LECTURE NOTES ON

IRRIGATION AND DRAINAGE ENGINEERING

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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:

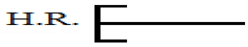
Water for irrigation is supplied to the field from the main source through different grades of canals, which form an irrigation network. The various grades of canals are ranked in a descending order *as follows:*

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.

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

Table (2-1): Grades of Canals

For planning an irrigation network, it has to be noted that any canal is represented by a continuous line. This line has the symbol (

) 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 (

). That is to dispose safely 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 through different grades of drains, which form a drainage network. The various grades of canals are ranked in an 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.

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

Table (2-2): Grades of Drains

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 a planning for irrigation and drainage networks.

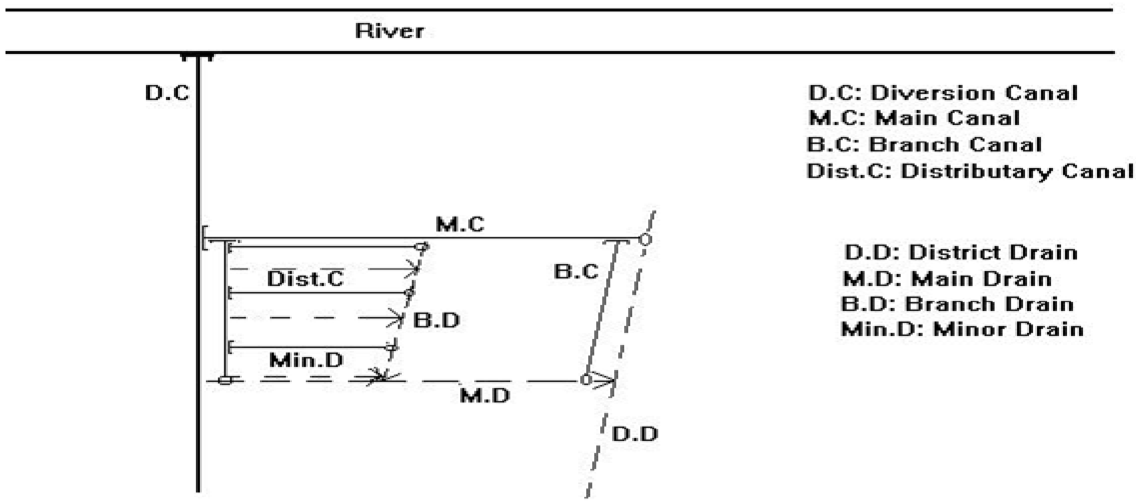


Figure (2-1): Irrigation and Drainage Networks

2-3 Planning of Irrigation and Drainage Networks:

In general, each canal has to cover all the area served required to be irrigated with 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 in order 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 shortest possible length. The drains are preferred to be planned at the low locations such that the excess water is disposed 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 (2-2).

Figure (2-3) shows a planning for the irrigation and drainage networks in the case of corrugated topography.

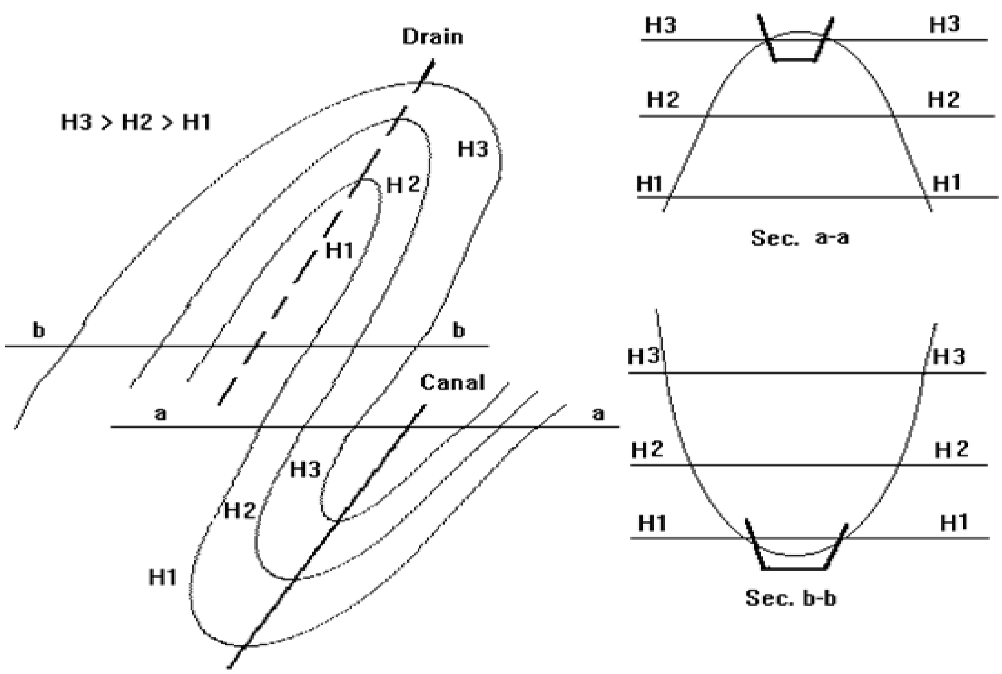


Figure (2-2): Ridges for Canals and Depressions for Drains

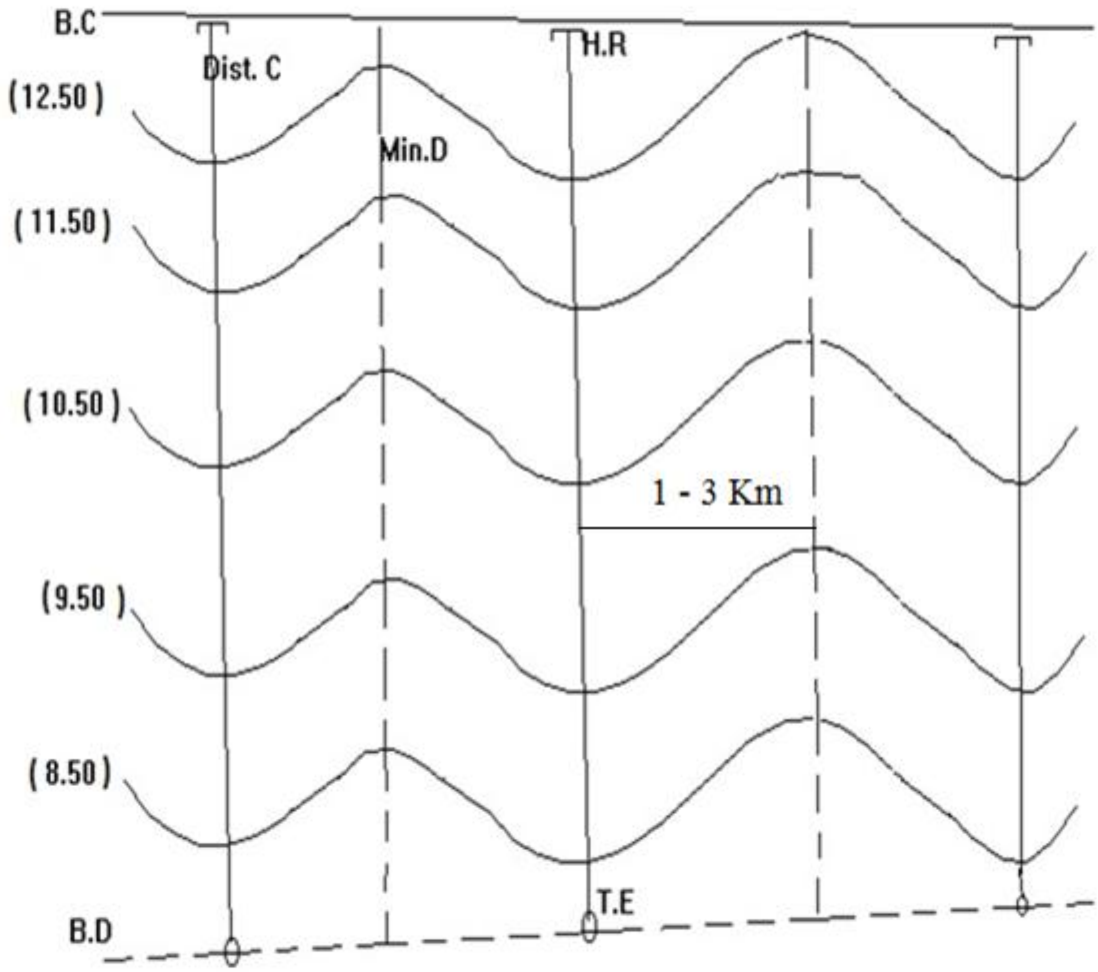


Figure (2-3): Planning for Corrugated Topography

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 it, as shown in figure (2-4 /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 it, as shown in figure (2-4 /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 it, as shown in figure (2-4 /c).

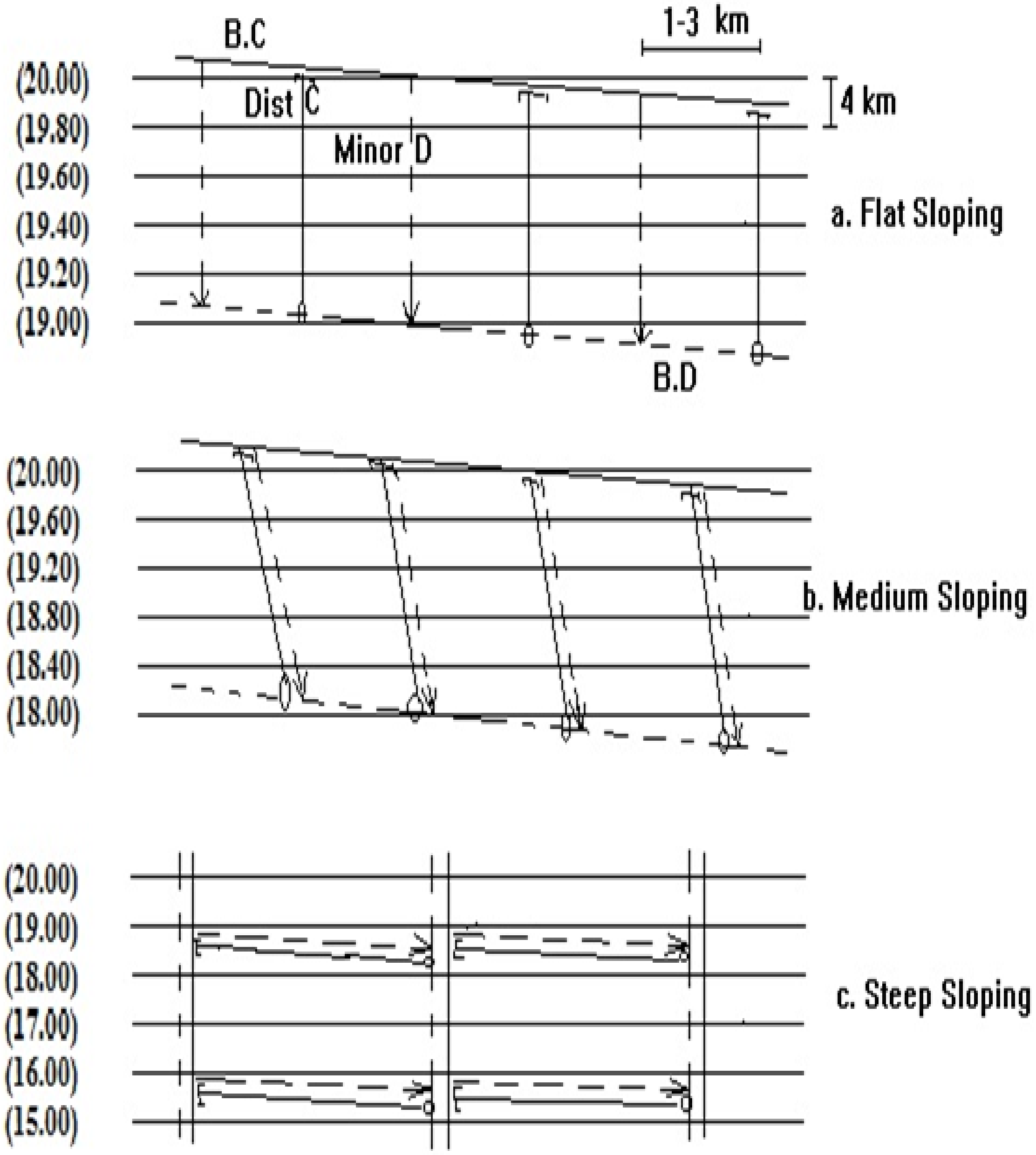


Figure (2-4): Planning for Sloping Topography

<u>Note:</u> ***<u>Correct planning has to:</u>***

1) Follow the planning rules with respect to the contour map.
2) Serve all the area 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.

<u>Exercise (2-1):</u>

Check the planning for the irrigation and drainage networks required to serve the illustrated area in figure (2-5)?

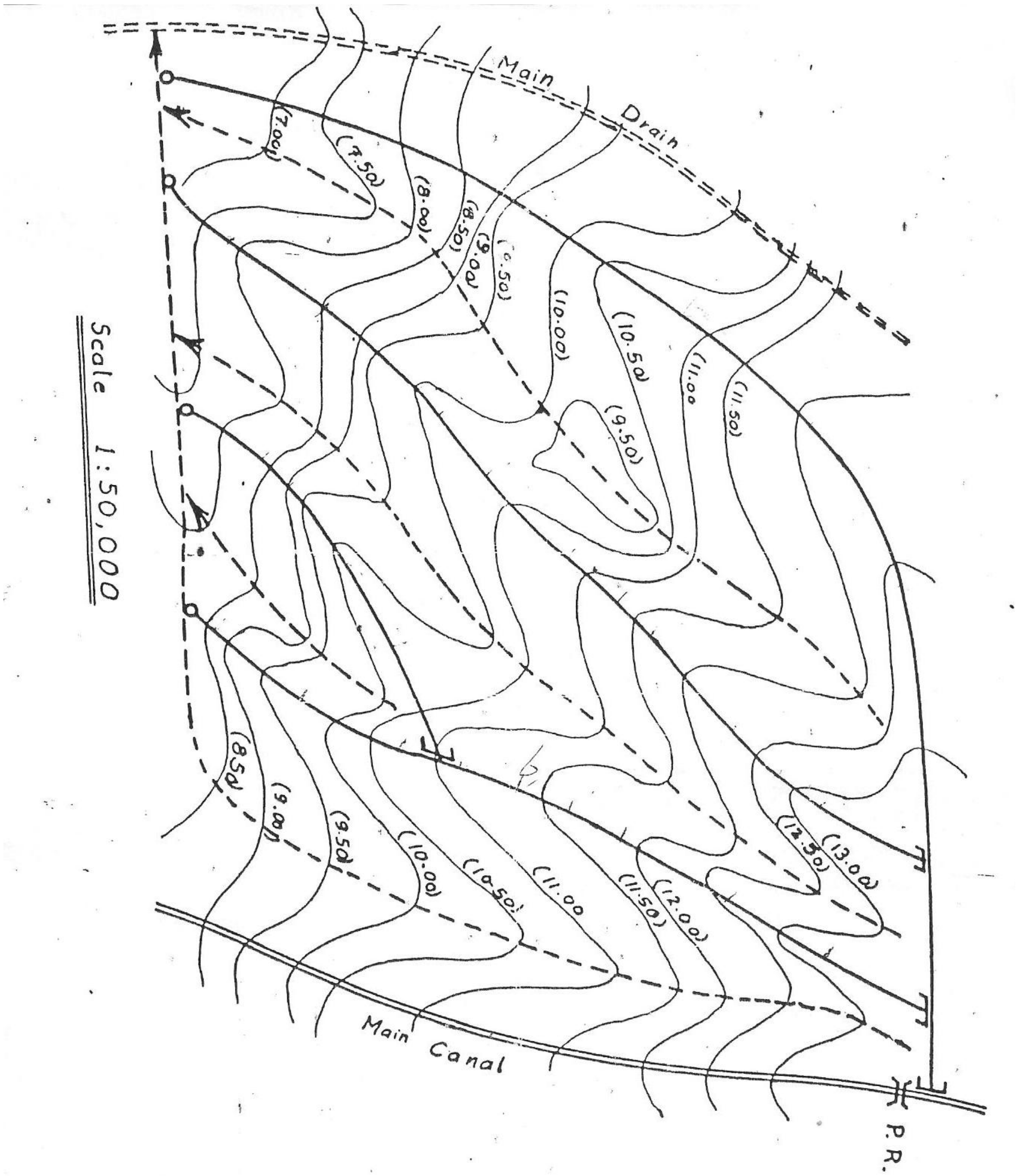


Figure (2-5): Contour Map for Exercise 2-1

<u>Exercise (2-2):</u>

An area of 7,500 Feddans is sloping from the north to the south, as shown in figure (2-6). This area is bounded by a 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 complete planning 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?

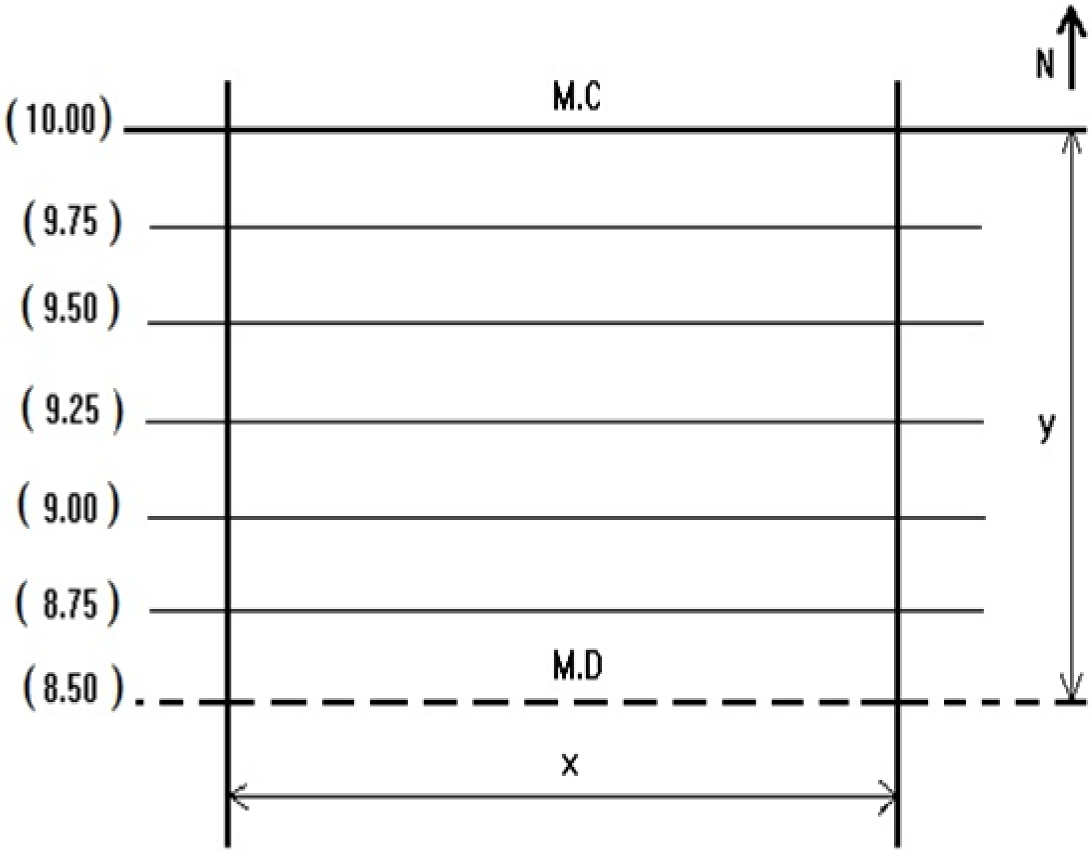


Figure (2-6): Contour Map for Exercise 2-2

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 water line. 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 (2-7).

2. The line representing the land levels (L.L.) is drawn for each canal according to the contour map, as shown in figure (2-8).

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 levels. For lift irrigation, water levels have to be 50 cm below the average land levels. The slope of the water line (i) depends on the ground slope (S) as illustrated in table (2-1).

The water lines for the two irrigation systems are shown in figure (2-9).
Figures (2-10) and (2-11) illustrate the water lines for the distributor canals according to the ground slope for both free and lift irrigation respectively.

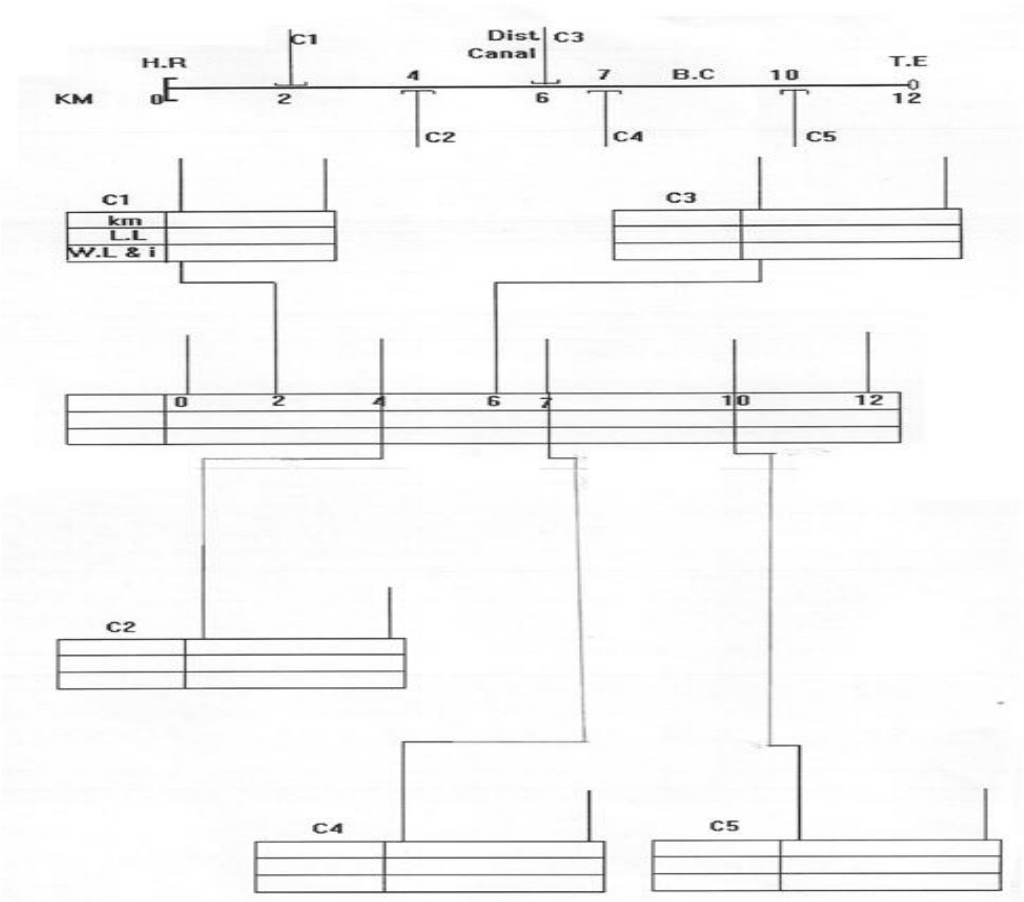


Figure (2-7): Longitudinal Section for Branch Canal and its Distributor Canals

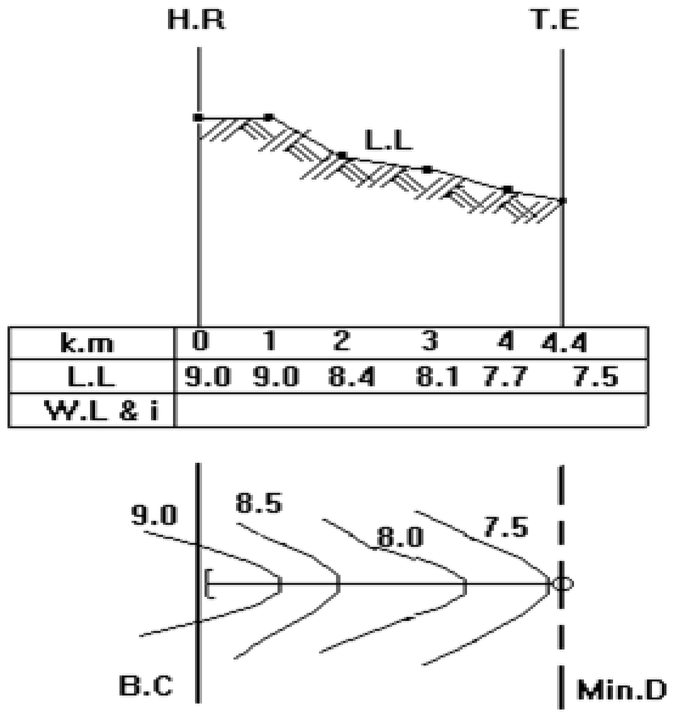


Figure (2-8): Land Levels for Canals

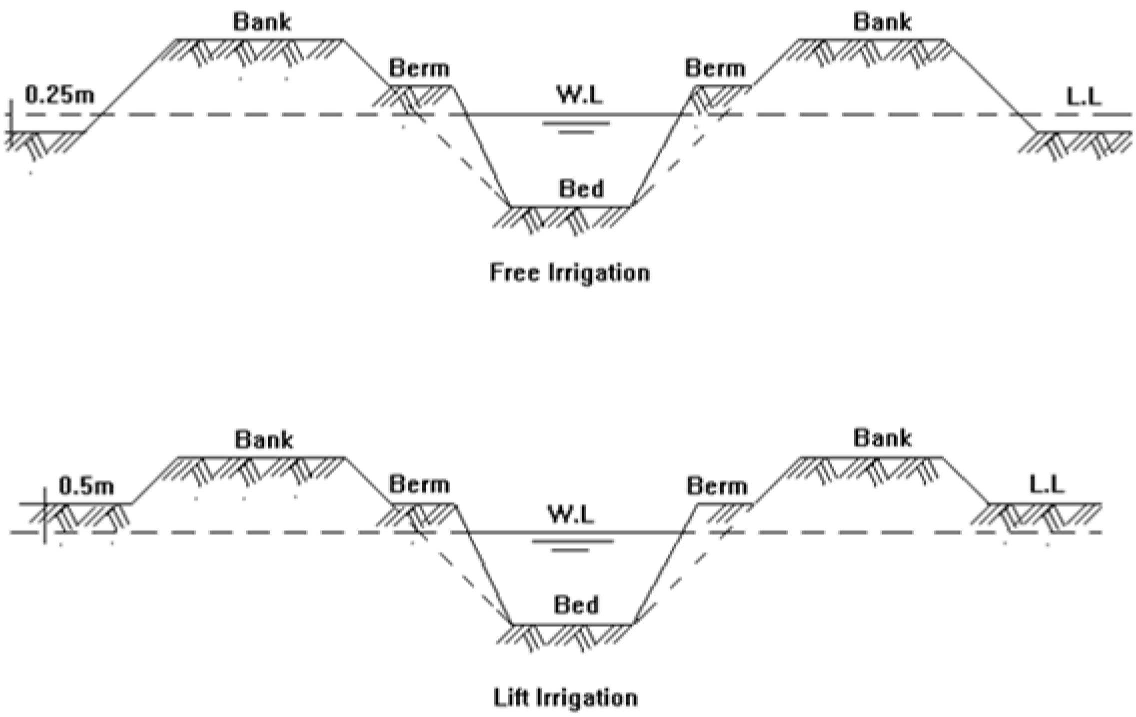


Figure (2-9): Water Line for the Irrigation Systems

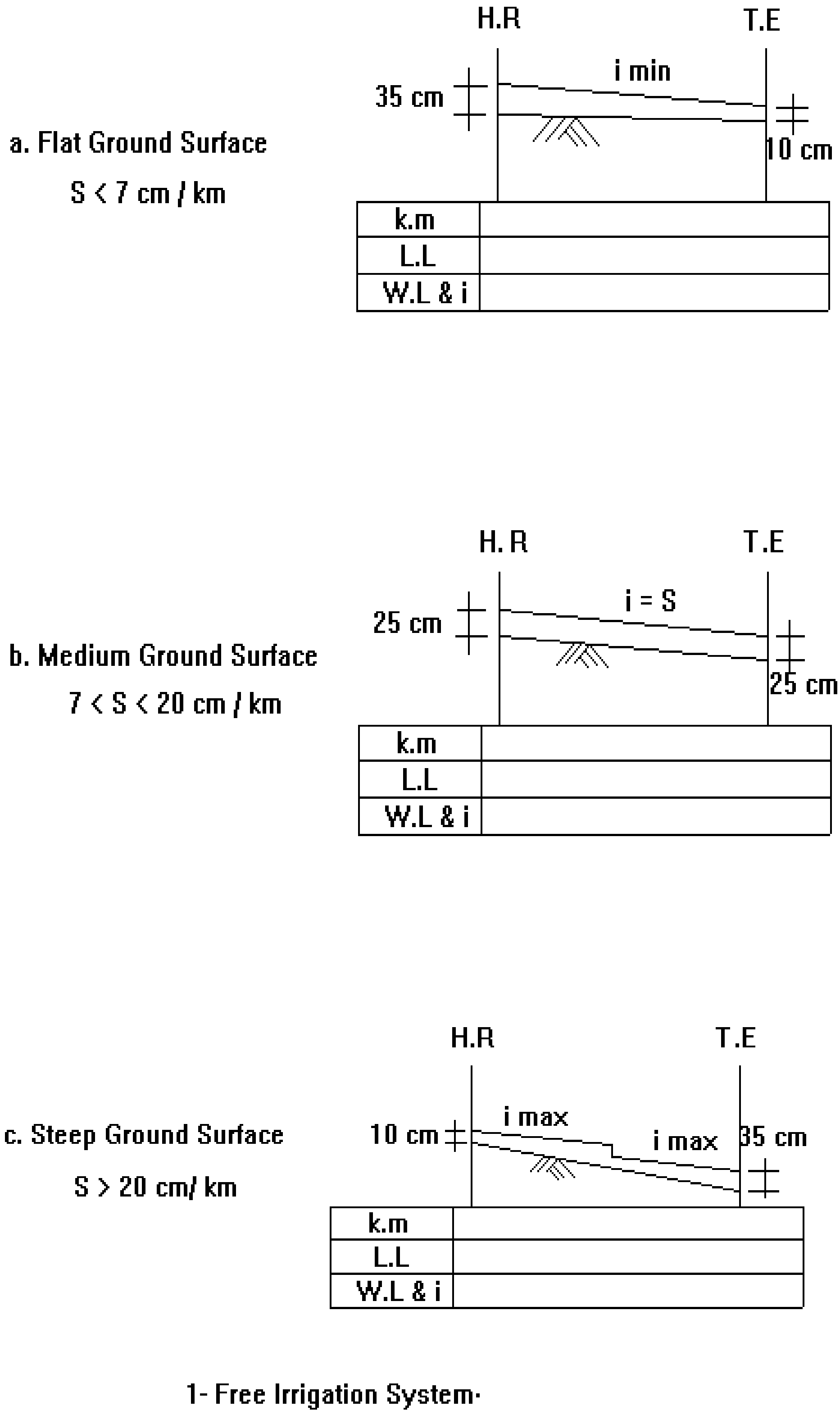


Figure (2-10): Water Line for the Distributor Canals for Free Irrigation

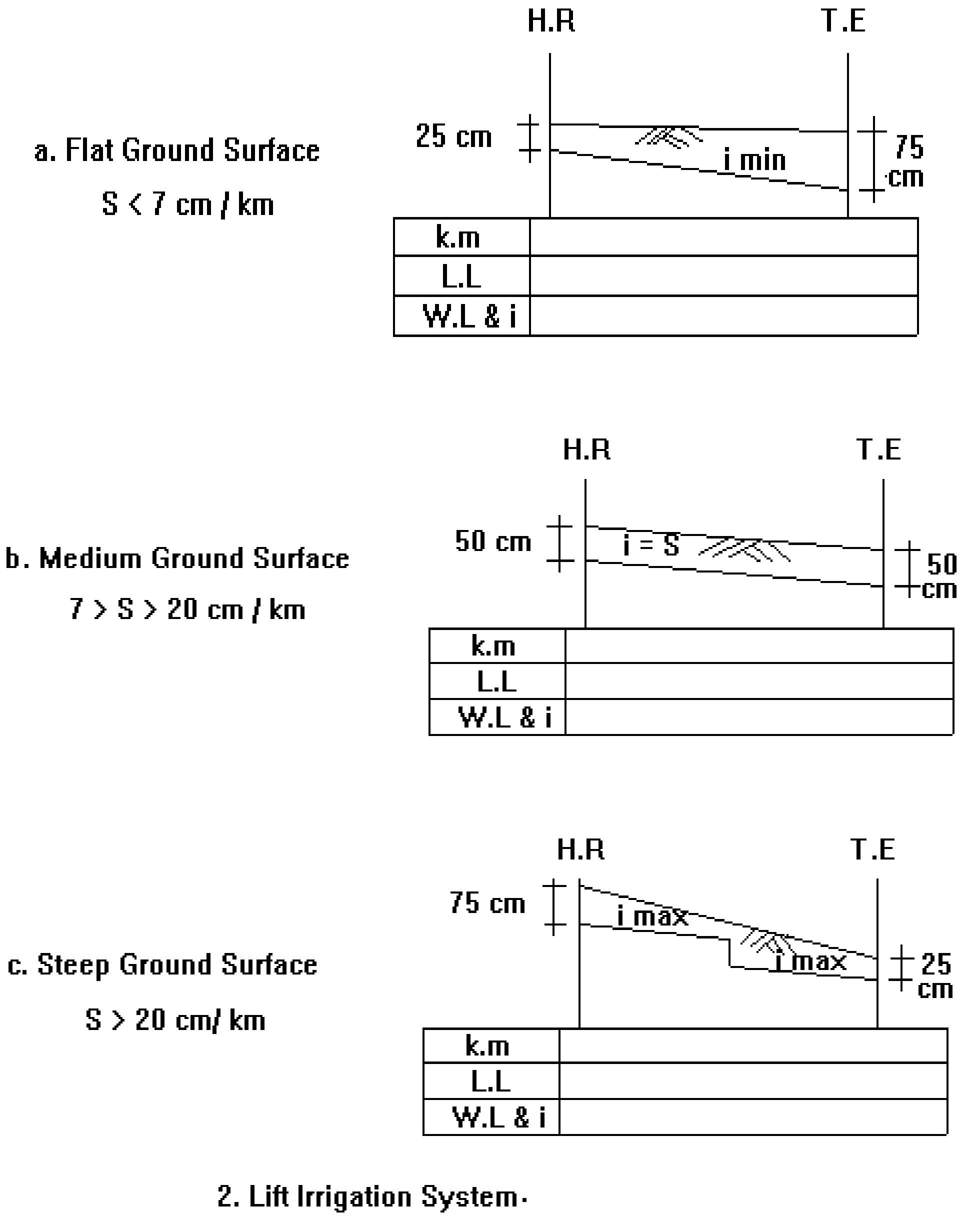


Figure (2-11): Water Line for the Distributor Canals for Lift Irrigation

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

5. Then, the water levels upstream 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 (2-12).

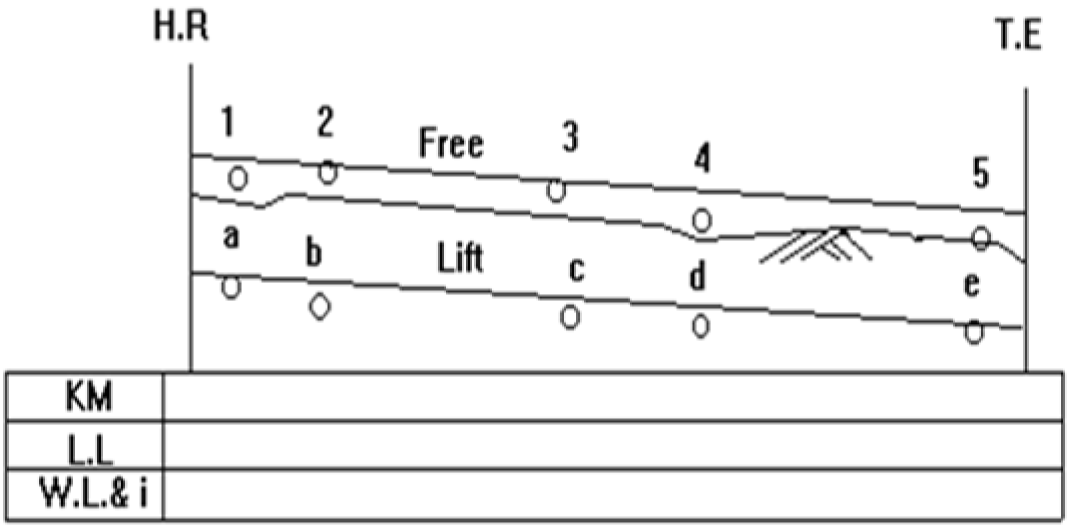


Figure (2-12): Water Lines for Branch Canals

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 in order 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 in order to control the water level in the canal (by disposing 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 (2-13). It is preferred to change the slope of the water line at the constructions existed along the canal.

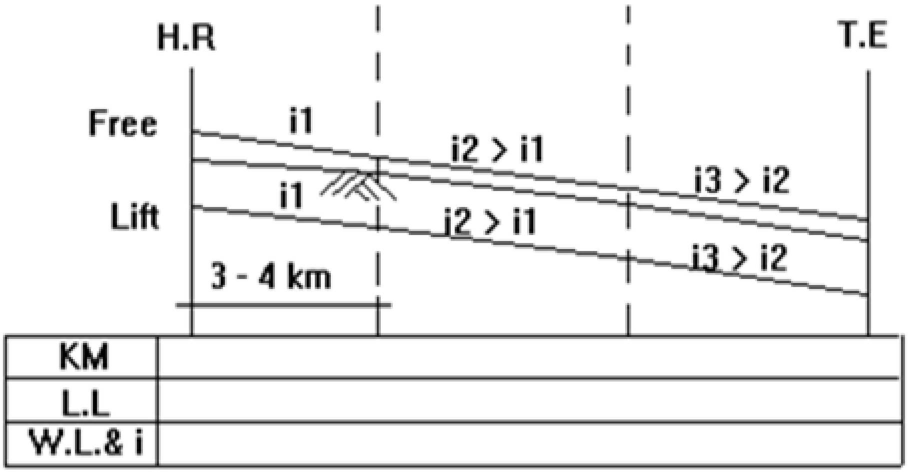


Figure (2-13): Changing the Slope of Water Lines for Canals

4. The height of the water required for the two types of irrigation systems is allowed to be decreased or increased in limited zones in order to use a constant slope for the water line for the distributor canals, as shown in figure (2-14).

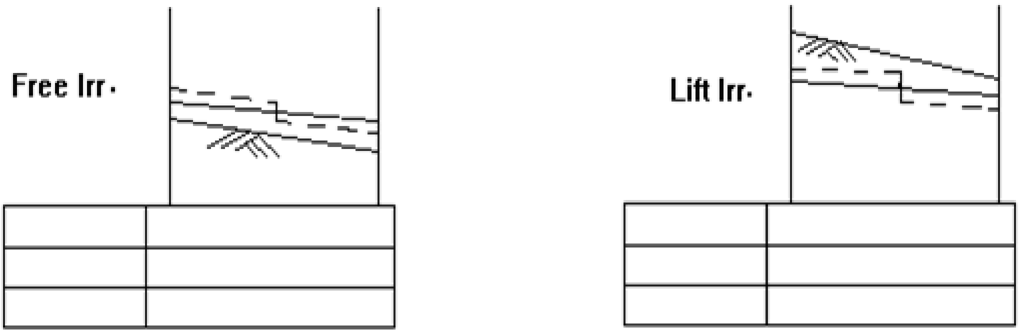


Figure (2-14): Allowable Heights for Irrigation Systems for Distributor Canals

5. It is allowed to change the followed type of irrigation system in limited zones in order to use a constant slope for the water line for the distributor canals, as shown in figure (2-15).

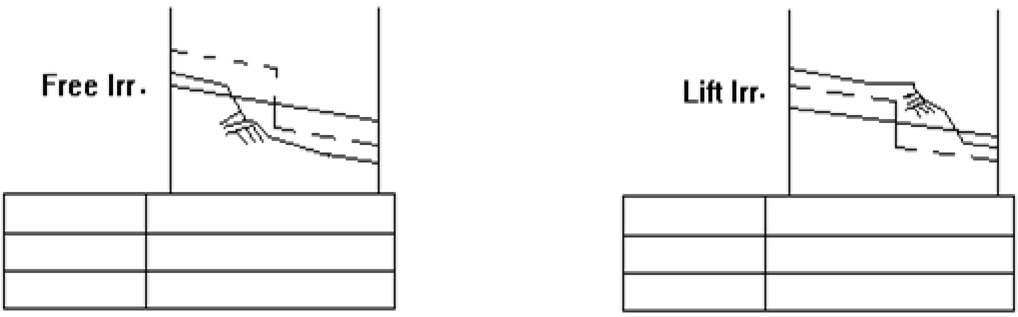


Figure (2-15): Allowable Changing for Irrigation Systems for Distributor Canals

6. The problem of drops in the water line for canals, if arises, can be solved, as shown in figure (2-16), *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 50 - 150 cm, a clear over fall weir can be used.
c) If the drop in the water line is greater than 150 cm, a regulator is to be used.

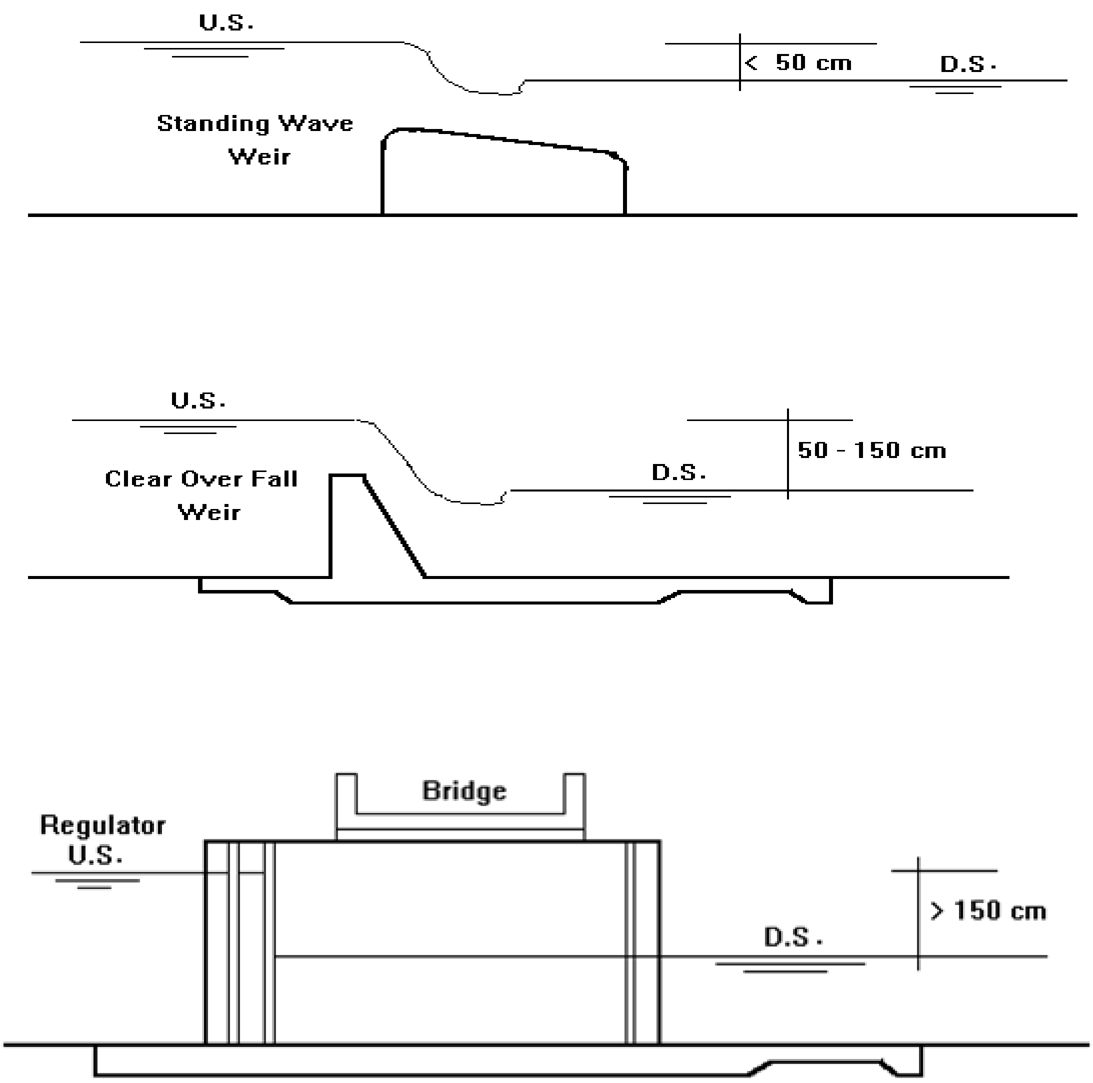


Figure (2-16): Drops in the Water Line for Canals

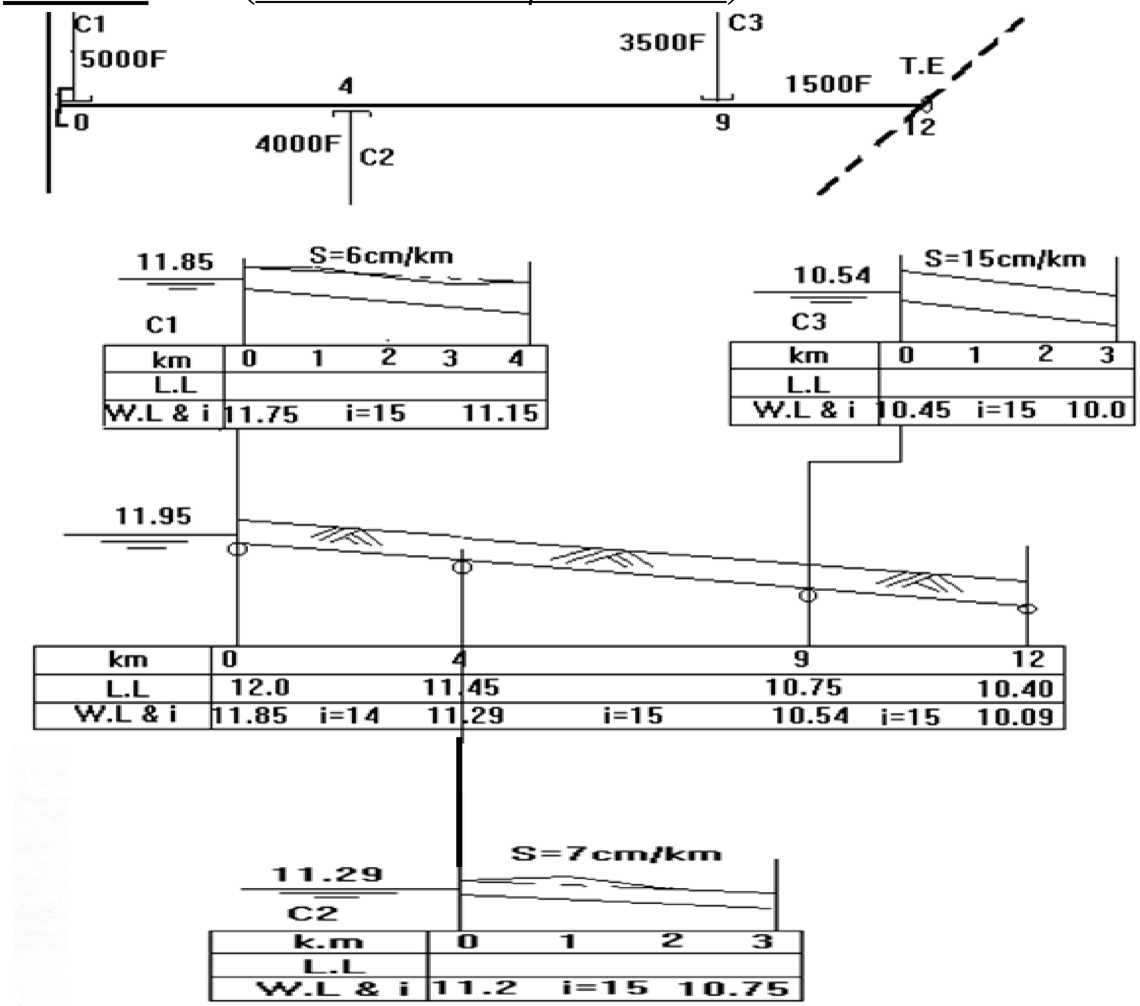
Example (2-1):

A branch canal has a length of 12.0 km, serves an area of 14,000 Feddans 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 (2-17). 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:

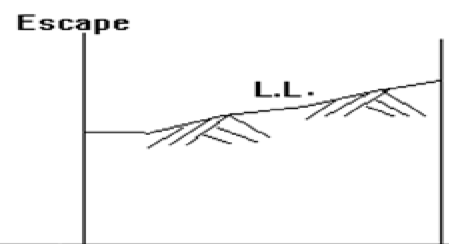
1. The water line has to be 1.25 - 1.50 m below the average land levels, as shown in figure (2-18).
2. The slope of the water line (i) depends on the ground slope (S) as illustrated in table (2-2).
3. The water level upstream the outfall of each minor drain has to be higher than the water level in the branch drain by 10 - 20 cm, as shown also in figure (2-19).

b) For the branch drains:

1. The water line has to be 1.5 - 2.0 m below the average land levels.
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 in order 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 levels.
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 in order to lift the water, as shown in figure (2-20).



k.m	0	1	2	3	4	4.4
L.L	9.0	9.0	9.5	9.8	10.2	10.5
W.L & i						

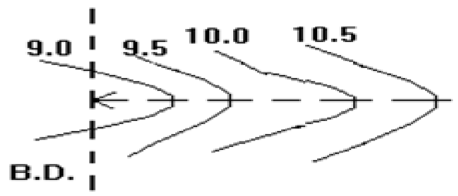


Figure (2-17): Land Levels for Drains

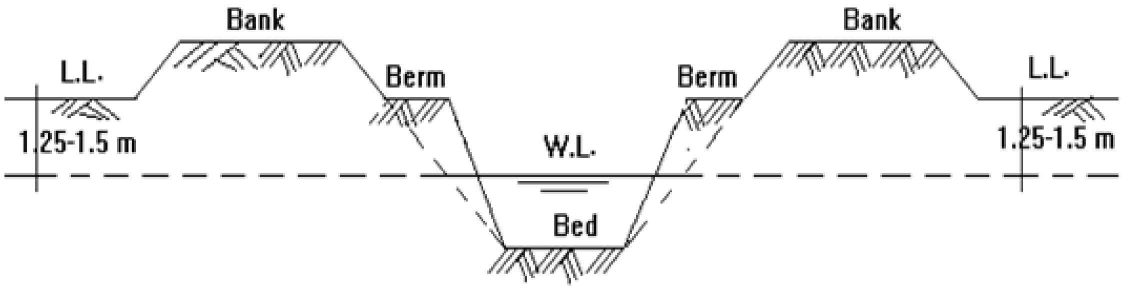


Figure (2-18): Water Line for the Minor Drains

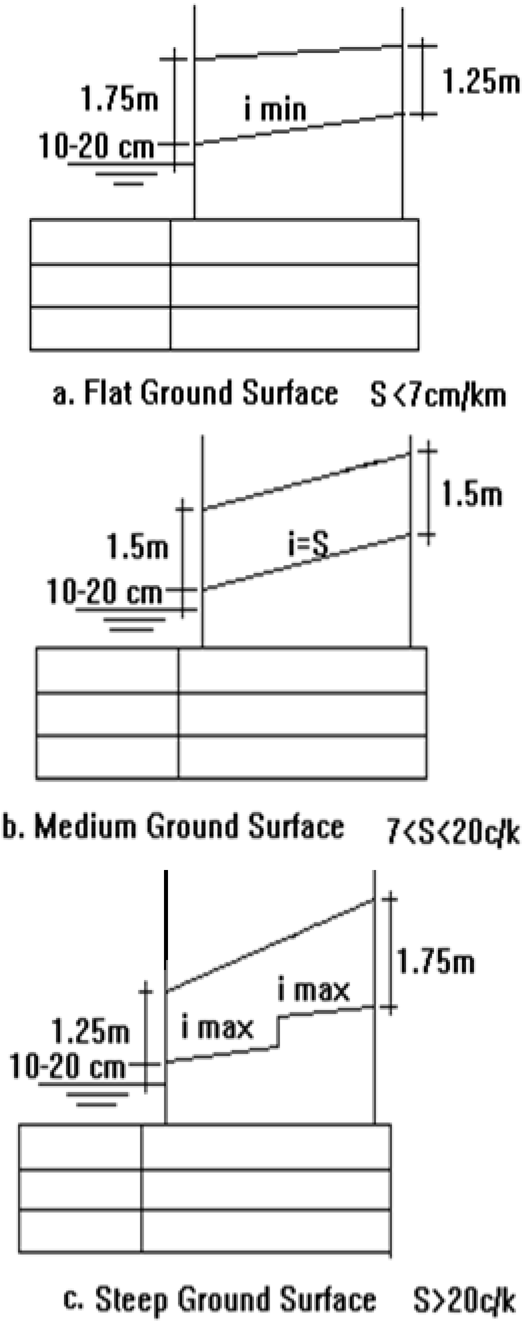


Figure (2-19): Longitudenal Water Line for the Minor Drains

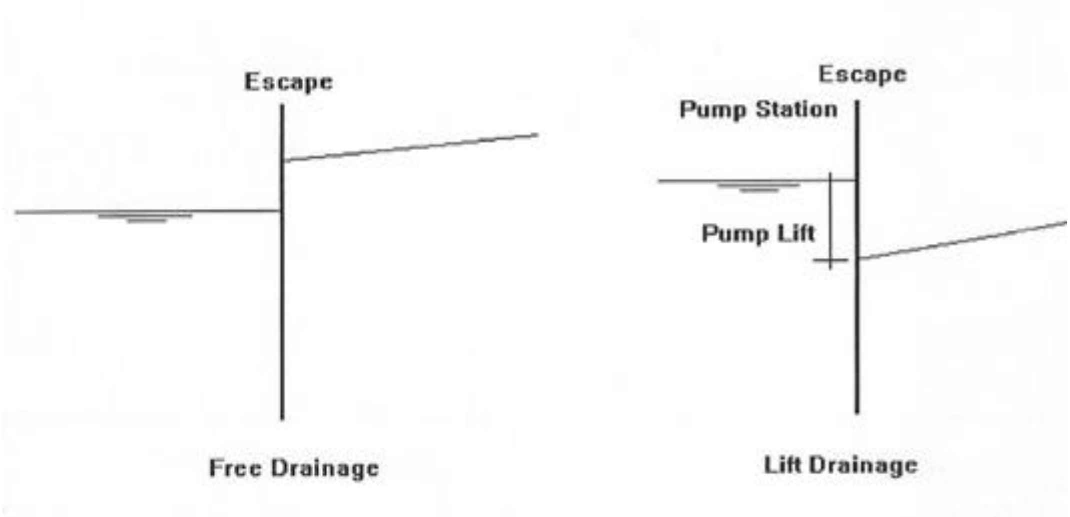


Figure (2-20): Drainage of the Main Drains into the District Drains

♦ **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 (2-21).

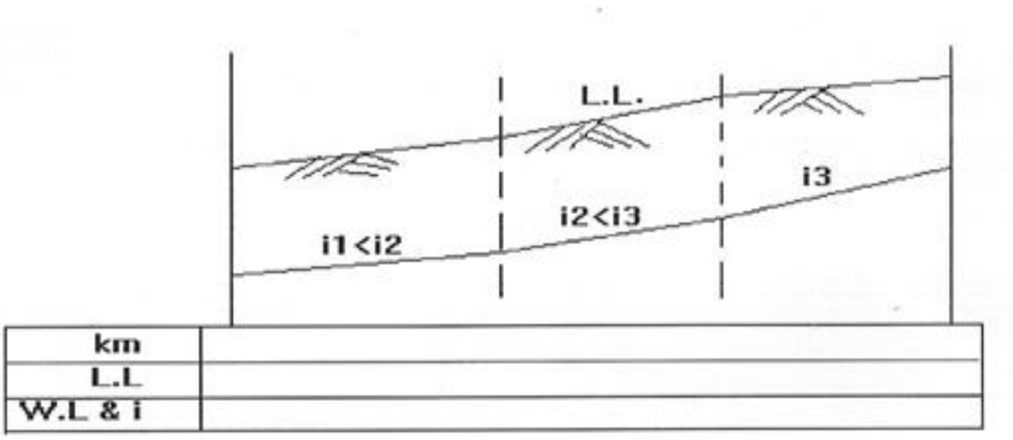


Figure (2-21): Changing the Slope of Water Line for Drains

2. The problem of drops in the water line for drains, if arises, can be solved, as shown in figure (2-22), *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.

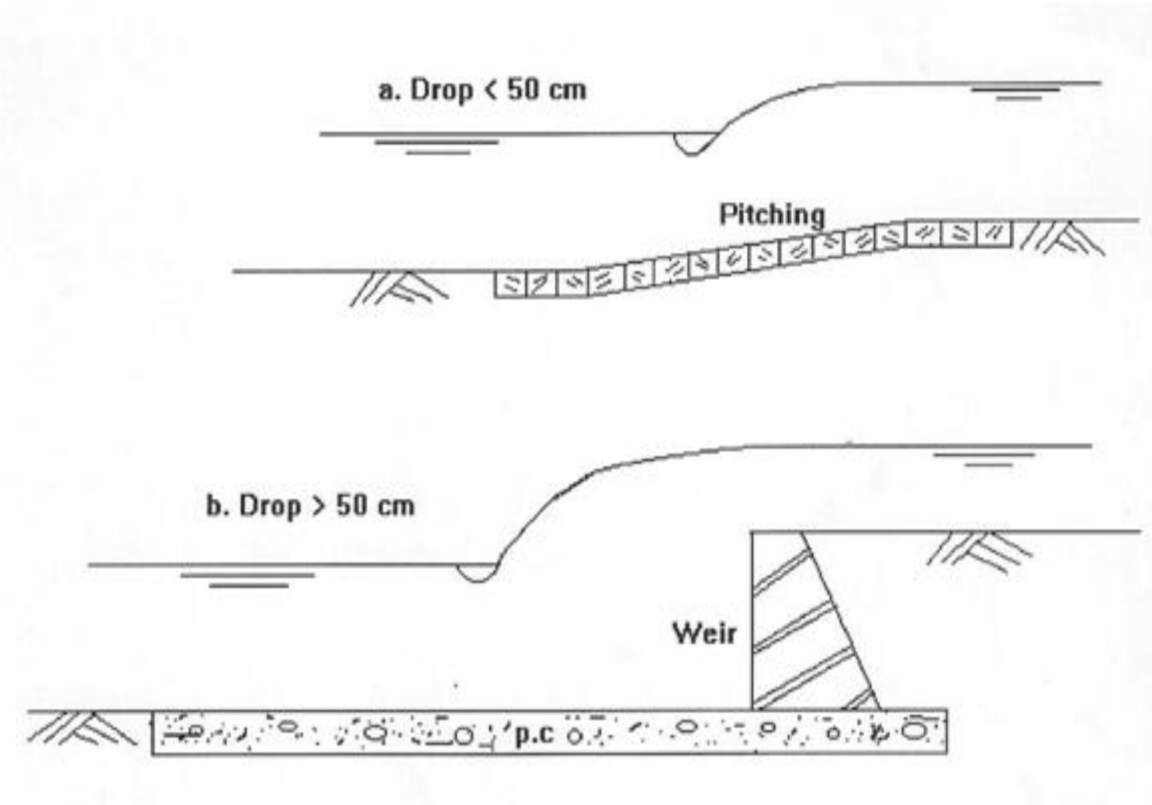


Figure (2-22): Drops in the Water Line for Drains

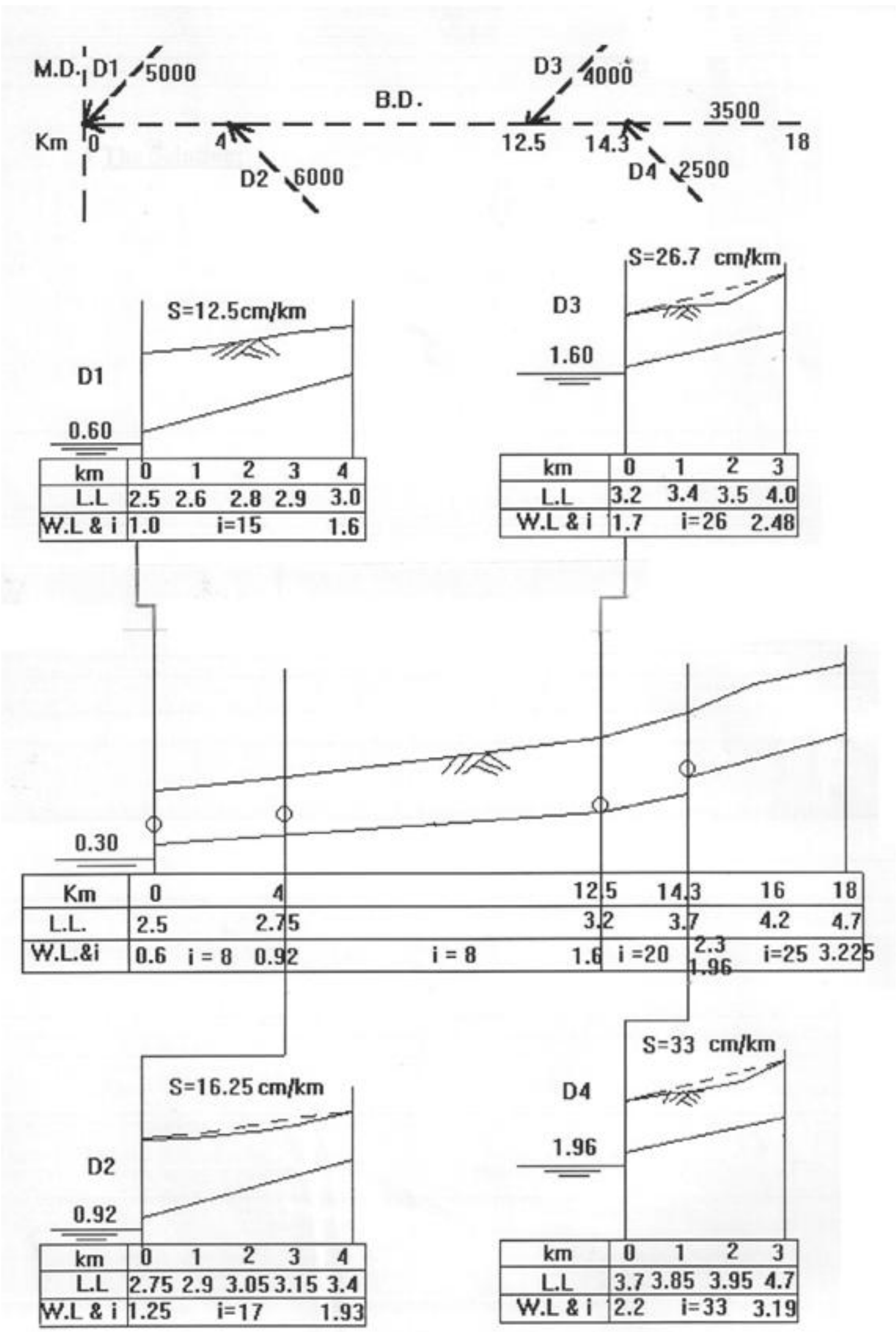
Example (2-2):

A branch drain has a length of 18.0 km, serves an area of 21,000 Feddans and falls in a 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 in order 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 Feddans. This branch canal feeds six distributor canals *as follows:*

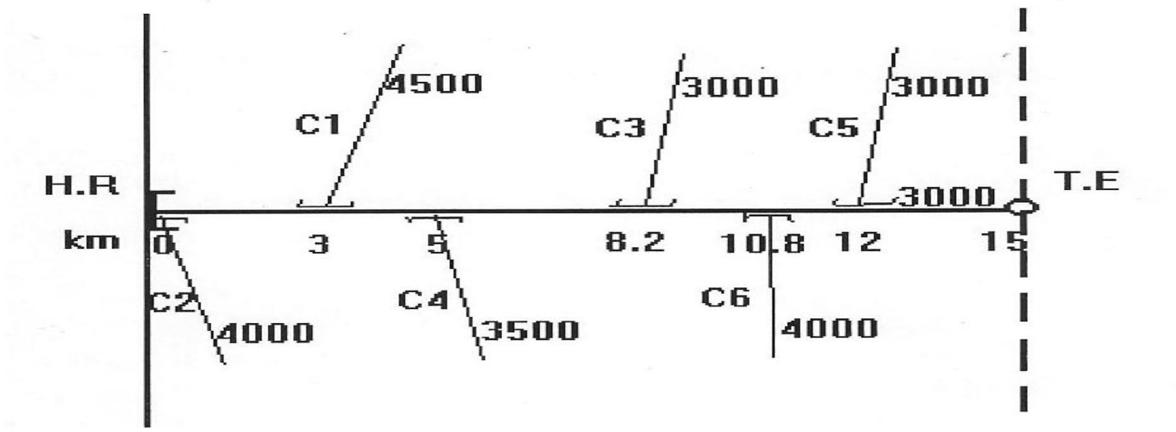
Distributor Canal	Location, Km	Area Served, Feddan
C 1	3.0, Left	4,500
C 2	0.0, Right	4,000
C 3	8.200, Left	3,000
C 4	5.0, Right	3,500
C 5	12.0, Left	3,000
C 6	10.800, Right	4,000

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

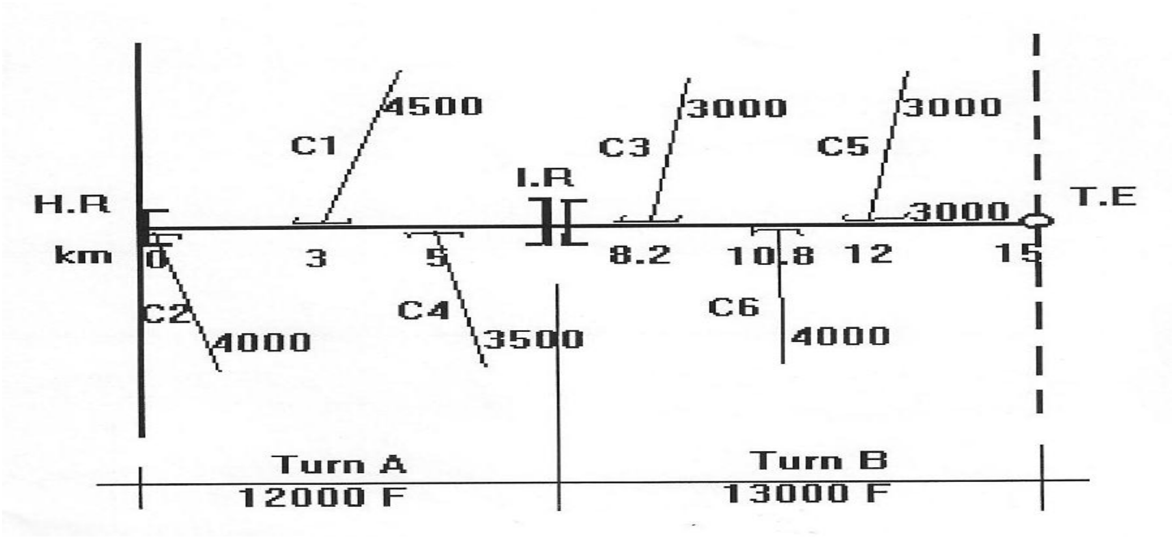


2) Case of no irrigation rotations:

Section	Location, Km	Area Served, Feddans
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, Km	Area Served, Fed		AS + Comp., Fed		AS$_{design}$, Fed
		A	B	A+0.3B	B+0.3A	
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			AS$_{design}$ 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 Feddans. 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

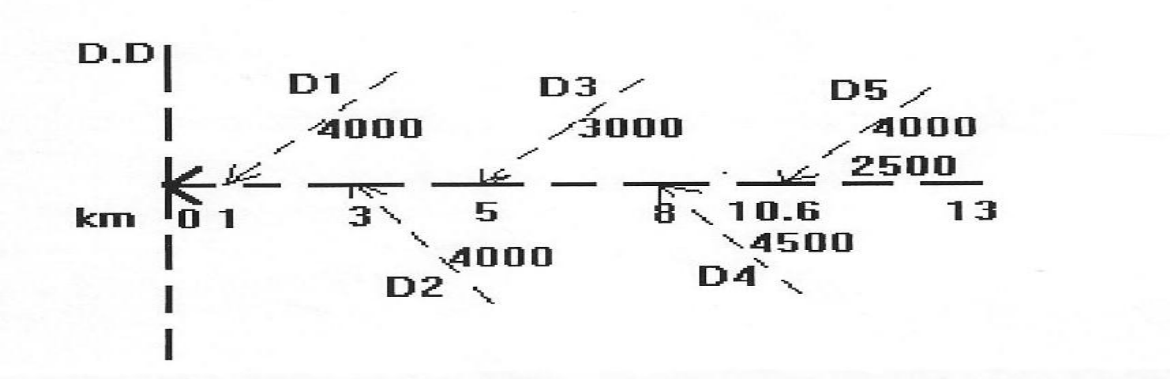
1) Sketch a plan for the branch drain and the minor drains?
2) Choose the sections to be designed and determine the area served for the design?

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 (2-23), **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 in order 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.

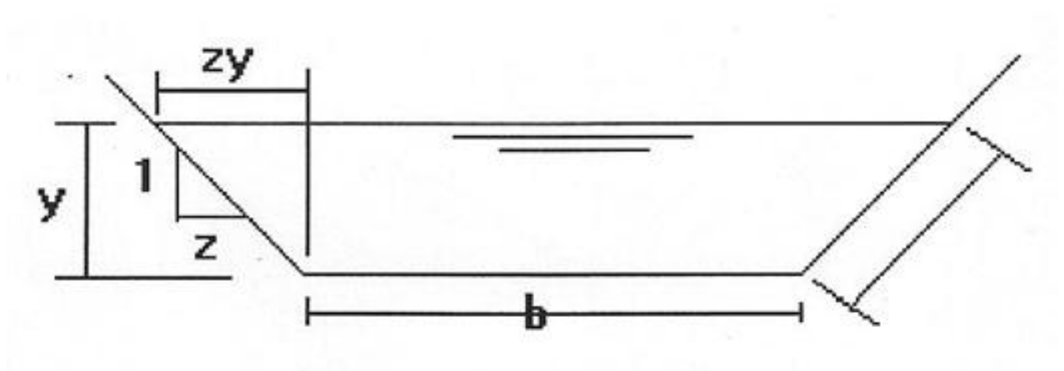


Figure (2-23): Trapezoidal Cross Section

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 common used formula is **Manning equation**, *which is:*

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

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

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

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 per 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 down 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 unit less coefficient that depends on the hydraulic condition of the channel. The values for (1/n) are given in tables (2-3) and (2-4) for different canals and drains.

1/n	**Hydraulic Condition of the Canal**
40	Canals with average conditions.
44	New earth canals.
50	Masonry canals.
60	Rough brick canals.
70	Concrete lined canals.

Table (2-3): Roughness Coefficients for Canals

1/n	**Hydraulic Condition of the Drain**
33	Drains with average conditions.
28	Very weedy drains.

Table (2-4): Roughness Coefficients for Drains

(5) The hydraulic mean radius (R):

R = A / P

For the trapezoidal cross section:

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

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

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

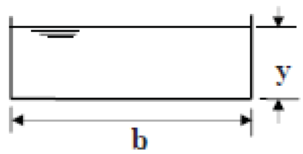
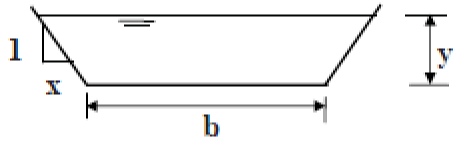
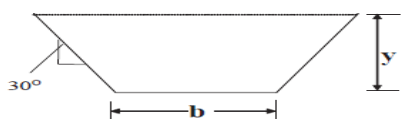
(6) The bed slope (S):

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 water line (i) of the canal in order to have a uniform flow. The value of (i) is got from the final synoptic diagram for the canal.

Thus, in order 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 maximum discharge for a given cross sectional area (through least wetted perimeter).

$P = 2y + \frac{A}{y}$ $\frac{dP}{dy} = 0$ b = 2 y	
$P = \frac{A}{y} - xy + 2y\sqrt{1 + x^2}$ $\frac{\partial P}{\partial y} = 0$ $\frac{\partial P}{\partial x} = 0$ $b = 2\,\frac{\sqrt{3}y}{3}$	

Microsoft Excel software, as a spread sheet, was employed to obtain the required best hydraulic sections for trapezoidal channels (A published paper, Dr. Alaa El-Hazek, VII – International Conference on Environmental Hydrology, Cairo, Egypt, 2012). *The design sheet can be downloaded from my page on the university site.*

2-8 Non Silting Non Scouring Sections:

2-8-1 Cross Sections for Irrigation Networks:

One of the following two equations for non-silting and non-scouring conditions can be used:

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

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

Where, i : cm/km

The value of the bed width (b) has to be modified to nearest 0.5 m. So, the corresponding modified value for the water depth (y_m) is calculated *as follows:*

$$A_{calculated} = A_m$$

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

Example (2-5):

A canal serves an area of 7,000 Feddans, has a water duty of 50 m^3/Fed/day and has a trapezoidal cross section. The canal runs in a silt soil.

Design the cross section of the canal at km 0.0 where the water slope is 10 cm/km?

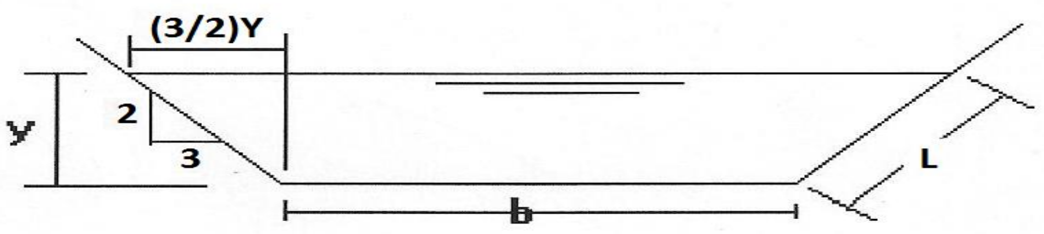
Solution:

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

Trapezoidal section. Silt soil ∴ z : 1 = 3 : 2

i = 10 cm/km

$$Q = A.S. \times W.D. = \frac{7{,}000 \times 50}{24 \times 60 \times 60} \qquad \therefore Q = 4.051 \text{ m}^3/\text{sec}$$



$A = b\,y + 2 \times \frac{1}{2} \times y \times 1.5\,y$

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

Assume, y < 1.62 m, *then:*

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

$\therefore\ b = 2\,y$

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

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

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

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

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 → R.H.S. = 10.875

y = 1.65 → R.H.S. = 9.828

y = 1.68 → 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

$A_{calculated} = A_m$

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

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

$1.5\ y_m^2 + 3.5\ y_m - 10.22 = 0$

$y_m^2 + 2.33\ y_m - 6.81 = 0$

$$\therefore y_m = \frac{-2.33 \pm [(2.33)^2 - (4 \times 1 \times -6.81)]^{1/2}}{2 \times 1}$$

$\therefore y_m = 1.7$ m

2-8-2 Cross Sections for Drainage Networks:

In order to design the cross sections of the drains, Manning equation is to be used with one of *the following equations:*

For i < 10 cm./km.

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

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

For i > 10 cm./km.

$y = b$ **for b < 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.

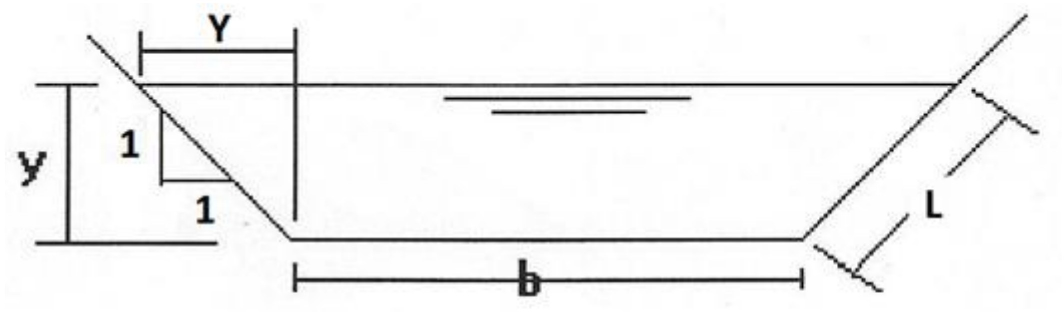
Example (2-6):

A minor drain serves an area of 6,000 Feddans 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

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



$$A = b\,y + 2 \times \frac{1}{2} \times y \times y$$

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

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

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

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

$$\therefore b = 1.49 \text{ m} < 2 \text{ m} \qquad \text{O.K.}$$

Take $b_m = 1.5$ m

$$A_{calculated} = A_m$$

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

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

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

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

2-9 <u>Longitudinal Sections:</u>

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 (2-24) and (2-25). It includes four main lines that represent <u>the land line</u>, <u>the water line</u>, <u>the bed line</u> and <u>the bank line</u>.

Also, the longitudinal section includes a table indicating *<u>the following:</u>*

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.

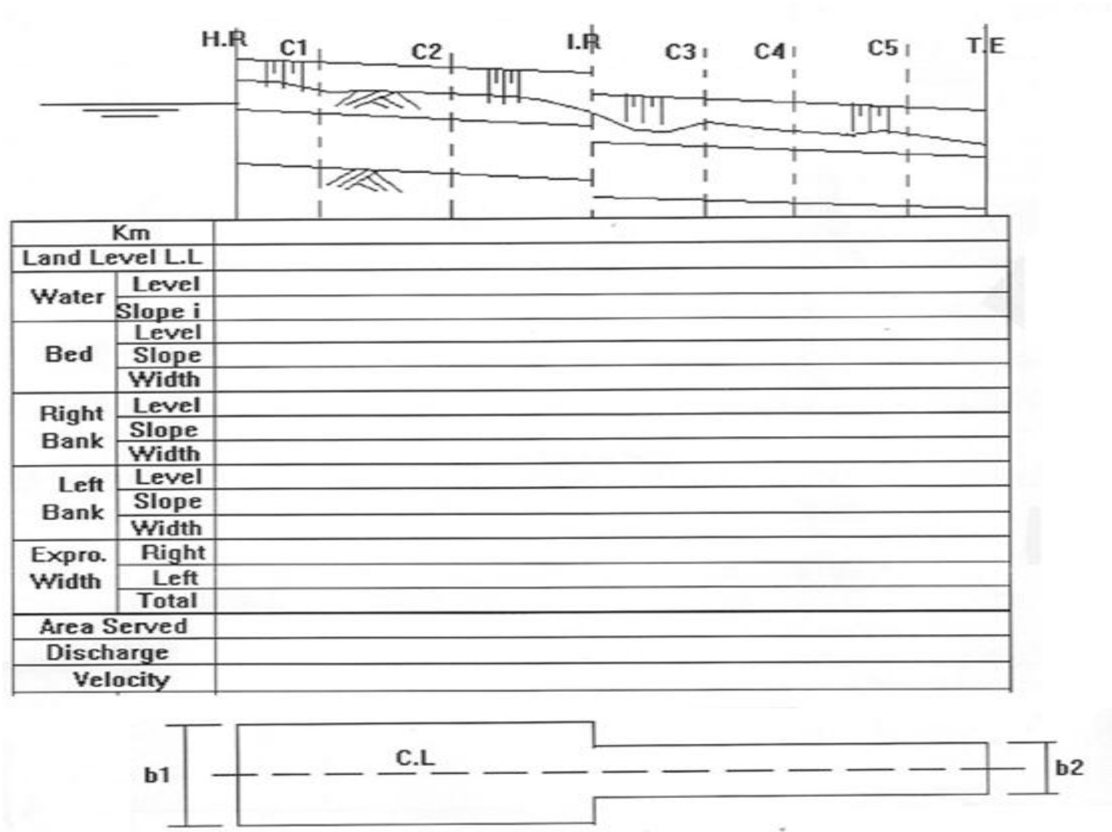


Figure (2-24): Longitudinal Section for a Branch Canal

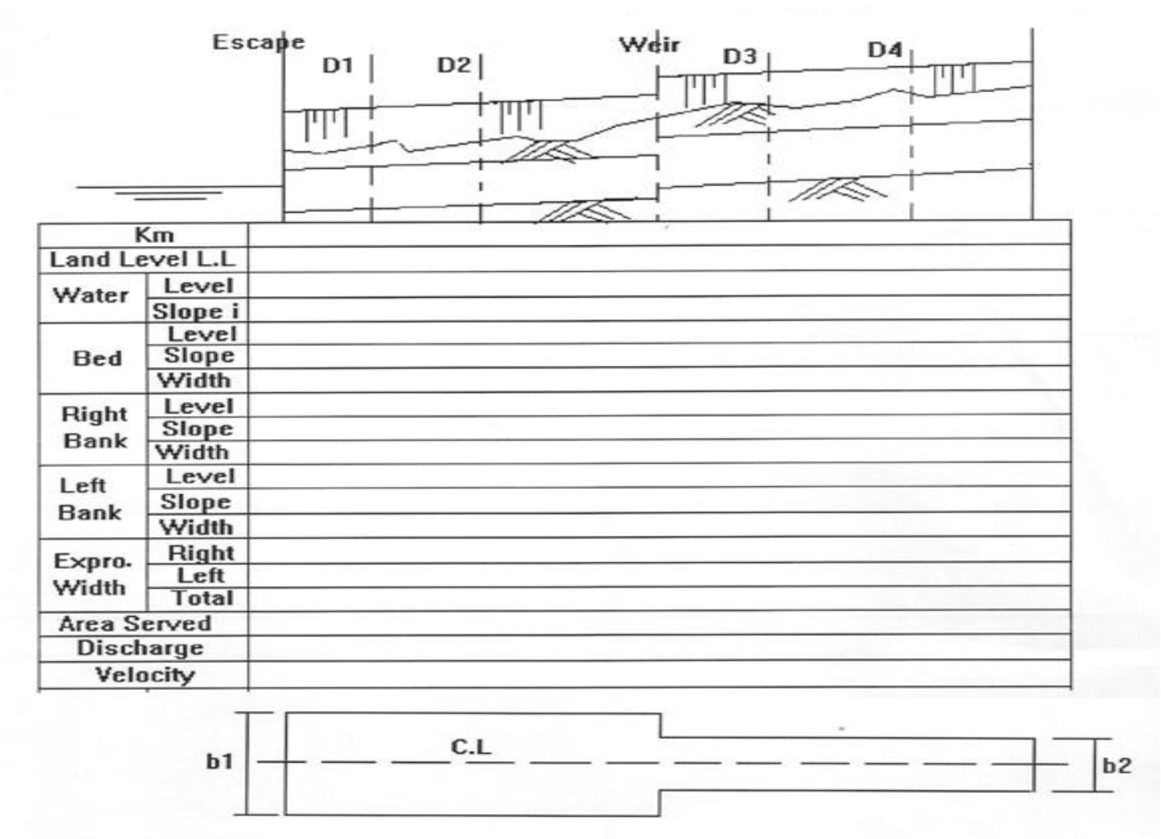


Figure (2-25): Longitudinal Section for a Branch Drain

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

These two lines are drawn as got from the final 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 is the same as the water line slope in order to satisfy the ideal condition for the uniform flow.

Drop(s) in the bed line can be made only at the locations of constructions. 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 or the bed width. 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 water line. 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 (2-5).

While for drains, the rise of the bank depends mainly on the amount of cut that is to be disposed.

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.

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

Table (2-5): Banks for Canals

2-10 <u>The Typical Cross Section:</u>

The most common cross section for the irrigation channels is the trapezoidal section. Figure (2-26) shows a model for the typical cross section.

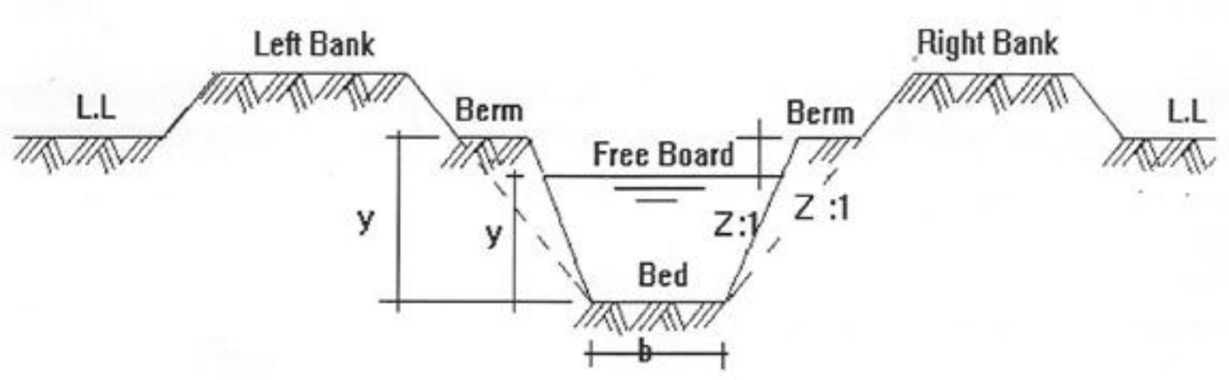


Figure (2-26): A Model for the Typical Cross Section

<u>2-10-1 The Berm:</u>

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

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

<u>Where,</u>	(z : 1)	: side slope of the water way.
	$(z_1 : 1)$	: 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 (2-27) and (2-28),
Minimum width for the berm = $(z_1 - z)\ y_1 + 5.0$ m

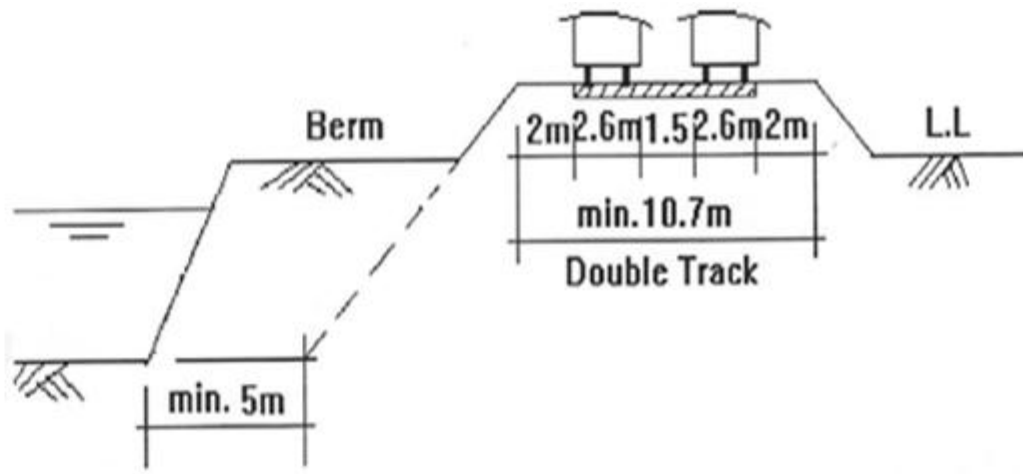


Figure (2-27): A Railway Bank beside a Channel

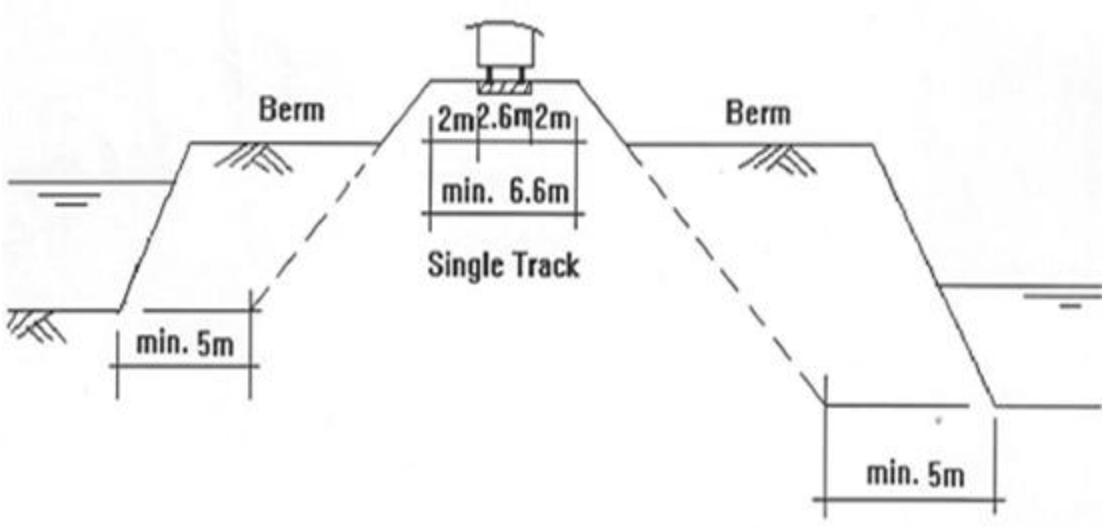


Figure (2-28): A Railway Bank between Two Channels

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 to be 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 (2-29), (2-30), (2-31) and (2-32).

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

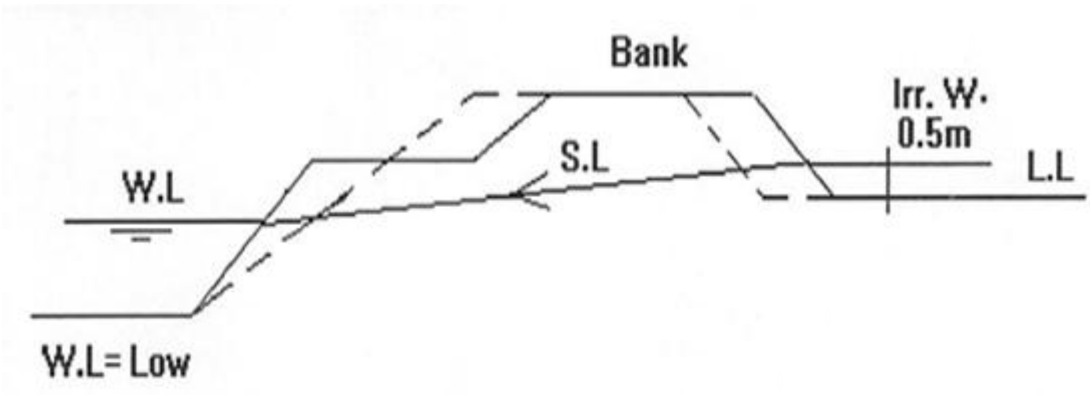


Figure (2-29): Check for Seepage, W.L. < L.L.

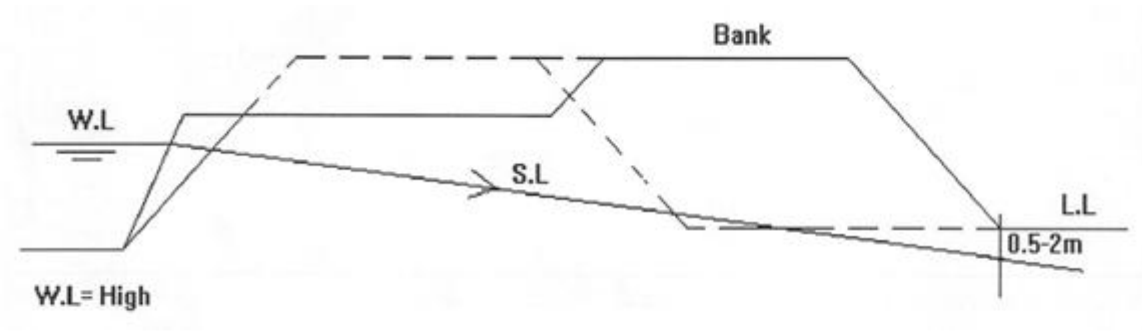


Figure (2-30): Check for Seepage, W.L. > L.L.

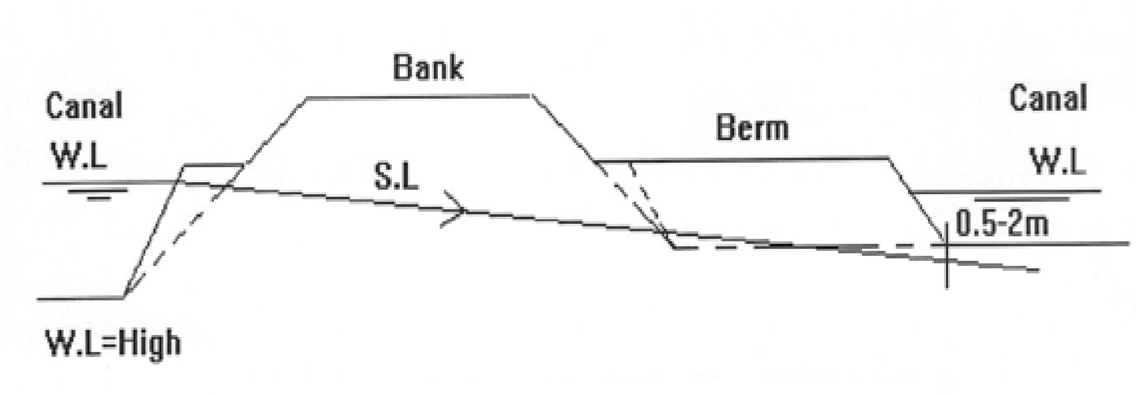


Figure (2-31): Check for Seepage, Two Canals

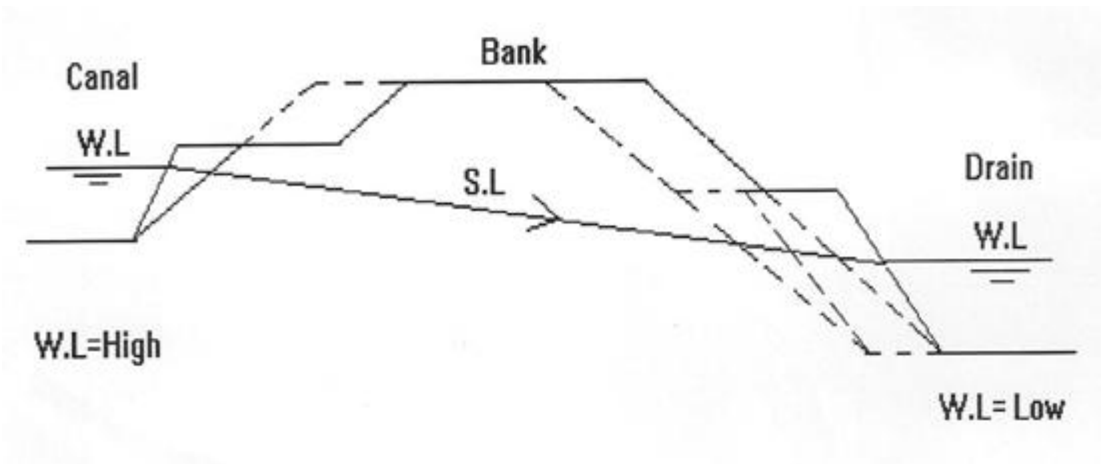


Figure (2-32): Check for Seepage, Canal and Drain

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 (2-33).

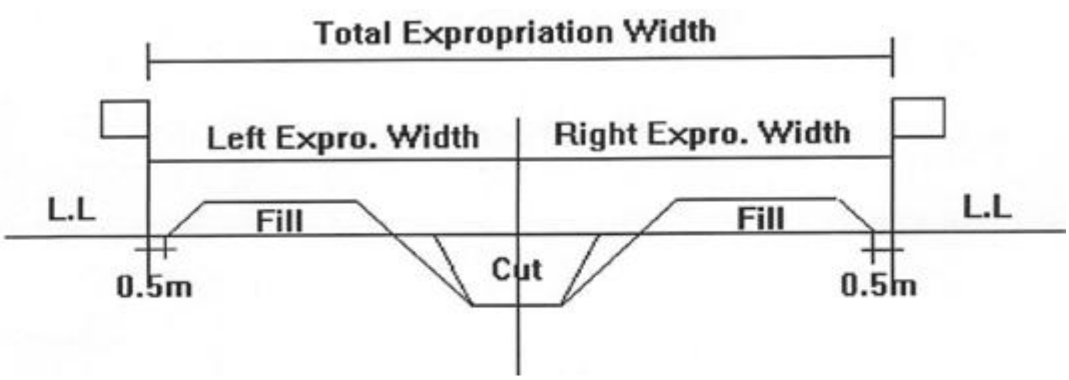


Figure (2-33): Volume of Cut = Volume of Fill

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 (2-34).

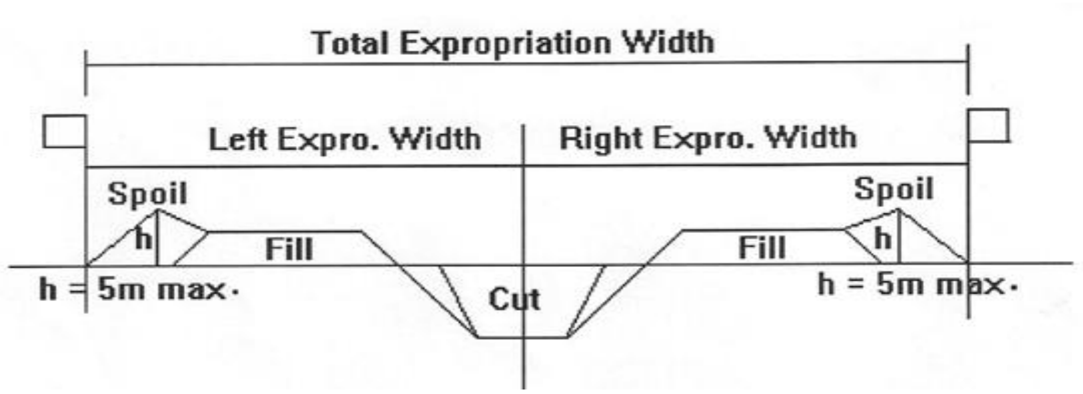


Figure (2-34): Volume of Cut > Volume of Fill

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 (2-35).

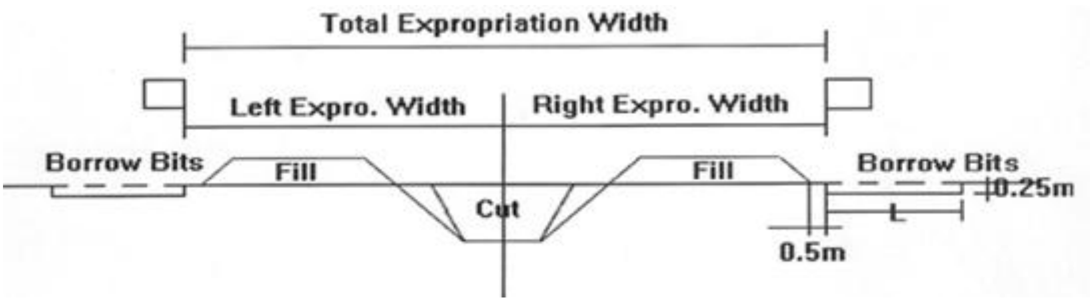


Figure (2-35): Volume of Cut < Volume of Fill

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.