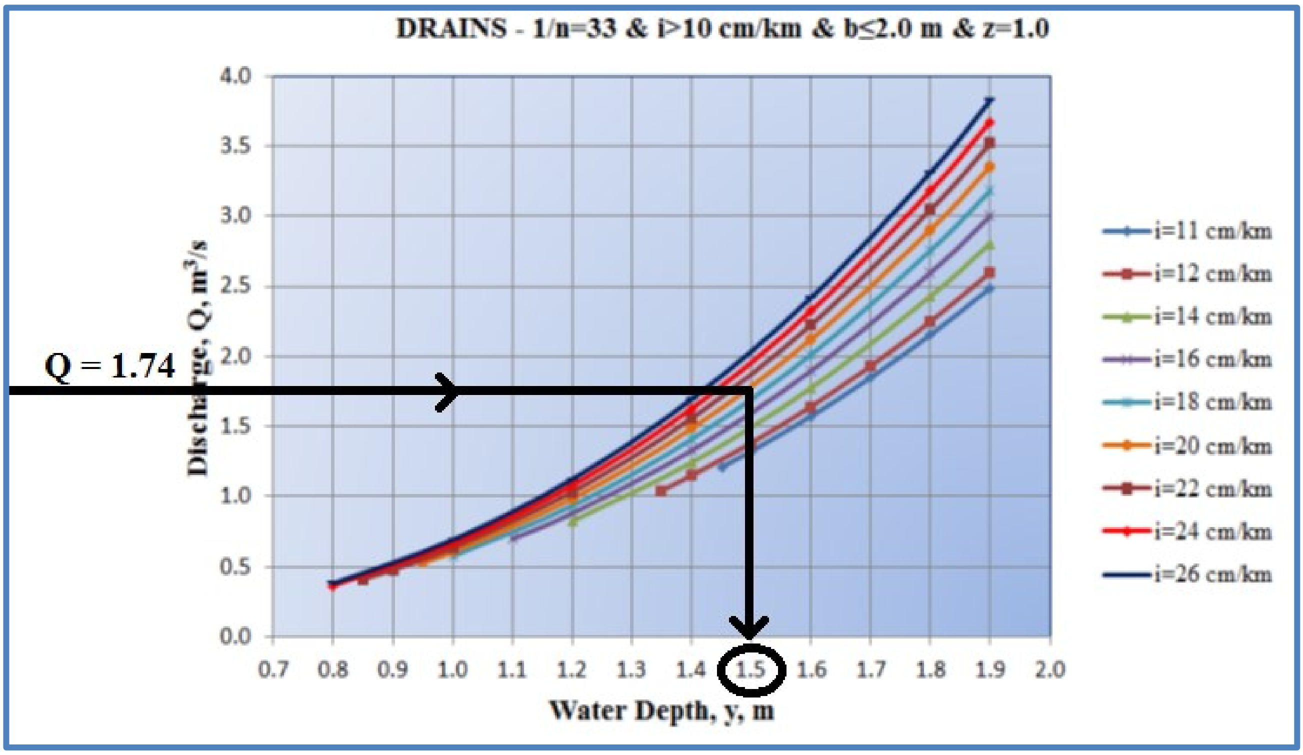
	A	B	C	D	E	F	G	H	I	J
1		**Best Hydraulic Trapezoidal Sections for Open Channels**								
2					**z = 1**					
3										
4–5		$Q = \frac{1}{n} * R^{\frac{2}{3}} * S^{\frac{1}{2}} * A$			Manning Equation					
6										
7		Section 1			Section Number					
8		20			Water Surface Slope "i" (cm/km)					
9		0.0002			Bed Slope "$S = i$" (m/m)					
10		1.736			Discharge "Q" (m^3/sec)					
11		33			1 / Manning Coefficient "$1/n$"					
12		For Best Hydraulic Section			x' = T / 2 & z = 1 & b = 0.82 y					
13		Basic Solution								
14		1.5561			Water Depth "y" (m)					
15		1.2760			Bed Width "b" (m)					
16		4.406993977			Cross Sectional Area "A" (m^2)					
17		5.67973926			Wetted Perimeter "P" (m)					
18		0.77591484			Hydraulic Radius "$R = A / P$" (m)					
19		4.388182113			Top Width "T" (m)					
20		Additional Solution for Modified Bed Width (to nearest 0.05 m)								
21		4.406993977			Cross Sectional Area "A" (m^2)					
22		1.30			Modified Bed Width "b_m" (m)					
23		1.55			Modified Water Depth "y_m" (m)					
24		5.68			Modified Wetted Perimeter "P" (m)					
25		0.78			Modified Hydraulic Radius "$R = A / P$" (m)					
26		4.40			Top Width "T" (m)					
27	OPTION	Additional Solution for Modified Water Velocity (0.3 < v < 0.9 m/sec)								
28		0.393919304			Velocity "v = Q / A" (m/sec)					
29					Modified Cross Sectional Area "A = Q / 0.9" (m^2)					
30					Modified Water Depth "y_m" (m)					
31					Modified Bed Width "b_m" (m)					
32					Modified Velocity "v" (m/sec)					
33–41										
42				1.3 m						
43										
44										



1.55 m

Design Charts and Design Equations for Non-Silting Non-Scouring Sections[7]

Graphical Design (via Design Charts):



From the curve: $y = 1.5$ m

For $i > 10$ cm/km, assume $b \leq 2$ m, *then:* $y = b$

$\therefore\ b = 1.5$ m

Analytical Design (via Design Equations)

$Q = C\, y^{2.666}$

From Table (2-4), For drains, $b \leq 2.0$ m, $z = 1$, $i = 20$ cm/km $\therefore\ C = 0.6057$

$1.736 = 0.6057 * y^{2.666}$

$y = (1.736 / 0.6057)^{1/2.666}$

$y = 1.48 \approx 1.5$ m

$\therefore\ b = y = 1.5$ m

[7]Alaa Nabil El-Hazek (2019). "Design Charts and Design Equations for Trapezoidal Earthen Open Channels". Sumerianz Journal of Scientific Research, Vol. 2, No. 12, pp. 166-182

2-9 Longitudinal Sections:

A longitudinal section for either irrigation canal or drain can be drawn from the data got from both the synoptic diagram and the design of the cross-sections at different locations.

The longitudinal section is very important as it contains all information about the channel, as shown in Figures (2-30) and (2-31). It includes four main lines that represent the landline, the waterline, the bed line, and the bank line.

Also, the longitudinal section includes a table indicating *the following data:*

1. The kilometer.
2. The water levels and slopes.
3. The bed levels, slopes, and widths.
4. The right bank levels, slopes, and width.
5. The left bank levels, slopes, and width.
6. The right, the left, and the total expropriation widths.
7. The area served.
8. The discharge.
9. The velocity.

All branches, regulators, and other constructions have to be shown on the drawn longitudinal section at their locations along the channel. A plan for the bed widths has also to be drawn below the table of the longitudinal section.

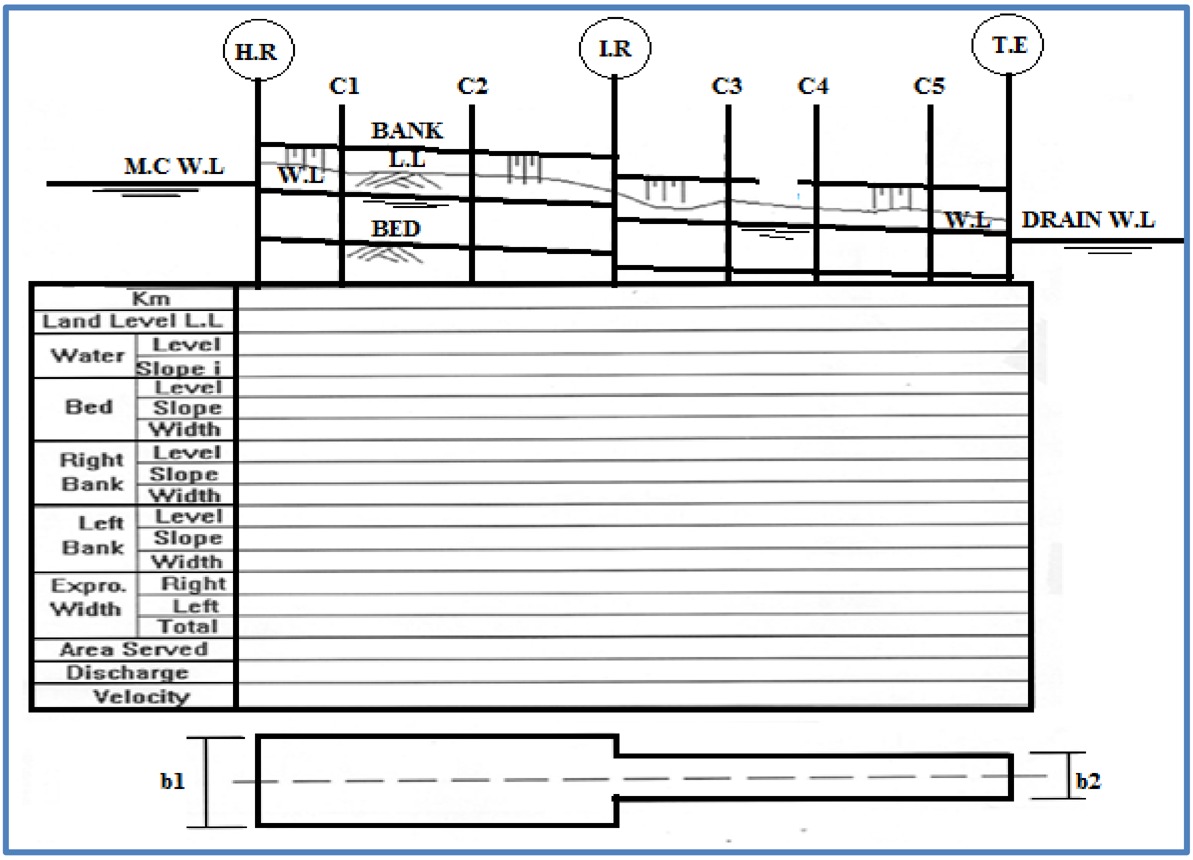


Figure (2-30): Longitudinal Section for a Branch Canal

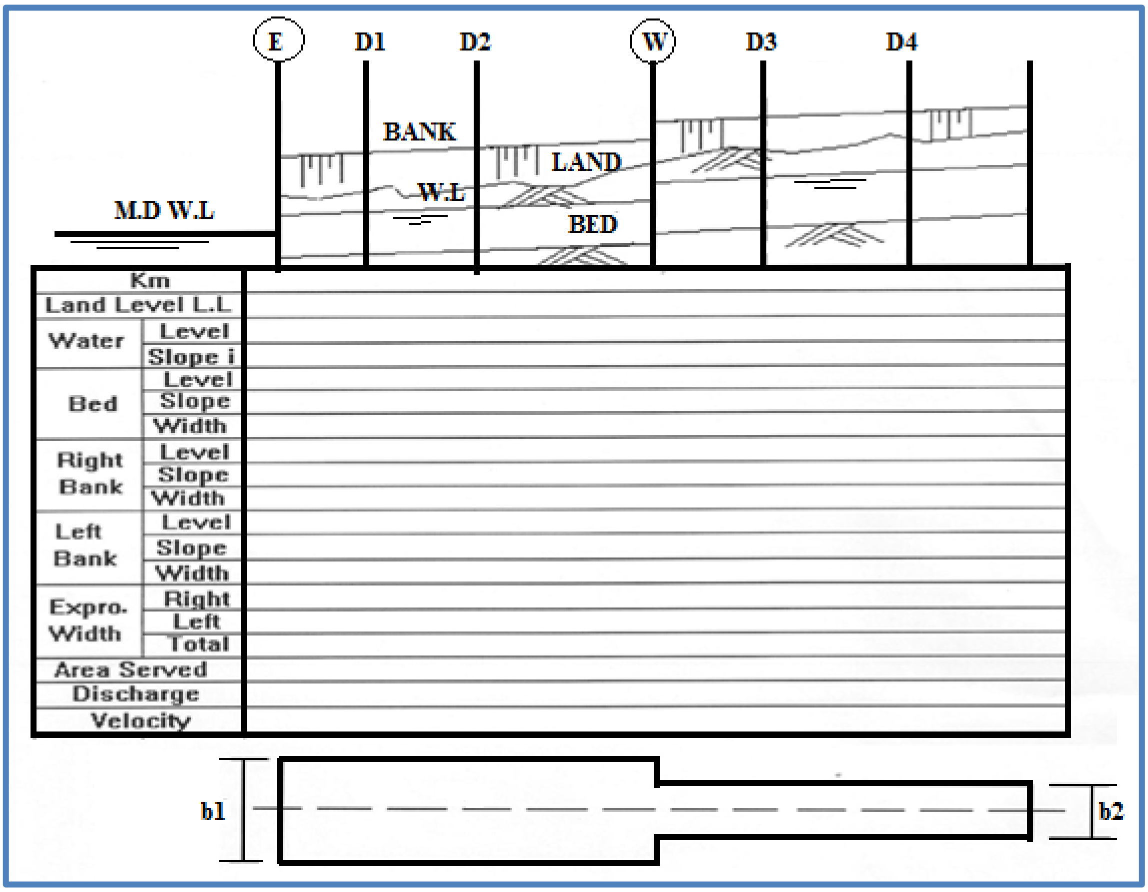


Figure (2-31): Longitudinal Section for a Branch Drain

2-9-1 <u>The Land Line and the Water Line:</u>

These two lines are drawn as got from the <u>final</u> synoptic diagram.

2-9-2 <u>The Bed Line:</u>

The water depths from the design of the cross-sections are marked on their locations and then the bed line can be obtained having a suitable slope(s). There may be more than one slope for the bed line. It is recommended that the bed slope (S) is the same as the water line slope (i) to satisfy the ideal condition for the uniform flow.

Drop(s) in the bed line can be made only at the locations of construction. The bed width can be changed after the locations of branches or constructions.
If the required depths at some locations are higher or lower than the suitable bed line, a modification can be made by changing either the water slope (i) or the bed width (b). In these cases, a check has to be made for the discharge and the velocity.

2-9-3 <u>The Bank Line:</u>

The bank line is parallel to the waterline. There are two banks, one to the right of the channel and the second is at its left side.

The rise and the widths of the bank for canals are shown in Table (2-7).
While for drains, the rise of the bank depends mainly on the amount of cut that is to be disposed of. However, the rise of the bank is at least 1.0 m above the berm level.

Thus, the longitudinal section for any channel can be drawn and its associated table is completed except for the expropriation widths, which can be calculated after drawing the typical cross-sections.

Table (2-7): Banks for Canals

Grade of Canal	Rise of Bank above Water Level, m	Width of Bank, m	
		Main Bank	Secondary Bank
Distributor	0.75 – 1	4 – 5	3
Branch	1 – 1.5	5 – 6	3
Main	1.5 – 2	6 – 8	5
Diversion	2	10	10

2-10 The Typical Cross Section:

The common cross-section for the irrigation channels (canals and drains) is the trapezoidal section. Figure (2-32) shows a model for the typical cross-section.

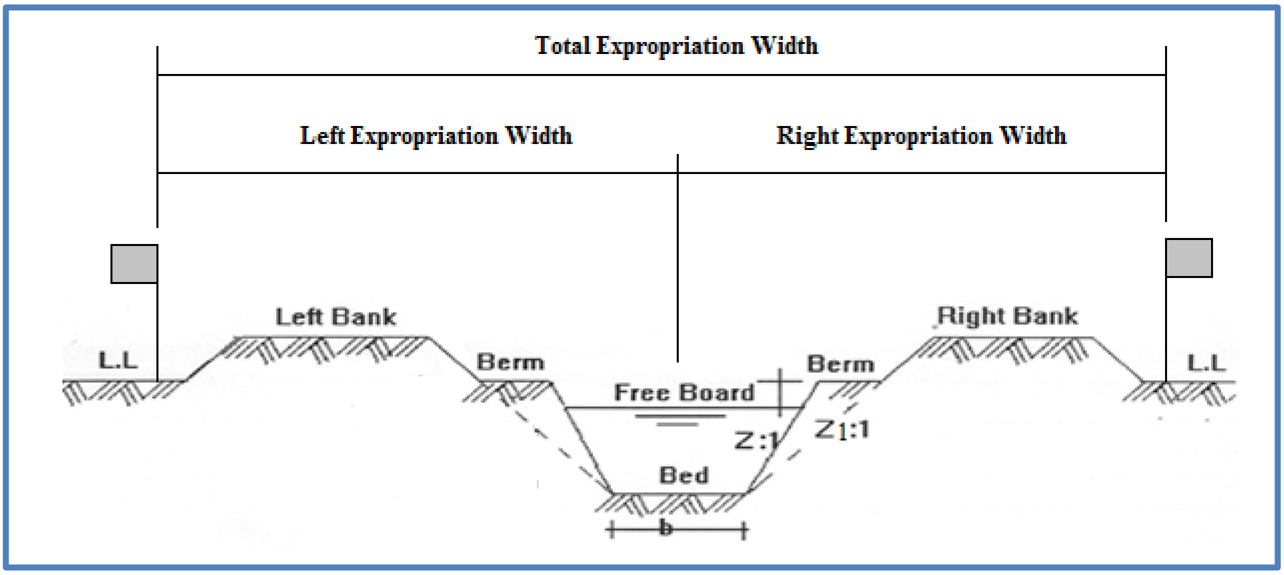


Figure (2-32): A Model for the Typical Cross Section

2-10-1 The Berm:

The berm is a narrow strip of land between the bank and the beginning of cutting for the waterway. It is important for maintenance purposes and it is 0.25 - 0.50 m above the water level (freeboard) for the irrigation canals.

Minimum width for the berm = $(z_1 - z)\ y_1$

Where, $(z : 1)$: side slope of the waterway.

$(z_1 : 1)$: side slope of the bank.

$z_1 > z$ (If $z = 1$, then $z_1 = 1.5$ or $z_1 = 2$).

y_1 : Berm depth = Water depth + Free board

= y + (0.25 - 0.50 m for canals).

For a railway bank, as shown in Figures (2-33) and (2-34),

Minimum width for the berm = $(z_1 - z)\ y_1 + 5.0$ m

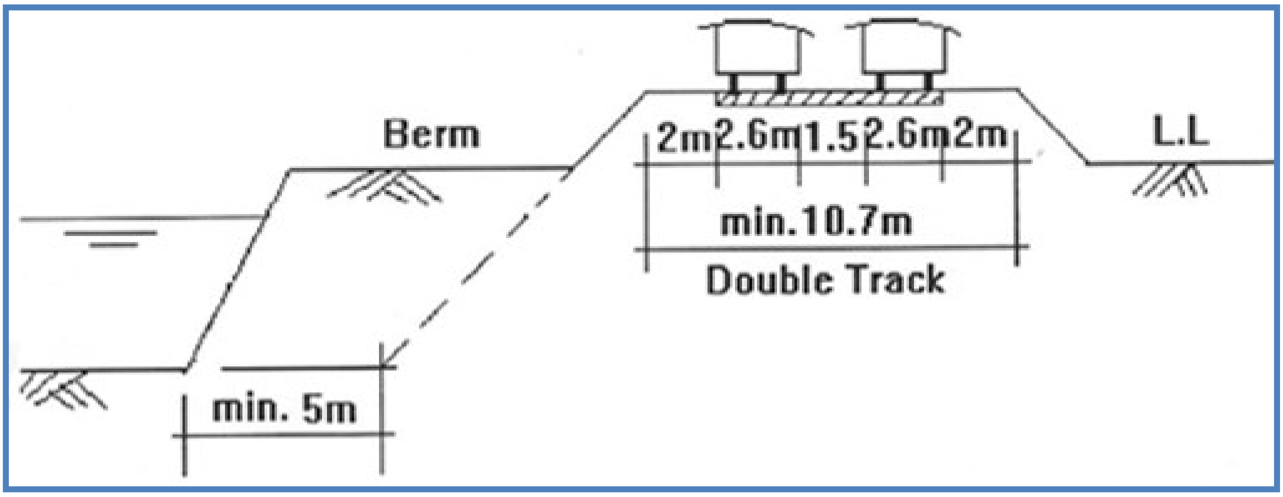


Figure (2-33): A Railway Bank beside a Channel

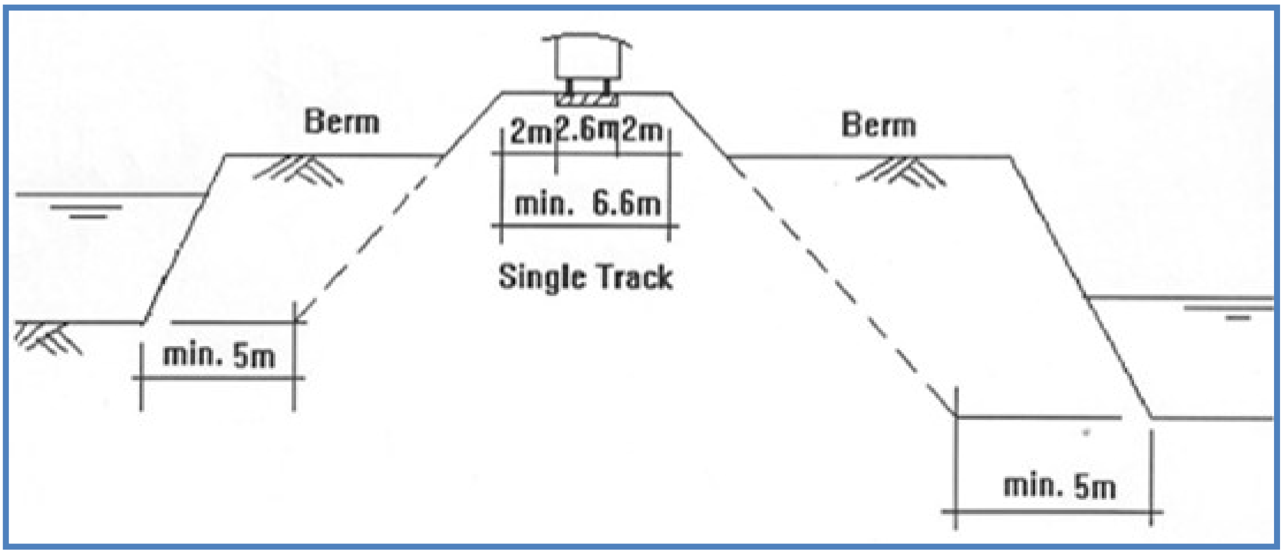


Figure (2-34): A Railway Bank between Two Channels

2-10-2 Check for Stability of the Side Slopes:

The side slopes have to be stable against slipping, so they are checked for seepage. The seepage line is drawn as a straight line (although it is parabolic in fact) with the slopes of 4 : 1 for clay soil, 6 : 1 for clayey loam soil, 8 : 1 for loam soil, 10 : 1 for sandy loam soil and 15 : 1 for sand soil.
However, the slopes of 7 : 1 for the clayey & loamy soils and 10 : 1 for the sandy soils are considered and used for convenience.

The seepage line has to be covered by 0.5 - 2.0 m of the soil or reaches to the low water level (L.W.L.). This can be achieved by increasing the berm width, as shown in Figures (2-35), (2-36), (2-37), and (2-38).

This may result in a bigger expropriation width, but the maintenance cost of the channel decreases.

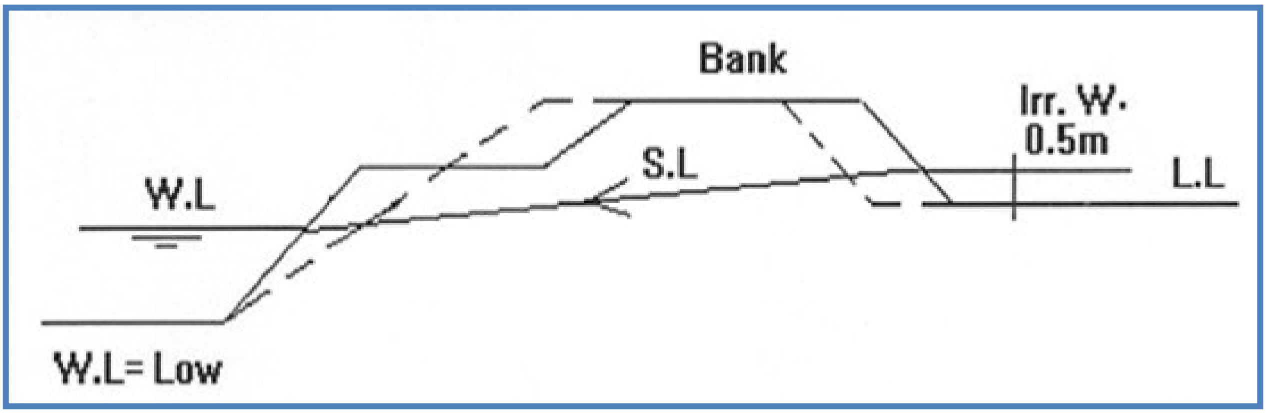


Figure (2-35): Check for Seepage, W.L. < L.L.

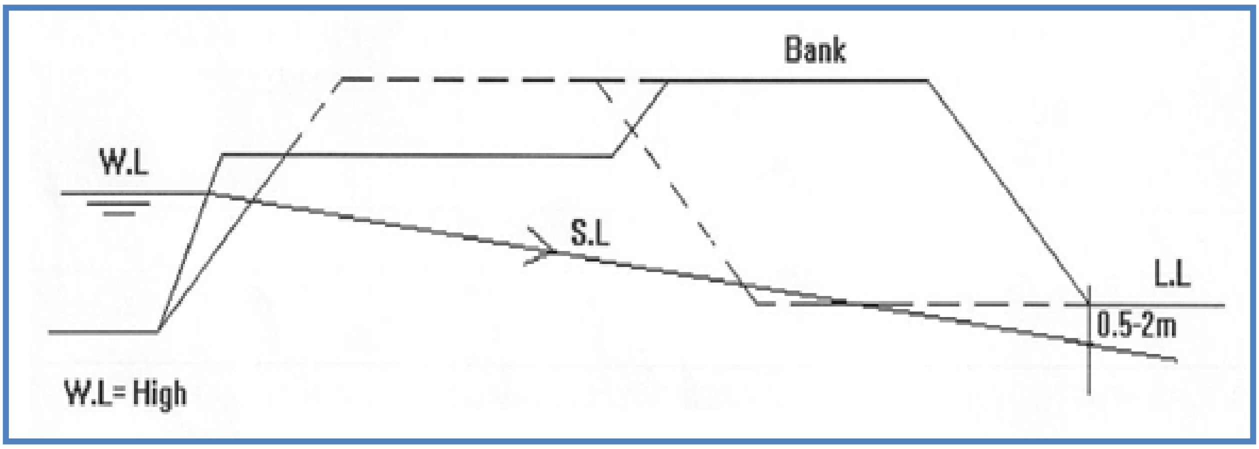


Figure (2-36): Check for Seepage, W.L. > L.L.

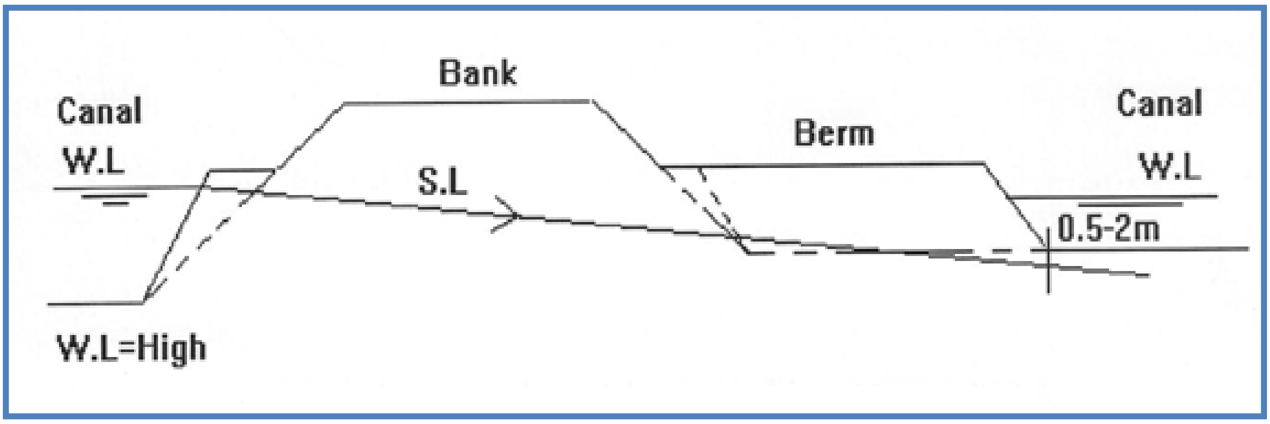


Figure (2-37): Check for Seepage, Two Canals

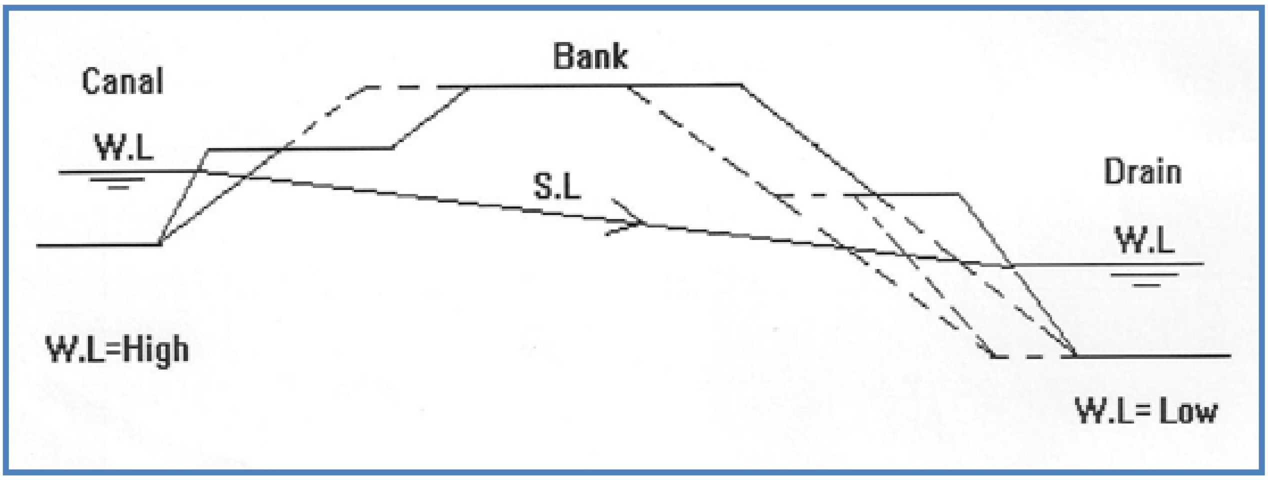


Figure (2-38): Check for Seepage, Canal, and Drain

2-10-3 <u>The Expropriation Width:</u>

The expropriation width is the horizontal distance between the ends of the right and the left banks. It depends mainly on the required volume of excavation <u>*as follows:*</u>

1) Volume of Cut = Volume of Fill:

It is the economic case, as shown in Figure (2-39).

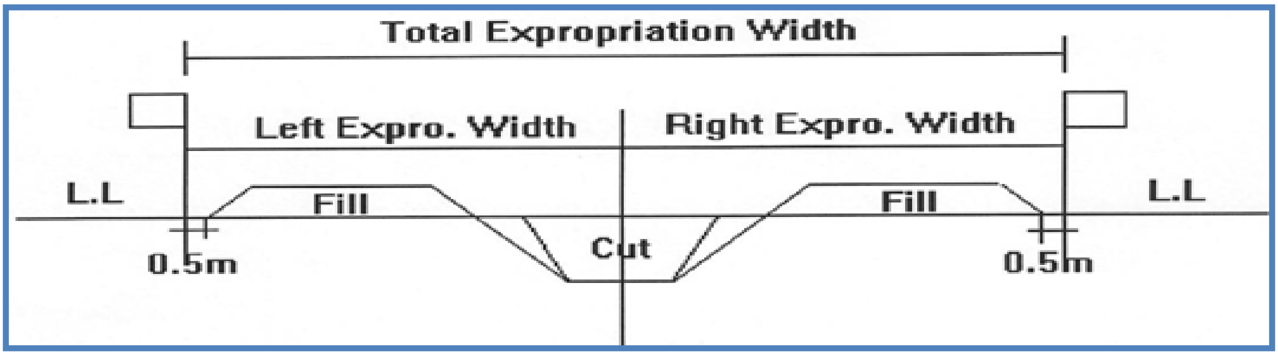


Figure (2-39): Volume of Cut = Volume of Fill

2) Volume of Cut > Volume of Fill:

In this case, the excess volume of cut is heaped as spoils beside the two banks with a height not to exceed 5.0 m, as shown in Figure (2-40).

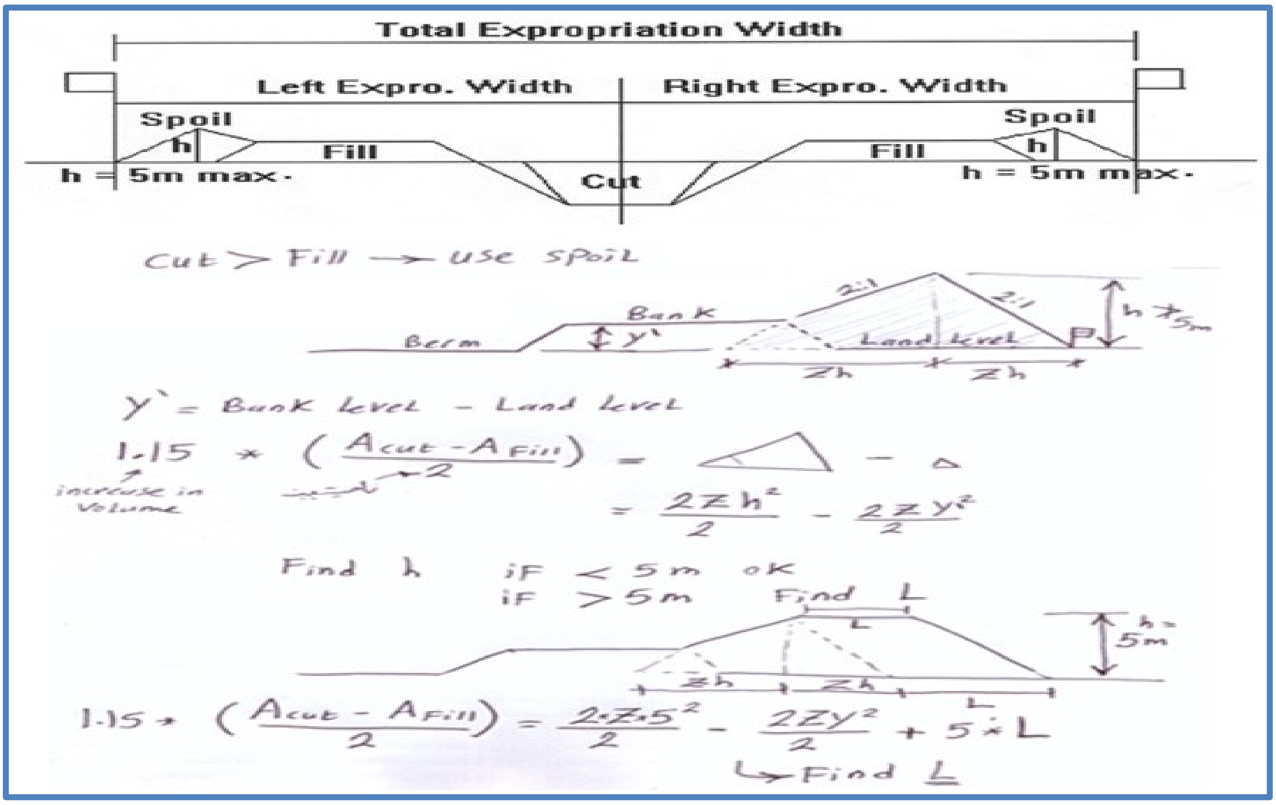


Figure (2-40): Volume of Cut > Volume of Fill

3) Volume of Cut < Volume of Fill:

In this case, the required volume of fill is taken from the adjacent land forming borrow bits of a width (L) and a depth not more than 25 cm to maintain the land suitable for agriculture, as shown in Figure (2-41).

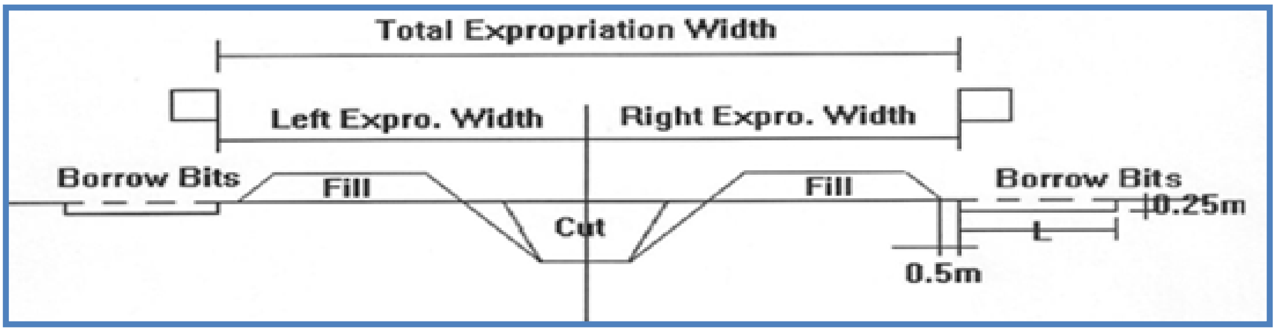


Figure (2-41): Volume of Cut < Volume of Fill

Thus, the expropriation width can be calculated, the associated table of the longitudinal section is completed, and the typical cross-section can be easily drawn for the required different locations.

2-11 Irrigation Openings:

It is an opening (hole) in the distributary canal to convey the water to the field's mesqa. It is commonly concrete pipes with a suitable diameter according to the area served. As shown in Figure (2-42), the pipe is placed such that its upper limit is at least 25 cm below the water level in the distributary canal.

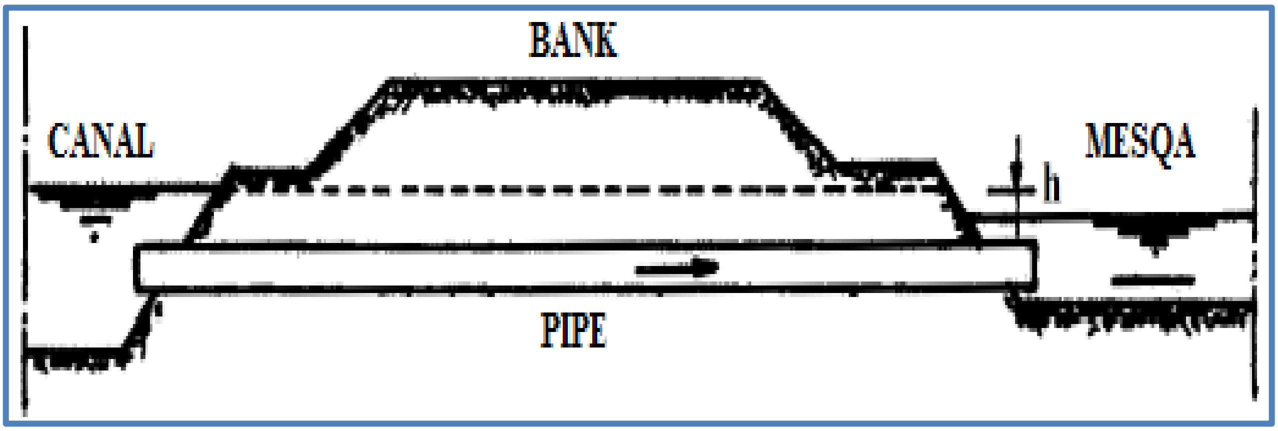


Figure (2-42): Irrigation Opening (A Pipe from Distributary Canal to Mesqa)

The head above the pipe must cover the losses due to friction, inlet, and outlet.

$$h = \frac{f\,L\,v^2}{2\,g\,d} + \frac{1.5\,v^2}{2\,g} \quad \text{...} \quad (12)$$

Where:

h: Total head losses, cm

f: Friction coefficient, according to the material of the pipe

L: Length of pipe, m

v: Velocity in the pipe, m/s

g: Gravitational acceleration, g = 9.8 m/s^2

d: Diameter of the pipe, m

A: Area served, Fed

$$f = 1.5(0.01989 + (0.0005078 / d) = 0.03 + (0.00076 / d)$$

$$A = \frac{3000\,d^2}{\sqrt{\frac{f\,L}{d} + 1.5}} \quad \text{...} \quad (13)$$

Tables (2-8) and (2-9) illustrate the area served for different diameters and lengths for 50 m^3/Fed/day water duty and 0.25 m head.

From the appropriate table, choose the column of the required length of the pipe, go vertically to the required area served, and then go horizontally to get the suitable diameter.

In Tables (2-8) and (2-9) also, note that the first column indicates the area served for only 10 m long pipe specifically for the Ministry of Water Resources and Irrigation, Egypt.

For the heads, more than 0.25 m, Table (2-10) is used to get the suitable conversion ratio. From Table (2-10) also, choose from the first column the required tens of the head, then go horizontally to the required units and get the conversion ratio.

Table (2-8): Diameter of Pipes according to Length (5-50 m) and Area Served

Area Served for L=10 m	**d, cm**	(WD = 50 m^3/Fed/day and h = 0.25 m) **Area Served, Fed, for Length, m**									
		5	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**
10	**10**	16	13	11	9	9	8	7	7	7	6
20	**12.5**	25	22	19	17	15	14	14	13	12	12
30	**15**	41	34	30	27	24	23	21	20	19	18
45	**17.5**	58	49	42	39	36	33	31	30	28	27
65	**20**	78	67	59	54	50	46	44	41	39	37
85	**22.5**	101	88	78	72	66	62	58	55	53	51
110	**25**	126	111	100	92	85	80	75	71	68	65
135	**27.5**	157	138	125	115	107	101	95	90	86	83
165	**30**	188	167	152	140	131	123	117	111	106	102
235	**35**	263	236	217	201	188	177	168	167	154	149
315	**40**	348	316	292	272	256	242	231	221	212	204
405	**45**	447	406	380	356	337	320	305	293	281	271
510	**50**	555	513	479	451	427	407	389	374	360	347
625	**55**	680	630	590	558	530	506	485	465	450	435
760	**60**	817	760	715	678	643	618	593	571	551	534
900	**65**	960	900	847	810	772	740	710	687	663	642
1060	**70**	1120	1051	998	953	909	873	840	813	785	762
1220	**75**	1290	1220	1158	1105	1060	1018	983	950	920	893
1400	**80**	1478	1398	1330	1273	1222	1177	1137	1100	1066	1035
1590	**85**	1675	1590	1515	1453	1397	1347	1347	1303	1262	1190
1790	**90**	1880	1790	1762	1644	1585	1530	1480	1435	1395	1355
2000	**95**	2100	2000	1922	1846	1785	1762	1670	1618	1575	1533
2230	**100**	2330	2230	2140	2010	1990	1925	1865	1813	1760	1717
	105	2575	2465	2370	2285	2202	2140	2080	2020	1970	1920
	110	2840	2720	2620	2530	2455	2370	2302	2240	2180	2130
	115	3100	2980	2870	2770	2690	2610	2540	2470	2410	2350
	120	3390	3260	3150	3050	2960	2870	2790	2720	2650	2590

Table (2-9): Diameter of Pipes according to Length (55-100 m) and Area Served

Area Served for L=10 m	**d, cm**	(50 m3/Fed/day and h = 0.25 m) **Area Served, Fed, for Length L, m**									
		55	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
10	**10**	6	6	5	5	5	5	5	5	4	4
20	**12.5**	11	10	10	9	9	9	9	8	8	8
30	**15**	17	17	16	15	15	14	14	14	13	13
45	**17.5**	26	25	24	23	22	22	21	21	20	20
65	**20**	36	35	33	32	31	30	30	29	28	27
85	**22.5**	49	47	45	44	42	41	40	39	38	37
110	**25**	63	61	59	57	55	53	52	51	50	49
135	**27.5**	80	77	74	72	70	68	66	64	63	62
165	**30**	99	95	92	89	87	84	82	80	78	76
235	**35**	143	139	134	130	126	123	120	117	114	113
315	**40**	197	191	185	180	175	170	166	162	159	155
405	**45**	262	254	246	240	233	228	222	217	212	206
510	**50**	336	326	317	308	300	293	286	280	274	268
625	**55**	421	409	398	387	377	368	360	352	345	328
760	**60**	528	503	489	477	465	454	444	435	426	417
900	**65**	623	606	590	577	562	551	537	527	515	507
1060	**70**	740	720	708	684	668	652	640	636	614	603
1220	**75**	869	845	824	805	787	770	754	738	725	711
1400	**80**	1005	982	955	937	914	895	876	860	846	838
1590	**85**	1160	1130	1103	1076	1053	1034	1010	992	972	957
1790	**90**	1320	1288	1258	1223	1205	1180	1157	1134	1114	1095
2000	**95**	1495	1460	1425	1365	1365	1336	1313	1295	1265	1243
2630	**100**	1675	1636	1600	1568	1535	1503	1475	1448	1434	1398
	105	1875	1830	1790	1750	1715	1685	1655	1635	1595	1565
	110	2080	2035	1990	1950	1910	1875	1840	1810	1780	1750
	115	2300	2250	2200	2150	2110	2070	2030	2000	1970	1940
	120	2530	2480	2430	2380	2330	2290	2250	2210	2180	2150

Table (2-10): Conversion Ratio
of the Area Served from h=0.25 m to Another Head

h (Tens)	h 0	1	2	3	4	5	6	7	8	9
0	0.20	0.20	0.28	0.346	0.40	0.447	0.49	0.53	0.565	0.60
10	0.632	0.663	0.692	0.72	0.748	0.775	0.80	0.825	0.848	0.871
20	0.894	0.916	0.938	0.96	0.98	1.00	1.02	1.04	1.06	1.078
30	1.096	1.114	1.131	1.148	1.165	1.182	1.199	1.215	1.231	1.247
40	1.263	1.279	1.295	1.31	1.325	1.34	1.355	1.37	1.385	1.404
50	1.415	1.43	1.444	1.458	1.472	1.485	1.498	1.511	1.524	1.537
60	1.55	1.563	1.576	1.589	1.602	1.614	1.626	1.638	1.65	1.662
70	1.674	1.686	1.698	1.71	1.712	1.724	1.746	1.757	1.768	1.779
80	1.79	1.801	1.812	1.823	1.839	1.845	1.856	1.867	1.878	1.889
90	1.90	1.91	1.92	1.93	1.94	1.95	1.96	1.97	1.98	1.99
100	2.00									

Example (2-7):
It is required to irrigate 150 Fed with a pipe 15 m long under 0.25 m head. Determine the diameter of the pipe?

Solution

From Table (2-8), choose the column of 15 m length of the pipe,
go vertically to the required area served, the nearest value is 152 Fed, OK
and then go horizontally to get the suitable diameter, $\therefore$ d = 30 cm.

Example (2-8):
It is required to irrigate 350 Fed with a pipe 15 m long under 0.25 m head. Determine the diameter of the pipe?

Solution

From Table (2-8), choose the column of 15 m length of the pipe,
go vertically to the required area served, the nearest value is 380 Fed, OK
and then go horizontally to get the suitable diameter, $\therefore$ d = 45 cm.

Example (2-9):

It is required to irrigate 200 Fed with a pipe 20 m long under 0.34 m head. Determine the diameter of the pipe?

Solution

From Table (2-10), choose 30 from the first column of the head, then go horizontally to the column of 4 and get the conversion ratio = 1.165.
Modified area served = 1.165 * 200 = 232 Fed

From Table (2-8), choose the column of 20 m length of the pipe,
go vertically to the required area served, the nearest value is 272 Fed, OK
and then go horizontally to get the suitable diameter, ∴ d = 40 cm.

Example (2-10):

It is required to irrigate 200 Fed with a pipe 10 m long under 0.34 m head. Determine the diameter of the pipe?

Solution

From Table (2-10), choose 30 from the first column of the head, then go horizontally to the column of 4 and get the conversion ratio = 1.165.
Modified area served = 1.165 * 200 = 232 Fed

From Table (2-8), choose the column of 10 m length of the pipe,
go vertically to the required area served, the nearest value is 236 Fed, OK
and then go horizontally to get the suitable diameter, ∴ d = 35 cm.

It must be noted that for lift irrigation, lifting pumps are placed behind the irrigation opening with the required discharge.

Notes

	h, m	L, m	A, Fed	d, cm	A, Fed for L=10 m
Example 2-7	0.25	15	150 → 152	30	165
Example 2-8	0.25	15	350 → 380	45	405
Example 2-9	0.34	20	200 → 272	40	315
Example 2-10	0.34	10	200 → 236	35	235

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