MINISTRY OF AGRICULTURE

Participatory Small scale Irrigation Development Program

TRAINING MANUAL ON THE DESIGN OF IRRIGATION INFRASTRUCTURE FOR SMALL SCALE IRRIGATION PROJECTS

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July, 2018
BAHIR DAR, ETHIOPIA

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1. INTRODUCTION

This manual is developed as a reference material for experts working in the area of irrigation and drainage and other experts who are responsible for the design and development of small scale hydraulic structures. This manual, together with its companions, is designed to offer practical guidance in the design and construction of small scale irrigation structure like, canals (lined and earthen), river crossings (flumes and culverts), road crosses, drainage structures and rehabilitation of irrigation conveyance structures such as drops, turnouts, canals, etc. on minor irrigation schemes etc. The manual contains practical examples of irrigation system planning, canal layout and associated structures which can be built using locally available materials by local artisans and mostly farmer labor.

In particular, this training manual is designed to assist engineers/experts in the design and upgrading of traditional irrigation schemes as well rehabilitation of modern schemes. It contains all necessary design guidelines and procedures for irrigation system designs starting from layout. The procedures and examples are arranged stepwise so that the user can easily understand. The guideline focuses on canal and drain design including design of small conveyance and water distribution structures.

2. PLANNING & DESIGN OF IRRIGATION INFRASTRUCTURE

Irrigation may be defined as the science of artificial application of water to the land, in accordance with the crop requirements throughout the crop period for full-fledged nourishment of the crops. Irrigation is the application of water by artificial and scientific way for plants to increase crop production. In order to plan, the irrigation system design, the following data's are needed to be available before the hydraulic & Structural design of irrigation systems: Hydrology (flood, demand, etc.), Agronomic data, Geological Data, Topographical Data (Topo map of the command area, detailing important features) and Soil Data, etc

2.1 Introduction

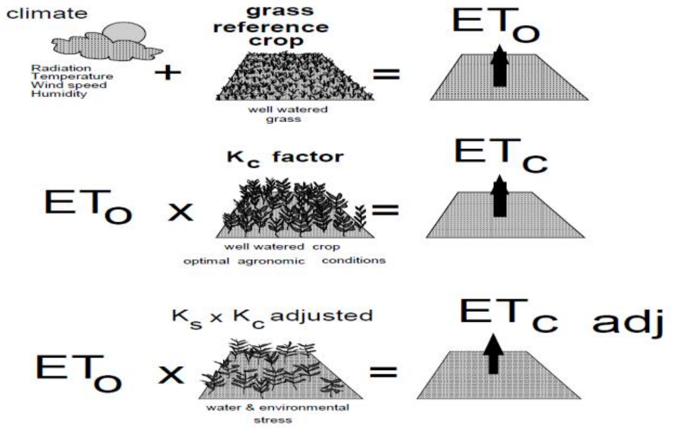
In several parts of the world, the moisture available in the root-zone soil, either from the rain or from underground waters, may not be sufficient for the requirement of the plant life. This deficiency may be either for the entire crop season or for only parts of the crop season. For optimum plant growth, therefore, it becomes necessary to make up the deficiency by adding water to the root-zone soil. This artificial application of water to land for supplementing the naturally available moisture in the root-zone soil for the purpose of agricultural production is termed *irrigation*.

Irrigation schemes can be broadly grouped in to two main categories: (i). Surface water irrigation schemes, and (ii). Ground water irrigation schemes. Surface water irrigation schemes uses diversions, storages, pumps, etc., methods to obtain their supplies from rivers and lakes. Ground water irrigation schemes use open wells, deep and shallow wells to lift water from the water bearing strata below the earth's surface. The choice of an irrigation scheme depends on several factors, such as surface topography, rainfall characteristics, type of source available, subsoil profile, etc. One should, however, always plan to use surface and ground water together to drive maximum benefits. Such use is termed *conjunctive use of surface and ground waters.*

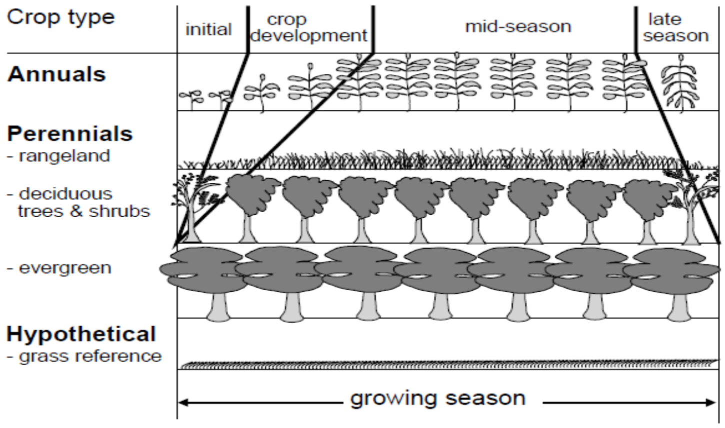
2.2 Duty (Design Discharge Determination):

It is used to determine Evapotranspiration, Crop evapotranspiration, Dependable rainfall and Net irrigation Requirement. It is the process of Identify peak value for the designed cropping pattern and adjusts the above value for Irrigation efficiencies, hours of irrigation in a day, etc. Normally crop water demand is determined by the agronomists by considering different parameters.

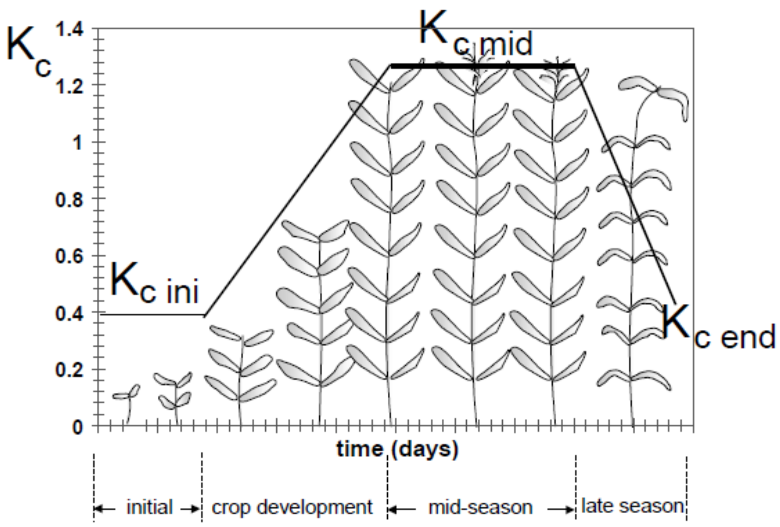
2.3 Potential Evapotranspiration & Crop evapotranspiration



Reference (ETo), crop evapotranspiration under standard (ETc) and non-standard conditions (ETc adj)



Crop growth stages for different types of crops



Generalized crop coefficient curve for the single crop coefficient approach

Figure 2-1: Crop water Requirement

2.4 Dependable and effective rainfall

It is the process used to determine 75% dependable rainfall from the time series of rainfall data collected from Meteorological station and for calculating the effective rainfall. The 75% dependable rainfall indicates that the rainfall can be available 75% of the time.

Methods to determine the dependable and effective rainfall:

i. **Fixed Percentage:** Effective Rainfall = % of Total Rainfall

ii. **An empirical formula developed by FAO/AGLW**

Effective Rainfall = 0.6 * Total Rainfall – 10……… (Total Rainfall < 70 mm)

Effective Rainfall = 0.8 * Total Rainfall – 24………… (Total Rainfall > 70 mm)

iii. **Method of USDA Soil Conservation Service**

Effective Rainfall = Total Rainfall / 125 * (125 - 0.2 * Total Rainfall) … **(Total Rainfall < 250 mm)**

Effective Rainfall = 125 + 0.1 * Total Rainfall……. **(Total Rainfall > 250 mm)**

2.5 Net Irrigation Water Requirement

It is the amount of water required to balance the water requirement of the root zone.

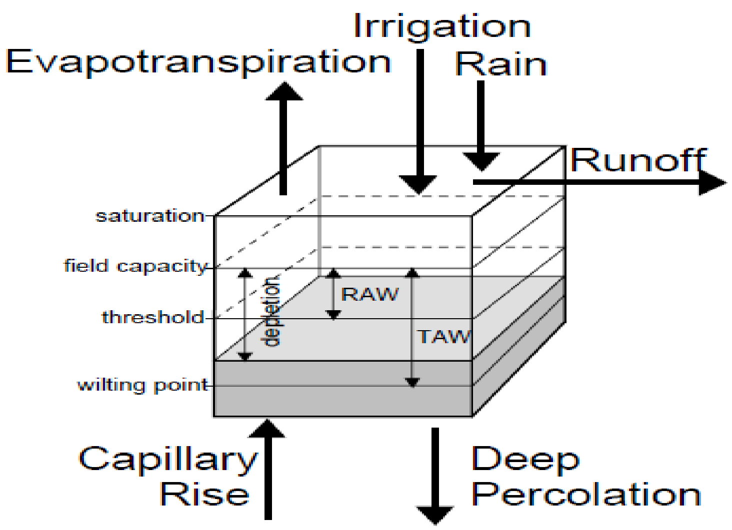


Figure 2-2: Net Irrigation Requirement

2.6 Irrigation Efficiencies

Not all water taken from a source (river, well) reaches the root zone of the plants. Part of the water is lost during transport through the canals and in the fields. The remaining part is stored in the root zone and eventually used by the plants. In other words, only part of the water is used efficiently, the rest of the water is lost for the crops on the fields that were to be irrigated.

Irrigation water losses in the field are due to:

1. Surface runoff, whereby water ends up in the drain
2. Deep percolation to soil layers below the root zone

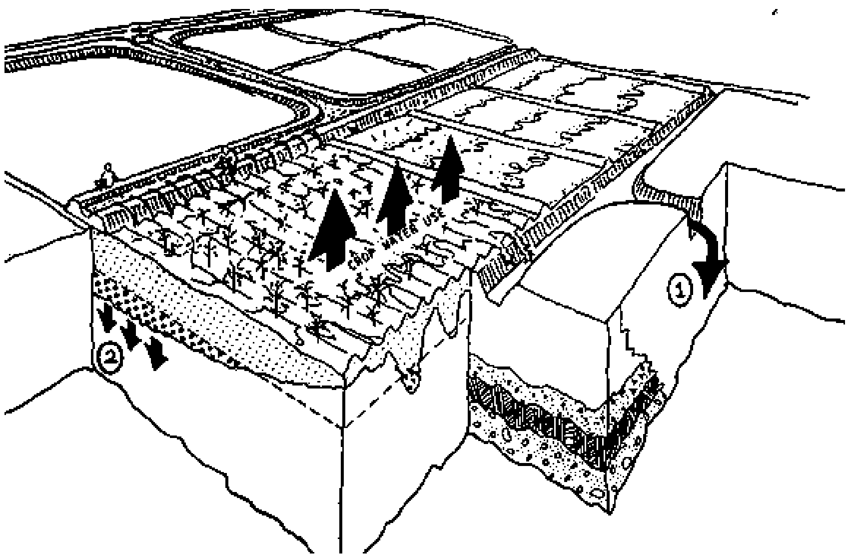


Figure 2-3: Irrigation water losses in the field

To express which percentage of irrigation water is used efficiently and which percentage is lost, the term **irrigation efficiency** is used. The **scheme irrigation efficiency** (e in %) is that part of the water pumped or diverted through the scheme inlet which is used effectively by the plants. The scheme irrigation efficiency can be sub-divided into:

- ✓ Conveyance **efficiency (ec)** which represents the efficiency of water transport in canals. The conveyance efficiency (ec) mainly depends on the length of the canals, the soil type or permeability of the canal banks and the condition of the canals.
- ✓ F**ield application efficiency (ea)** which represents the efficiency of water application in the field. The **field application efficiency** (ea) mainly depends on the irrigation method and the level of farmer discipline.

Table 2-1: Indicative values of conveyance Efficiency

Soil type	**Earthen canals**			**Lined canals**
Canal length	**Sand**	**Loam**	**Clay**	
Long(>2000m)	60%	70%	80%	95%
Medium(200-2000m)	70%	75%	85%	95%
Short(<200m)	80%	85%	90%	95%

Table 2-2: Indicative values of the field application efficiency (ea)

Irrigation methods	**Field application efficiency**
Surface irrigation (border, furrow, basin)	60%
Sprinkler irrigation	75%
Drip irrigation	90%

Once the conveyance and field application efficiency have been determined, the **scheme irrigation efficiency (e)** can be calculated, using the following formula:

$$e = \frac{ec \times ea}{100}$$

Where:

e = scheme irrigation efficiency (%)

ec = conveyance efficiency (%)

ea = field application efficiency (%)

A scheme irrigation efficiency of 50-60% is good; 40% is reasonable, while a scheme Irrigation efficiency of 20-30% is poor.

2.7 Irrigation Scheduling

An irrigation scheduling criteria includes the definition of the following three variables:

1. **Irrigation Application Timing:** Defines ***WHEN*** irrigation applications should be given. The default option is to irrigate when 100% of Readily Available Moisture (RAM) is depleted. This option is aimed at preventing the crops from being under any stress (optimal scheduling).
2. **Application Depths:** Defines ***HOW MUCH*** water should be given in each irrigation application. The default option is to refill the soil to its field capacity (100% of readily available moisture).
3. **Start of Scheduling:** Defines the date at which scheduling calculations should start. The default option is to start at the first planting date of each crop in the cropping pattern.

2.8 Selection of Irrigation Methods

To choose the designed irrigation method, the designer in consultation of the farmer must know the advantages and disadvantages of the various methods. He or she must know which method suits the local conditions best. Unfortunately, in many cases there is no single best solution: all methods have their advantages and disadvantages. Testing of the various methods, under the prevailing local conditions, provides the best basis for a sound choice of irrigation method.

Normally, the suitability of the various irrigation methods, i.e. surface, sprinkler or drip irrigation depends mainly on the following factors:

i. **Natural conditions: -** The natural conditions such as soil type, slope, climate, water quality and availability, have direct impact on the choice of an irrigation method. The following table summarizes the natural condition that affects the type of irrigation methods.

Table 2-3: Effect of natural condition on the selection of type of irrigation methods

Soil type	Sandy soils have a low water storage capacity and a high infiltration rate. Therefore, it needs frequent but small irrigation applications, in particular when the sandy soil is also shallow. Under these circumstances, sprinkler or drip irrigation are more suitable than surface irrigation. On loam or clay soils all three irrigation methods can be used, but surface irrigation is more commonly found. Clay soils with low infiltration rates are ideally suited to surface irrigation.
Slope	Sprinkler or drip irrigation are preferred above surface irrigation on steeper or unevenly sloping lands as they require little or no land levelling.
Climate	Strong wind can disturb the spraying of water from sprinklers. Under very windy conditions, drip or surface irrigation methods are preferred.
Water availability	It is higher with sprinkler and drip irrigation than surface irrigation and so these methods are preferred when water is in short supply.
Water quality	Surface irrigation is preferred if the irrigation water contains much sediment. The sediments may clog the drip or sprinkler irrigation systems.
	If the irrigation water contains dissolved salts, drip irrigation is particularly suitable, as less water is applied to the soil than with surface methods.
	Sprinkler systems are more efficient that surface irrigation methods in leaching out salts.

ii. **Type of crop**: - Surface irrigation can be used for all types of crops. Sprinkler and drip irrigation, because of their high capital investment per hectare, are mostly used for high value cash crops, such as vegetables and fruit trees. Drip irrigation is suited to irrigating individual plants or trees or row crops such as vegetables and sugarcane. It is not suitable for close growing crops (e.g. rice).

iii. **Required depth of irrigation application: -** When the irrigation schedule has been determined, it is known how much water (in mm) has to be given per irrigation application. It must be checked that this amount can indeed be given, with the irrigation method under consideration. Field experience has shown that most water can be applied per irrigation application when using basin irrigation, less with border irrigation and least with furrow irrigation. In practice, in small-scale irrigation projects, usually 40-70 mm of water are applied in basin irrigation, 30-60 mm in border irrigation and 20-50 mm in furrow irrigation. This means that if only little water is to be applied per application, e.g. on sandy soils and a shallow rooting crop, furrow irrigation would be most appropriate. However, none of the surface irrigation methods can be used if the sand is very coarse, i.e. if the infiltration rate is more than 30 mm/hour. If, on the other hand, a large amount of irrigation water is to be applied per application, e.g. on a clay soil and with a deep rooting crop, border or basin irrigation would be more appropriate. The net irrigation application values used are only a rough guide. They result from a combination of soil type and rooting depth. For example: if the soil is sandy and the rooting depth of the crop is medium, it is estimated that the net depth of each irrigation application will be in the order of 35 mm.

Table 2-4: Selection of an irrigation method based on the depth of the net irrigation application

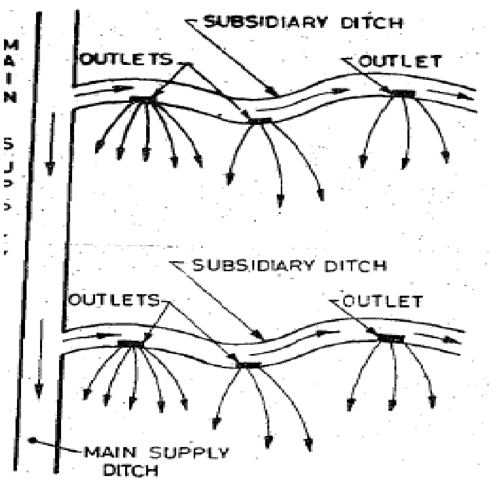
Soil type	Rooting depth of the crop	Net irrigation depth per application (mm)	Irrigation method
Sand	Shallow	20-30	short furrows
	Medium	30-40	medium furrows, short borders
	Deep	40-50	long furrows, medium borders, small basins
Loam	Shallow	30-40	medium furrows, short borders
	Medium	40-50	long furrows, medium borders, small basins
	Deep	50-60	long borders, medium basins
Clay	Shallow	40-50	long furrows, medium borders, small basins
	Medium	50-60	long borders, medium basins
	Deep	60-70	large basins

iv. **Type of technology**: - The type of technology affects the choice of irrigation method. In general, drip and sprinkler irrigation are technically more complicated methods. The purchase of equipment requires high capital investment per hectare. Surface irrigation systems, in particular small-scale schemes are usually requires less sophisticated equipment for both construction and maintenance (unless pumps are used). The equipment needed is often easier to maintain and less dependent on the availability of foreign currency.

v. **Previous experience with irrigation**: - The choice of an irrigation method also depends on the irrigation tradition within the region or country. Introducing a previously unknown method may lead to unexpected complications. It is not certain that the farmers will accept the new method. The servicing of the equipment may be problematic and the costs may be high compared to the benefits. Often it will be easier to improve the traditional irrigation method than to introduce a totally new method.

vi. **Required labour inputs**: - Surface irrigation often requires a much higher labour input for construction, operation and maintenance than sprinkler or drip irrigation. Surface irrigation requires accurate land levelling, regular maintenance and a high level of farmers' organization to operate the system. Sprinkler and drip irrigation require little land levelling; system operation and maintenance are less labour-intensive.

Generally, surface irrigation is by far the most widespread irrigation method. It is normally used when conditions are favourable: mild and regular slopes, soil type with medium to low infiltration rate, and a sufficient supply of surface or groundwater. In the case of steep or irregular slopes, soils with a very high infiltration rate or scarcity of water, sprinkler and drip irrigation may be more appropriate. When introducing sprinkler and drip irrigation it must be ensured that the equipment can be maintained.



Here are the methods of water application for the command area which is selected based on the above discussed points.

2.8.1 Free flooding irrigation method

There are many cases where croplands are irrigated without regard to efficiency or uniformity. These are generally situations where the value of the crop is very small or the field is used for grazing or recreation purposes. Small land holdings are generally not subject to the array of surface irrigation practices of the large commercial farming systems. Also in this category are the surface irrigation systems like check-basins which irrigate individual trees in an orchard, for example. While these systems represent significant percentages in some areas, they will not be discussed in detail in this paper. The evaluation methods can be applied if desired, but the design techniques are not generally applicable nor need they be since the irrigation practices tend to be minimally managed.

Figure 2-4: Check flooding irrigation

2.8.2 Check flooding irrigation method

The system is similar to ordinary flooding. Water is controlled by surrounding the check area with low and flat levees. The check is filled with water at a fairly high rate and allowed to stand until the water infiltrates. The confined plot area varies from 0.2 to 0.8 hectares

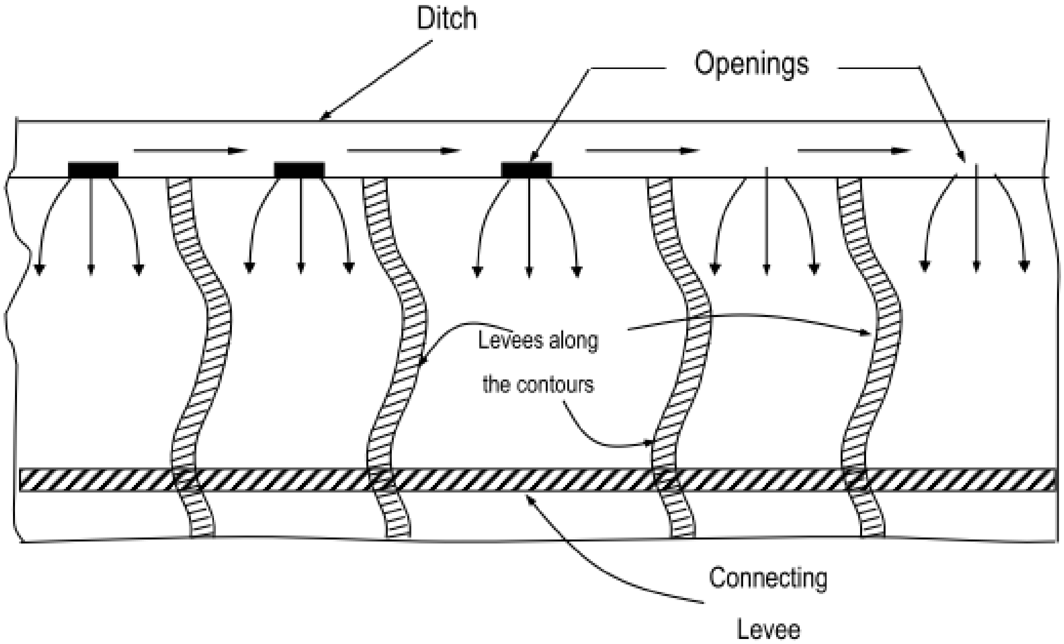


Figure 2-5: Check flooding irrigation

2.8.3 Basin flooding irrigation method

Basin irrigation is the most common form of surface irrigation, particularly in regions with layouts of small fields. If a field is level in all directions, is encompassed by a dyke to prevent runoff, and provides an undirected flow of water onto the field, it is herein called a basin.

There are few crops and soils not amenable to basin irrigation, but it is generally favoured by moderate to slow intake soils, deep-rooted and closely spaced crops. Crops which are sensitive to flooding and soils which form a hard crust following irrigation can be basin irrigated by adding furrowing or using raised bed planting. Basins can be served with less command area and field watercourses than can border and furrow systems because their

level nature allows water applications from anywhere along the basin perimeter.
Basin irrigation has a number of limitations, two of which, are associated with soil crusting and crops that cannot accommodate inundation.

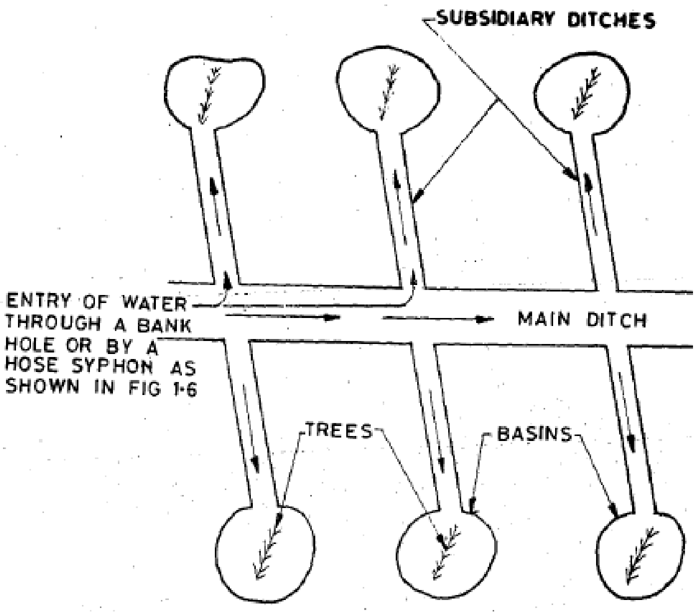
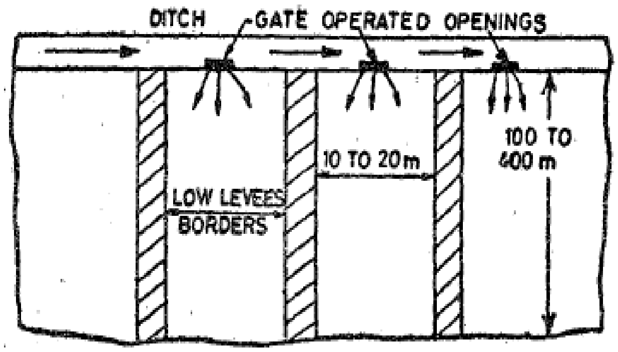


Figure 2-6: Basin flooding irrigation system

2.8.4 Border irrigation method

Border irrigation can be viewed as an extension of basin irrigation to sloping, long rectangular or contoured field shapes, with free draining conditions at the lower end. Water is applied to individual borders from small hand-dug checks from the field head ditch. When the water is shut off, it recedes from the upper end to the lower end. Sloping borders are suitable for nearly any crop except those that require prolonged ponding.



(a) (b)

Figure 2-7: (a) Border flooding irrigation system, (b) Tail water outlet for a block-end border system

2.8.5 Furrow irrigation method

Furrow irrigation avoids flooding the entire field surface by channeling the flow along the primary direction of the field using furrows. Water infiltrates through the wetted perimeter and spreads vertically and horizontally to refill the soil reservoir. Furrows are often employed in basins and borders to reduce the effects of topographical variation and crusting. The distinctive feature of furrow irrigation is that the flow into each furrow is independently set and controlled as opposed to furrowed borders and basins where the flow is set and controlled on a border by border or basin by basin basis.

Furrow irrigation is suitable for a wide range of soil types, crops and land slopes. It is suitable for many crops, especially row crops. Crops that would be damaged if water covered their stem or crown should be irrigated by furrow irrigation systems. Furrows provide better on-farm water management flexibility under many surface irrigation conditions. The discharge per unit width of the field is substantially reduced and topographical variations can be more severe. A smaller wetted area reduces evaporation losses. Furrows provide the irrigator more opportunity to manage irrigations toward higher efficiencies as field conditions changed for each irrigation throughout a season.

There are several disadvantages with furrow irrigation. These may include: (1) an accumulation of salinity between furrows; (2) an increased level of tailwater losses; (3) the difficulty of moving farm equipment across the furrows; (4) the added expense and time to make extra tillage practice (furrow construction); (5) an increase in the erosive potential of the flow; (6) a higher commitment of labour to operate efficiently; and (7) furrow systems are more difficult to automate, particularly with regard to regulating an equal discharge in each furrow.

Figure 2-8: Field layout of Furrow Irrigation system

2.8.5.1 Furrow Layout

This section deals with the shape, length and spacing of furrows. Generally, the shape, length and spacing are determined by the natural circumstances, i.e. slope, soil type and available stream size. However, other factors may influence the design of a furrow system, such as the irrigation depth, farming practice and the field length.

2.8.5.1.1 Furrow length

Furrows must be on consonance with the slope, the soil type, the stream size, the irrigation depth, the cultivation practice and the field length. The impact of these factors on the furrow length is discussed below.

1. **Slope**: - Although furrows can be longer when the land slope is steeper, the maximum recommended furrow slope is 0.5% to avoid soil erosion. Furrows can also be level and are thus very similar to long narrow basins. However a minimum grade of 0.05% is recommended so that effective drainage can occur following irrigation or excessive rainfall. If the land slope is steeper than 0.5% then furrows can be set at an angle to the main slope or even along the contour to keep furrow slopes within the recommended limits. Furrows can be set in this way when the main land slope does not exceed 3%. Beyond this there is a major risk of soil erosion following a breach in the furrow system. On steep land, terraces can also be constructed and furrows cultivated along the terraces.
2. **Soil type**: - In sandy soils water infiltrates rapidly. Furrows should be short, so that water will reach the downstream end without excessive percolation losses. In clay soils, the infiltration rate is much lower than in sandy soils. Furrows can be much longer on clayey than on sandy soils.
3. **Stream size**: - Normally stream sizes up to 0.5 l/sec will provide an adequate irrigation provided the furrows are not too long. When larger stream sizes are available, water will move rapidly down the furrows and so generally furrows can be longer. The maximum stream size that will not cause erosion will obviously depend on the furrow slope; in any case, it is advised not to use stream sizes larger than 3.0 l/sec.
4. **Irrigation depth**: - Applying larger irrigation depths usually means that furrows can be longer as there is more time available for water to flow down the furrows and infiltrate.
5. **Cultivation practice: -** When the farming is mechanized, furrows should be made as long as possible to facilitate the work. Short furrows require a lot of attention as the flow must be changed frequently from one furrow to the next. However, short furrows

can usually be irrigated more efficiently than long ones as it is much easier to keep the percolation losses low.

6. **Field length: -** It may be more practical to make the furrow length equal to the length of the field, instead of the ideal length, when this would result in a small piece of land left over. Equally the length of field may be much less than the maximum furrow length. This is not usually a problem and furrow lengths are made to fit the field boundaries.

The table below gives some practical values of maximum furrow lengths under small-scale irrigation conditions. The values shown in Table 3 are lower than those generally given in irrigation handbooks. These higher values are appropriate under larger scale, fully mechanized conditions.

Table 2-5: practical values of maximum furrow lengths (m) depending on slope, soil type, stream size and net irrigation depth

Furrow slope (%)	**Maximum stream size (l/s) per furrow**	**Clay**		**Loam**		**Sand**	
		Net irrigation depth (mm)					
		50	**75**	**50**	**75**	**50**	**75**
0	3	100	150	60	90	30	45
0.1	3	120	170	90	125	45	60
0.2	2.5	130	180	110	150	60	95
0.3	2	150	200	130	170	75	110
0.5	1.2	150	200	130	170	75	110

2.8.5.1.2 Furrow shape

The shape of furrows is influenced by the soil type and the stream size as discussed below:

Soil type: - In sandy soils, water moves faster vertically than sideways (lateral). Narrow, deep V-shaped furrows are desirable to reduce the soil area through which water percolates. However, sandy soils are less stable, and tend to collapse, which may reduce the irrigation efficiency.

In clay soils, there is much more lateral movement of water and the infiltration rate is much less than for sandy soils. Thus a wide, shallow furrow is desirable to obtain a large wetted area to encourage infiltration.

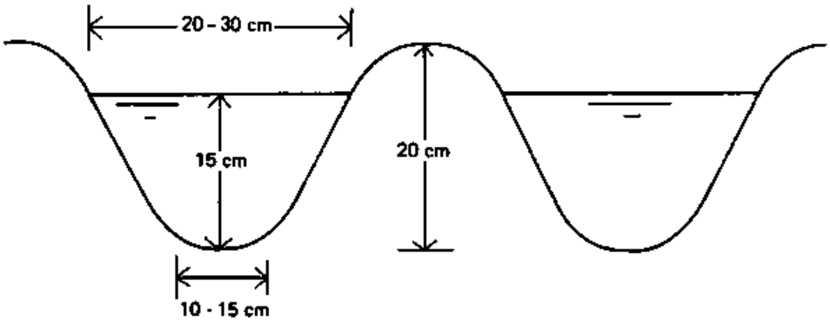


Figure 2-9: Deep, narrow furrow on a sandy soil

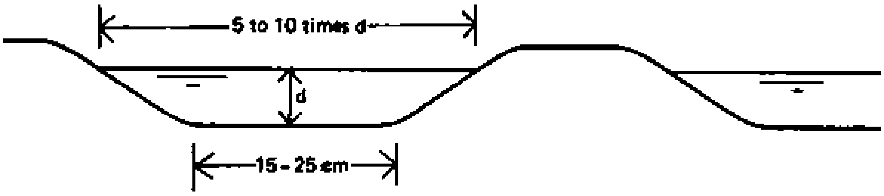


Figure 2-10: Wide, shallow furrows on a clay soil

Stream size: - In general, the larger the stream size the larger the furrow must be to contain the flow.

2.8.5.1.3 Furrow spacing

The spacing of furrows is influenced by the soil type and the cultivation practice as discussed below:

Soil type: - As a rule, for sandy soils the spacing should be between 30 and 60 cm (i.e. 30 cm for coarse sand and 60 cm for fine sand). On clay soils, the spacing between two adjacent furrows should be 75-150 cm. On clay soils, double-ridged furrows (sometimes called beds) can also be used. Their advantage is that more plant rows are possible on each ridge, facilitating manual weeding.

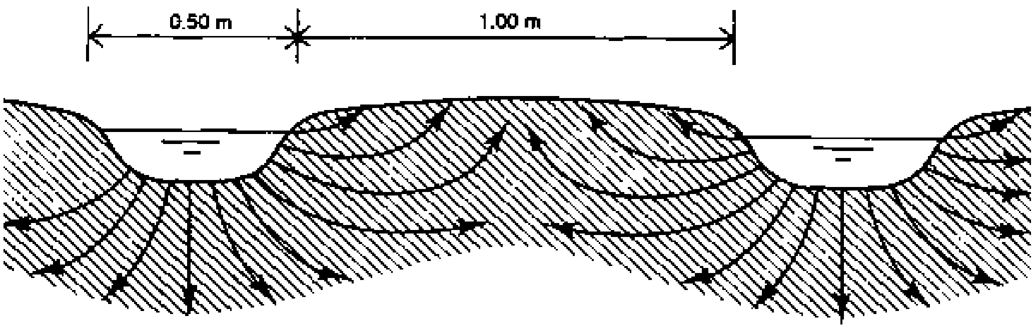


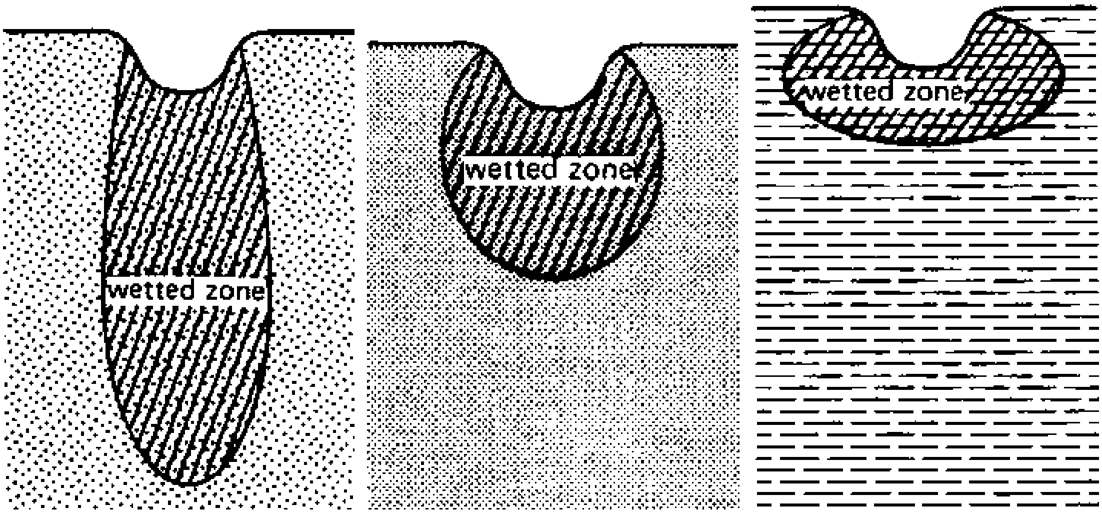
Figure 2-11: A double-ridged furrow

Cultivation practice: - In mechanized farming a compromise is required between the machinery available to cut furrows and the ideal spacings for crops. Mechanical equipment will result in less work if a standard width between the furrows is maintained, even when the crops grown normally require a different planting distance. This way the spacing of the tool attachment does not need to be changed when the equipment is moved from one crop to another. However, care is needed to ensure that the standard spacings provide adequate lateral wetting on all soil types.

2.8.5.2 Irrigating Furrows/ Wetting patterns

In order to obtain a uniformly wetted root zone, furrows should be properly spaced, have a uniform slope and the irrigation water should be applied rapidly.

As the root zone in the ridge must be wetted from the furrows, the downward movement of water in the soil is less important than the lateral (or sideways) water movement. Both lateral and downward movement of water depends on soil type.



(a) (b) (c)

Figure 2-12: Different wetting patterns in furrows, depending on the soil type (a- Sand, b- Loam and c- Clay)

Ideal wetting pattern: - In an ideal situation adjacent wetting patterns overlap each other, and there is an upward movement of water (capillary rise) that wets the entire ridge, thus supplying the root zone with water.

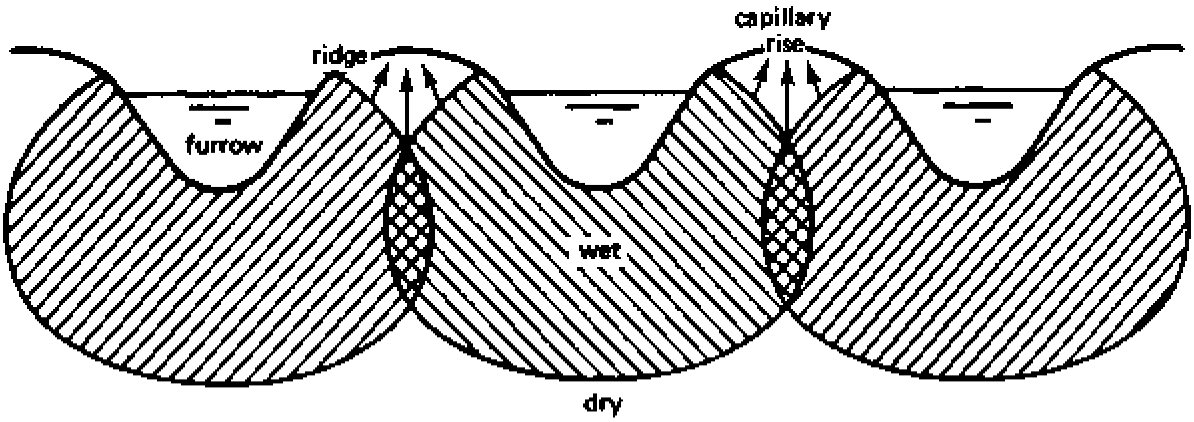


Figure 2-13: Ideal wetting pattern

To obtain a uniform water distribution along the furrow length, it is very important to have a uniform slope and a large enough stream size so that water advances rapidly down the furrow. In this way large percolation losses at the head of the furrow can be avoided.

2.8.6 Sprinkler irrigation method

With sprinkler irrigation, artificial rainfall is created. The water is led to the field through a pipe system in which the water is under pressure. The spraying is accomplished by using several rotating sprinkler heads or spray nozzles.

Figure 2-14: Sprinkler irrigation method

2.8.7 Drip irrigation method

In drip irrigation, also called trickle irrigation, the water is led to the field through a pipe system. On the field, next to the row of plants or trees, a tube is installed. At regular intervals, near the plants or trees, a hole is made in the tube and equipped with an emitter. The water is supplied slowly, drop by drop, to the plants through these emitters.

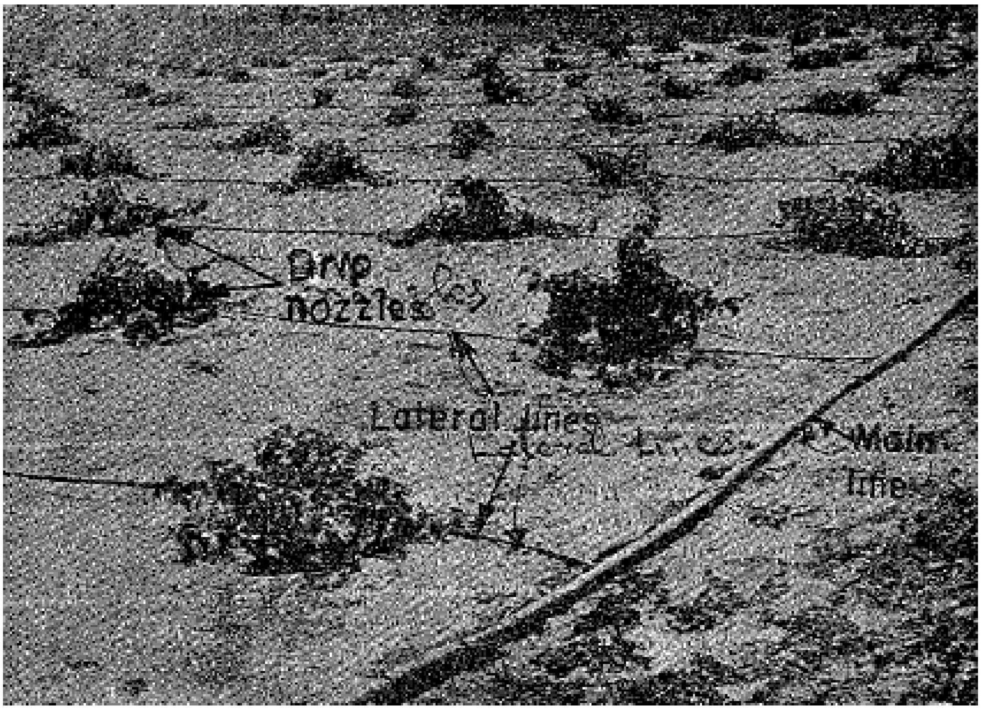


Figure 2-15: Drip irrigation method

3. IRRIGATION SYSTEM LAY-OUT

Desirable locations for irrigation canals on any gravity project, their cross-sectional designs and construction costs are governed mainly by topographic and geologic conditions along different routes of the cultivable lands. Any irrigation canal consists of different sizes and capacities. Accordingly, the canals are classified as main, secondary, tertiary and field canals depending on the size of the irrigation scheme. The main canals takes its supplies directly from the river through the head regulator and act as a feeder canal supplying water to secondary and tertiary canals. Usually, direct irrigation from the main canal is not practical. Main canals must convey water to the higher elevations of the cultivable area. The secondary canals takes their supplies from the main canals and feed the tertiary and/or the field canals. Secondary and tertiary canals convey water to the different parts of the irrigable areas. Field canals are the smaller units in the system and used to feed water to the furrows. The feeder (field) canals will be ready to deliver water to various blocks. The boundaries of these blocks should be determined by the farmers who will be jointly responsible for distribution of water within each block. Within the blocks, field canals are used to convey water to individual plots.

Technical and social issues are considered in determining the canal layout, alignments and the location of block boundaries for which the views of both the woreda expert and user farmers have been incorporated.

Irrigation system layout shows the network of irrigation canals main canals, secondary canals, etc) and the off-takes and the areas served by each; also land drainage networks.

3.1. System Lay out Considerations

A primary concern in the layout of the system is that it serves the purpose of conveying and distributing water to key locations in the areas of service. The excavation and earth fill volumes should not be excessive, otherwise the construction costs may be tremendous. In reaches constructed over fill, the seepage losses tend to be high, even if the canal is lined. Hence, canals are often designed to follow the existing topography for the design slope. The selection of bed slope (longitudinal bed slope) should also take into account the existing slopes of the terrain, so as to minimize deviations in canal routing. Curves in canals should not be too sharp.

The planning of an irrigation canal project includes the determination of canal alignment and the water demand. The type of the canals (trapezoidal or rectangular) and the lining materials (Masonry, concrete or earthen) may depend on the geological formation along the canal route and the slope of the canal.

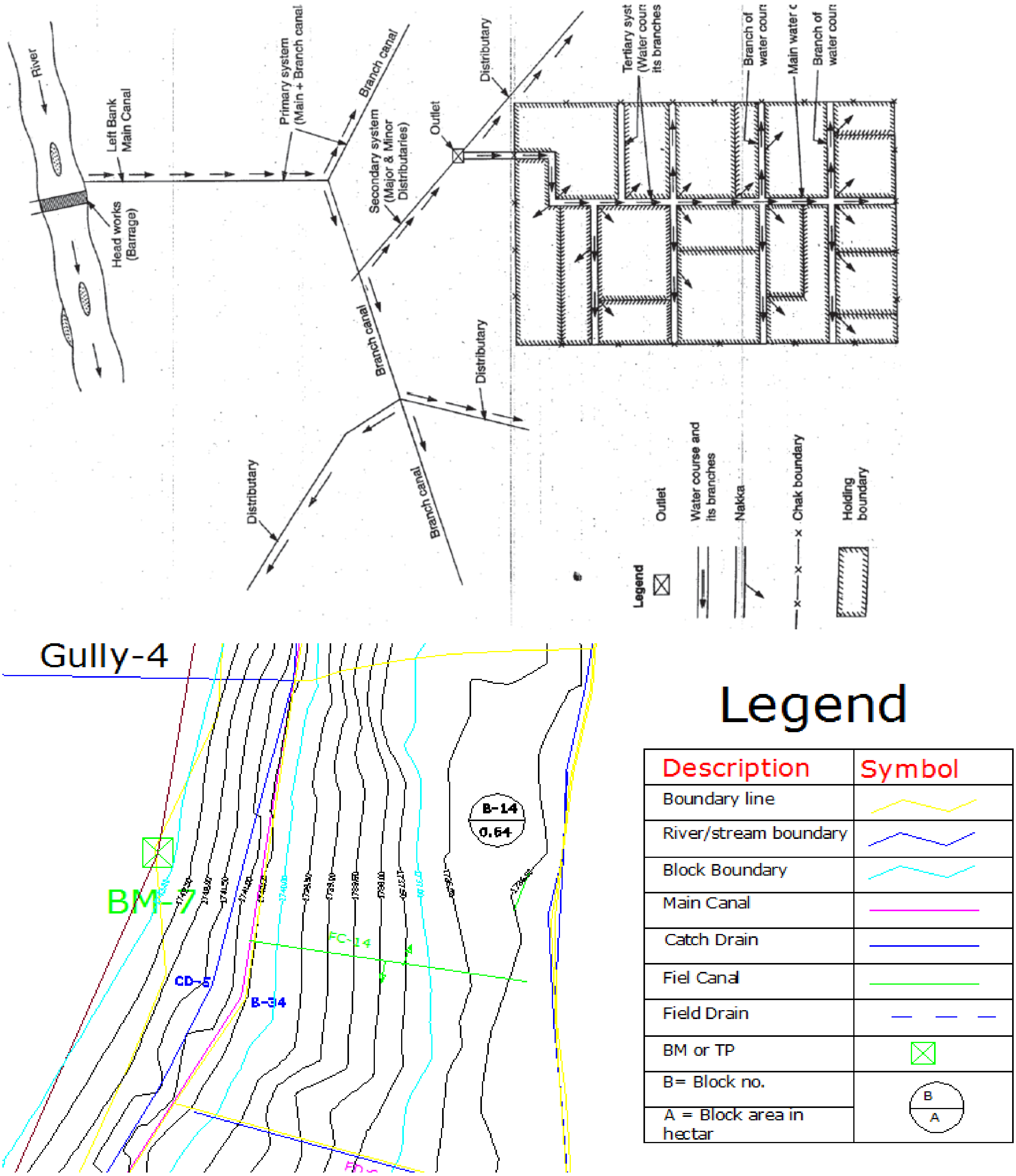


Figure 3-1: General of Irrigation System Lay out

3.2.Design of the canal system

Criteria to consider when designing canals are: Flow rate (discharge Capacity), slope, soil type, size of the command to be irrigated by the canal, Hydraulic operational characteristics, Cost and Site Conditions (geology of canal routes, etc).

3.2.1. Flow Depth and Section Capacity

The canal sections are designed using Manning's equations: $Q = \frac{A * R^{2/3} * S^{1/2}}{\eta}$

Normally, the followings are determined from the field:

- The command area to be irrigated, (A)
- The slope of the canal (s)
- The irrigation water requirement, duty
- The mannig's roughness coefficient (η)

From the above given conditions, by fixing the bed width and the section of the canal (rectangular or trapezoidal), it is possible to determine the flow depth.

Table 3-1: Recommended values of slope of canal

Type of canals	Range of Slope
Main canals	1/700-1/1,500
Secondary canals	1/700-1/1,000
Tertiary canals	1/500-1/700
Field ditches	1/300-1/500

Channel section type and Side slopes

Table 3-2: Some parameters of trapezoidal x-section

Discharge (m^3/s)	b/d	Side slope	Freeboard (m)	Velocity (m/s)
0 -0.15	1	1.1	0.3	0.25-0.30
0.15-0.30	1	1.1	0.3	0.30-0.35
0.30-0.40	1	1.1	0.35	0.35-0.40
0.40-0.50	2	1.1	0.4	0.40-0.45

Note: Use flow master software to determine the flow depth

Exercise-1: Design an earthen trapezoidal section of irrigation main canal for the following given conditions:

- Size of command area of 200ha,
- Longitudinal slope = 1/1000
- Side slope = 1V: 1H
- Duty= 2.0 lt/s/ha

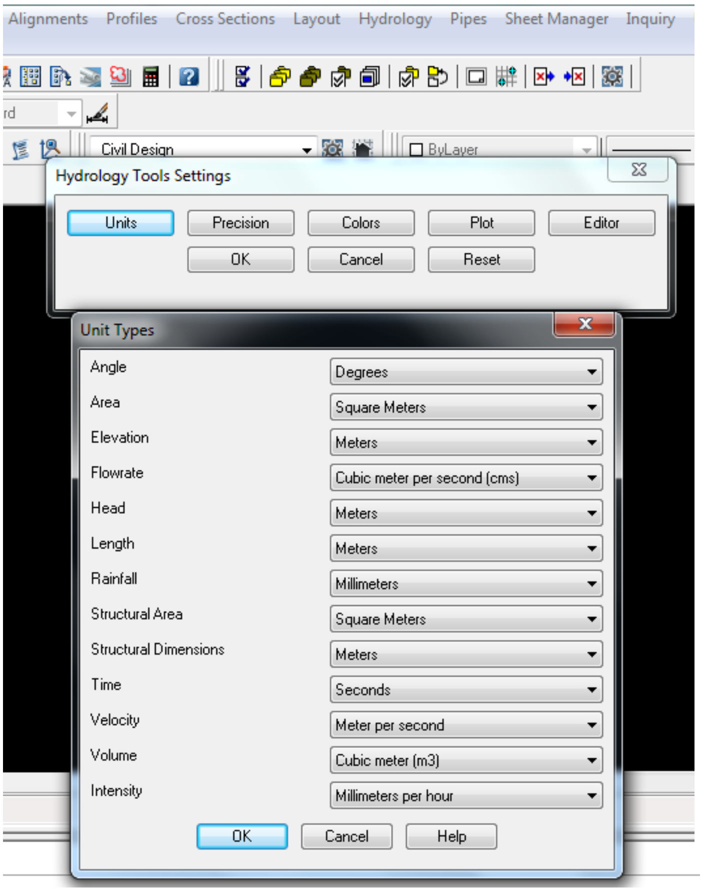
- Manning's roughness, η = 0.022

Solution: to design the canal dimensions, either trial and error using excel sheet, flow master software or Autodesk Land Desktop software can be used.

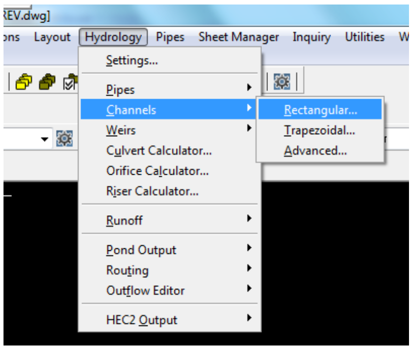
Here, the exercise is solved using Autodesk Land Desktop:

Step-1: Compute the required dischare to irrigate 200ha. Q= duty* Area = 200*2 =400lt/s

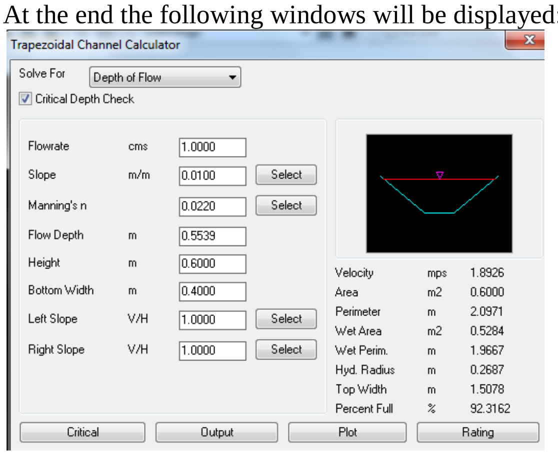
Step-2: adjust the unit, Click Hydrology, settings, and then units to adjust it.



Step-2: click hydrology, channel, Trapezoidal



At the end the following windows will be displayed:



Step-4: Adjust the data in the window, and then the calculated results are shown on the left side of the window.

Step-5: After adjusting all the data, it is possible to export the input and output data to the text format. Click output, text, then the final end result can be obtained as below.

Channel Calculator

Given Input Data:
- Shape .... Trapezoidal
- Solving for .... Depth of Flow
- Flowrate .... 0.4000 cms
- Slope .... 0.0010 m/m
- Manning's n 0.0220
- Height .... 0.8000 m
- Bottom width .... 0.6000 m
- Left slope .... 1.0000 m/m (V/H)
- Right slope .... 1.0000 m/m (V/H)

Computed Results:
- Depth .... 0.5490 m
- Velocity .... 0.6341 mps
- Full Flowrate .... 0.8612 cms
- Flow area 0.6308 m2
- Flow perimeter .... 2.1528 m
- Hydraulic radius .... 0.2930 m
- Top width .... 1.6980 m
- Area 1.1200 m2
- Perimeter .... 2.8627 m
- Percent full .... 68.6230 %

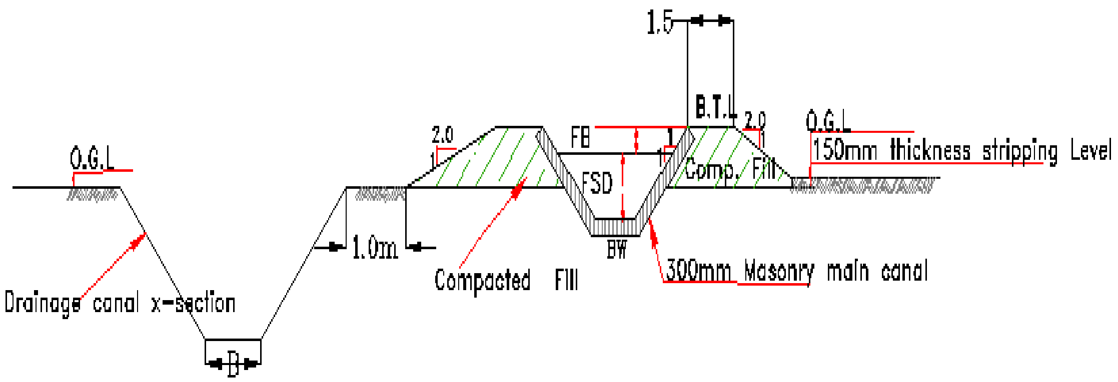


Figure 3-2: Typical Main Canal X-section

Table 3-3: Sample Design Format for a typical main canal

DESCRIPTION	REACH-I	REACH-II	REACH-III	REACH-IV	REACH-V
From chain age	0	325	466	1185	1725
To chainage (m)	325	466	1185	1725	1946
Value of n	0.023	0.02	0.023	0.023	0.02
Bed slope, s	0.002	0.03	0.001	0.001	0.04
Bed width (m)	0.5	0.5	0.5	0.4	0.4
Full supply depth (m)	0.3	0.16	0.38	0.33	0.12
Free board (m)	0.3	0.3	0.3	0.3	0.3
Side slope,	1.5	1	1.5	1.5	1
Velocity, (v)	0.71	1.84	0.5	0.45	2.02
Designed Discharge Qd (m3/s)	0.2	0.2	0.2	0.13	0.13

3.1.1. Curves in canals

Because of economic and other considerations, the canal alignment does not remain straight all through the length of the canal, and curves or bends have to be provided. The curves cause distributed flow conditions resulting in eddies or cross currents which increase the losses. In the curved channel portion, the water surface is not level in the transverse direction. There is a rise and drop of water surface in the outer and inner edge of the curves, resulting a decrease and increase of flow velocities, respectively. Hence, there may be erosion in the outer bank and deposition in the inner bends. Therefore, if curves are unavoidable, it should have a long radius of curvature. The permissible minimum radius of curvature for a canal curve depends on the type of canals, dimensions of cross-sections, velocities during full-capacity operations, earth formation along canal alignment and danger of erosion along the paths of curved canal.

Table 3-4: Values of minimum radii of canal curves for different canal capacities

Canal capacity (m^3/s)	Minimum radius of curvature (m)
Less than 0.3	100
0.3 to 3.0	150
3.0 to 15.0	300
15.0 to 30	600
30 to 85	900
More than 85	1500

3.1.2. Canal losses

When water comes in contact with an earthen surface, whether artificial or natural, the surface absorbs water. This absorbed water percolates deep into the ground and is the main cause of the loss of water carried by a canal. In addition some canal water is also lost due to evaporation, which may be estimated around 10% of the quantity of water lost due to seepage. The seepage loss is mainly depended on the material through which the canal passes. Obviously, the loss is greater in coarse, less in loam and still less in clay.

For the purpose of estimating the water requirements of a canal, the total loss due to evaporation and seepage, also known as conveyance loss, is expressed as m^3/s per million square meters of either wetted perimeter or the exposed water surface area.

3.2. Canal Design

With the water conveyance system for irrigation, comprising of the main canal, branch canals (secondary), tertiary canals, field canals and water courses agreed upon with the farmers, you are now ready to design canal sections and identify appropriate location of various conveyance structures. The design process comprises of finding out of longitudinal slopes of the channels and fixing the cross sections. The channels themselves may be made up of different construction materials. For example, the main canals and secondary canals may be lined and the smaller ones unlined depending upon the soil and estimates of seepage losses in the canal. During longitudinal surveys, lengths of canals passing through sandy soils or erodible soils should be marked on the longitudinal profile.

3.2.1. Main Canal Design

The basic data requirements to design the main canals are:

- Peak water requirement or duty of the area in (l/s/ha)
- The maximum command area, A in ha
- Manning's roughness coefficient
- Canal gradient or slope for the given soil
- The type of canal section to be used

Principle:

- The design discharge of the main canal is based on the peak crop water requirements which may account for the conveyance and field application efficiencies). In addition, an allowance, often up to 10 to 20% depending upon the soil and reliability of data, is sometimes included to account for inaccuracies in estimating some of the design parameters.
- In traditional or modern schemes in Amhara region, most canals are earthen canal cross section. Key elements to be determined include, top bank width, bottom width (b), side slopes (X: 1), water depth (d), freeboard, total depth (D = d + freeboard), wetted area (A_s), wetted perimeter (P).' And Hydraulic Radius ($R = A_s/P$) as shown in Figure below.

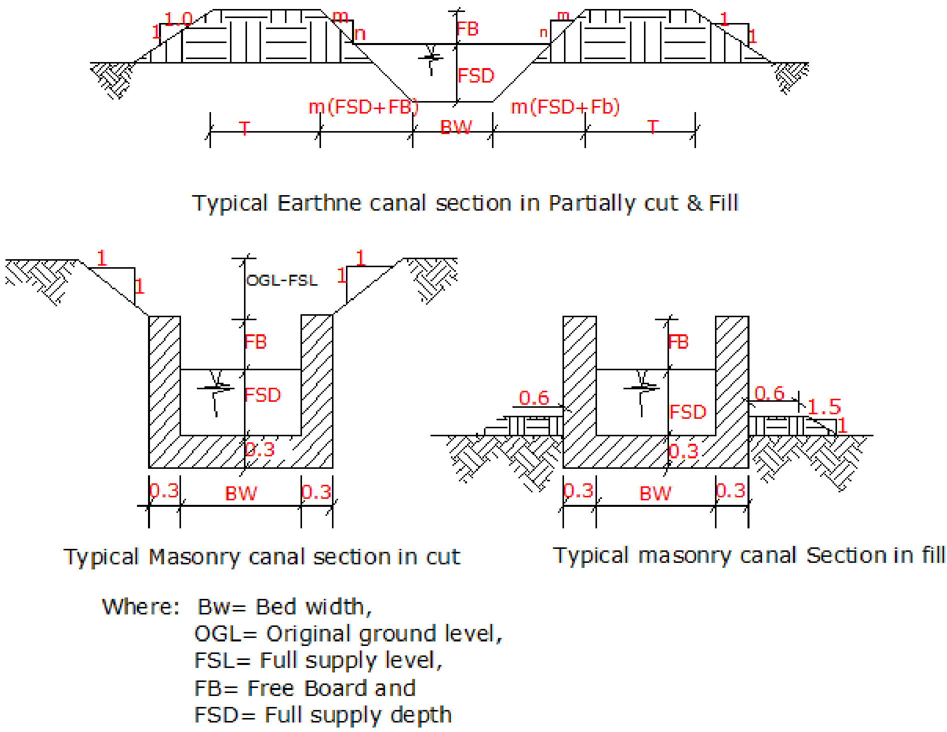


Figure 3-3: Typical Irrigation Canal Sections

Equation: The empirically derived Manning's equation is used to determine canal sections. The formula is expressed as follows: $Q = (1/n)\ A_s\ R^{2/3}\ S^{1/2}$

Where: Q = Discharge (m^3/sec) = V A_s

V = velocity (m/sec)

n = Manning roughness coefficient (sec/$m^{1/3}$)

A_s = Wetted cross-sectional area (m^2) = d (b + dX)

P = Wetted perimeter (m)

R = Hydraulic radius (m) ($R=A_s/P$)

S = Canal gradient or longitudinal slope of the canal

Procedures

- Select the known and unknown parameters

  In the Manning's equation, the known parameters are:

  Q = peak water requirement or Duty

  S = slope of the canal taken from the topographic map or longitudinal profile drawn earlier

  n = Manning roughness coefficient (empirical factor taken from tables)

  The unknowns are bottom width (b), depth of water (d) and side slope (X). With the determination of these dimensions, area (A), wetted perimeter (P) and hydraulic radius (R) can be estimated.

- Select assumed non-scouring and non-silting velocities for various soils of your command area.

Canals carrying water with excessively high velocities may cause erosion of the bed and the sides of the channel leading to the collapse of the canal. If the velocity is low, the sediment will deposit in the canal requiring frequent cleaning. Low velocities also encourage weed and plant growth in the channel. Therefore, the minimum permissible velocity should inhibit the growth of vegetation in the canal. In addition, the velocity should be high enough not to permit the settlement of suspended material (non-silting velocity). The velocity chosen should be higher than the "Minimum permissible velocity" to prevent growth of vegetation and lower than the "Maximum permissible velocity" which will deter both sedimentation and vegetative growth. Maximum permissible velocities depend on the soil material, but generally for small scale irrigation projects a design velocity of about 0.75 to 1 m/sec is recommended. The maximum velocity should vary with the soil type as recommended below.

Table 3-5: Limiting velocity for different types of soil formation

Material	**Limiting Velocity**
Sand:	Vmax = 0.3 to 0.7 m/sec;
Sandy loam:	Vmax = 0.5 to 0.7 m/sec;
Clay loam:	Vmax = 0.6 to 0.9 m/sec;
Clay:	Vmax = 0.9 to 1.5 m/sec;
Gravel:	Vmax = 0.9 to 1.5 m/sec; and,
Rock:	Vmax > 1.5 m/sec

Now you can select the dominant soil from the above data and velocity is known. Bank slope, Manning's coefficient and b/d ratio can be approximated from Table below.

Table 3-6: Recommended Values for Canal Parameters

Canal	**Water Depth (m)**	**b/d Ratio**	**Minimum Bank Width (m)**	**Side Slopes (H:V)**	**Minimum Free Board (m)**	**Manning's η**
Head ditch	< 0.3	1	0.3	1:1	0.1	0.04
Small	< 0.75	1(clay) – 2(sand)	0.5	1:1	0.2	0.035
Medium	0.75 – 1.5	2(clay) – 3(sand)	0.5 – 1	1:1 – 2:1	0.3	0.03 – 0.035
Large	> 1.5	> 3	> 1	> 2:1	0.4	0.03

Example: Design canal section using the known values of design parameters.

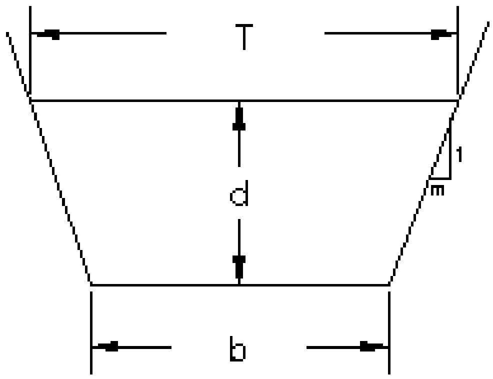
Canal section design using Manning's equation is based on trial and error procedure. The designer may have to assume either the bottom width or the depth of flow to arrive at the required section**.**

Given:

- Main canal design flow = Q = 0.8 m^3/sec
- S ,slope of the canal found from the profile = 0.005
- Clay loam soil/foundation conditions (medium soil)
    - Maximum velocity from table ……..0.9m/s
    - Canal side slope from above table 1.5:1
    - n from table =0.035

Computational procedures

$Q = (1/n)\, A_s\, R^{2/3}\, S^{1/2}$



- cross section area, As:

  $As = ((T+B)/2)*d = bd+md^2$

  $p = B + 2L = B + 2d\sqrt{m^2+1}$

- ***Conditions to check: after computation***
    - the velocity of Manning must be within the permissible range
    - the condition of Q = As*Velocity must be equal to the given discharge = 0.8m^3/s

3.2.2. Lining of irrigation canals

Irrigation canals can be earthen or lined. The major advantage of earthen canal is its low initial cost. The disadvantages are:

- Low velocity of flow mainteined to prevent erosion,
- Excessive seepage loss which may result in water logging and related problemes such as salinity of soils, expensive road maintenance, drainage activities, safety of foundation structures, etc.,
- Favourable condition for weed growth which further retads flow velocity and enhance seepage, and
- The breaching of banks due to erosion and burrowing of animals. These problems of earthen canals can be got rid by lining the canal.

A lined canal decreases the seepage loss and thus reduces the chances of waterlogging. It also saver water which can be utilized for additional irrigation. A lined canal provides safety against breaches and prevents weed growth thereby reducing the annual maintenance cost of the canal. Because of relatively smooth surface lining, a lined canal requires a flatter slope. This results in an increase in the command area.

3.2.3. Design of Distribution Systems (Secondary & Tertiary)

1. **Determination of Minimum Channel Water Level (MCWL) for Each Irrigation Block**

This is a level at the end of the canal and the elevation can be obtained by knowing the higher ground elevation at end of the canal. Then, to irrigate all areas below this bed level, all head loss back up to the outlet must be added and the outlet fixed.
MCWL = elevation at the end + canal length *(slope of canal) + head regulator (0.05)

Exercise: *The field channel slope is 1 in 1000; the distance from the weir outlet to the lower higher ground is 100m. Calculate MCWL if the culvert level is 10 m.*

MCWL = 10 + 100/1000 + 0.05 = 10.15 m

If the channel water level is at 10.15 m, the highest ground level in the irrigation block will be irrigated. The designer should make a judgment on the high ground level to ensure that the minimum channel water level is not too high.

2. **Plot the Design Top Water Level on the Longitudinal Section for Each Canal.**

Existing ground levels, taken from the surveying, are plotted for each channel and the MCWL for each channel are marked in the appropriate locations on a graph paper. A line, passing through the highest MCWL regarded as top water level (TWL), is produced backwards at the selected hydraulic gradient or slope of the bed level.

The slope of the canal should be adjusted to coincide as closely as possible with ground slopes thus minimizing earth moving. However steep slopes are dangerous. The maximum slope of earthen channels depends on soil type and must be selected in the ranges not greater than 1 in 300 in medium or heavy soils (clay loam or clay) or 1 in 1,000 in light soils (sand or loam).

For greater slopes or for sudden drops in ground levels, using channel lining or drop structures is necessary. For flatter Slopes, it is advisable to make the canal gradient as high as possible or the channel embankment height may be increased even though a certain amount of land may be reduced.

3. Mark the Channel TWL on the Longitudinal Profile of Main Canal

The longitudinal profile of the main canal has been prepared in the above steps. Mark the top water level (TWL) elevation on the longitudinal profile of the main canal at the division box. Once all the TWL of field channels have been marked, draw a line joining all TWLs. This line is the minimum canal water level (MCWL) of the main canal required to irrigate the entire command area.

The MCWL should be checked with the design depth (d) of water in the main canal. If the design depth is lower than MCWL, the canal section should be redesigned to increase the depth. If the design depth is higher than MCWL, attempts should be made to lower the depth either by lowering the bed elevation or adjusting the slope of the bed of canal. At a junction of two feeder canals (a division), the water level upstream must be adjusted for the canal with the higher command.

4. Determine Construction Levels for Field Canals.

After the top water level (TWL) has been drawn, the dimensions of the channel are decided. Typical cross sections for each of the channels can be estimated using the Manning's equation or selecting from standard sections. The depth of water is determined by the canal slope which may vary depending on soil type, existing ground slope and TWL. Knowing the depth of flow, the channel invert level (IL) may be calculated and entered into the channel design and drawn on the main section.

To prevent overtopping by surges resulting from fluctuations in discharge, or through the consolidation of embankments, a freeboard allowance is added to the TWL to obtain the bank top level (BTL).

5. Determine Construction Dimensions and Levels for Structures

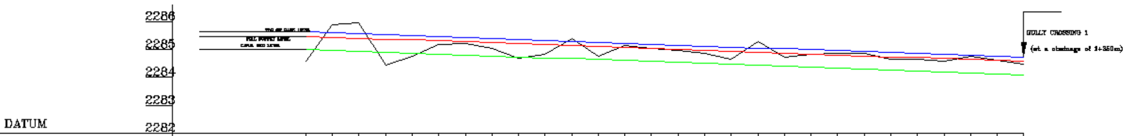
The locations of outlets, drop structures and division boxes are determined in previous Steps. The upstream invert level of a structure is determined by the invert of the upstream canal. This is equal to the upstream water level (MCWL) minus the depth of flow. The downstream invert level of a standard check or division structure by reducing the loss of energy caused by the structure. When loss of energy through the structure cannot be calculated, it is safe to assume an energy loss of 0.05m through the structure.

3.1.1. Canal L-Section

The slope of the channel is fixed based on existing topography/slope consistent with economy. A steeper slope governed by maximum permissible velocity, will be most economical, but it will lower the FSL, causing less irrigation. Hence, the maximum possible irrigation would indicate flatter slopes governed by minimum permissible velocity. A balance between these two limits must be adopted for selecting a suitable bed slope for the channel. If the chosen designed slope is found to be flatter than the natural available slope, the difference can be adjusted by providing suitably designed falls (drop structures).

Normally, the profiles of the canals are done by using simple dos based software called l-section. To use L-section, you have to have an AutoCAD 2002 or 2004 version and Microsoft excel 1997-2003 versions in your computer.

The output from the L-Section looks like the following.



DISTANCES IN MTRS	0	50	100	150	200	250	300	350	400	450	500	550	600	650
CUT DEPTH		0.923	1.017			0.337	0.401	0.254		0.131	0.724	0.108	0.541	0.455
FILL DEPTH	1.060			1.100	0.746	0.283	0.219	0.366	0.672	0.489		0.512	0.079	0.165
(TOP BANK LEVEL)	2285.620	2285.586	2285.553	2285.520	2285.485	2285.453	2285.419	2285.386	2285.352	2285.319	2285.285	2285.252	2285.219	2285.185
(FULL SUPPLY LEVEL)	2285.47	2285.43	2285.40	2285.37	2285.33	2285.30	2285.26	2285.23	2285.20	2285.16	2285.13	2285.10	2285.06	2285.03
FORMATION LEVEL (CANAL BED LEVEL)	2285.00	2284.96	2284.93	2284.90	2284.86	2284.83	2284.79	2284.76	2284.73	2284.69	2284.66	2284.63	2284.59	2284.56
GROUND LEVEL	2284.56	2285.89	2285.95	2284.42	2284.74	2285.170	2285.20	2285.02	2284.68	2284.83	2285.39	2284.74	2285.140	2285.02

DISTANCES IN MTRS	700	750	800	850	900	950	1000	1050	1100	1150	1200	1250	1300	1350
CUT DEPTH	0.418	0.372	0.165	0.849	0.322	0.456	0.519	0.552	0.396	0.419	0.363	0.596	0.490	0.363
FILL DEPTH	0.202	0.248	0.455		0.298	0.164	0.101	0.067	0.224	0.201	0.257	0.024	0.130	0.257
(TOP BANK LEVEL)	2285.152	2285.118	2285.085	2285.051	2285.018	2284.984	2284.951	2284.917	2284.884	2284.851	2284.817	2284.784	2284.750	2284.717
(FULL SUPPLY LEVEL)	2285.00	2284.96	2284.93	2284.90	2284.86	2284.83	2284.80	2284.76	2284.73	2284.70	2284.66	2284.63	2284.60	2284.56
FORMATION LEVEL (CANAL BED LEVEL)	2284.53	2284.49	2284.46	2284.43	2284.39	2284.36	2284.33	2284.29	2284.26	2284.23	2284.19	2284.16	2284.13	2284.09
GROUND LEVEL	2284.95	2284.87	2284.63	2285.28	2284.72	2284.82	2284.85	2284.85	2284.66	2284.65	2284.56	2284.76	2284.62	2284.46

Figure 3-4: Result from Canal L-Section

4. LAND DRAINAGE WORKS

A drainage system is necessary to remove excess water from the irrigated land. This excess water may be e.g. waste water from irrigation or surface runoff from rainfall. It may also include leakage or seepage water from the distribution system.

Excess surface water is removed through shallow open drains. Excess groundwater is removed through deep open drains or underground pipes. Two types of drainage can be provided

- ✓ Surface drainage,

- ✓ Sub-surface drainage

Surface drainage

- ✓ The removal of excess rain water falling on the fields or the excess irrigation water applied to the fields, by constructing open ditches, field drains, and other related structures.
- ✓ The land is sloped towards these ditches or drains, as to make the excess water flow in to these drains

Main activities in this category are:

- ✓ *Drainage System layout (to be prepared simultaneously with the irrigation canal layout)*
- ✓ *Drainage System Selection*
- ✓ Drainage canals design
    - ▪ *Drainage Canal Design Discharge Estimation*
    - ▪ Drainage canal x-sections
- ✓ Interceptor Drain (Catch Drain)
- ✓ Drainage canal structures

4.1. Drainage Canal Design Discharge Estimation

The in-field drainage can be designed for the 1 in 5 year 24 hour rainfall event i.e. the drains are designed to remove the volume of runoff from a 1 in 5 year, 24 hour storm in 24 hours. The rational method estimates the peak run off at a specific watershed location as a function of the drainage area, run off coefficient, and mean rainfall intensity for a duration equal to the time of concentration, Tc. $Q = \frac{1}{3.6}$ *C*i*A

Where, Q: design peak discharge (m^3/sec)

C: runoff coefficient

i: rainfall intensity in mm/h for the design return period and for a duration equal to the "time of concentration " of the watershed

A: the watershed area (km^2)

Table 4-1: Value of "C" is based on the recommendation of tables

Topography and vegetation			**Soil texture**		
			Open sandy loam	**Clay and silt loam**	**Tight clay**
Woodland	Flat	0-5% slope	0.1	0.3	0.4
	Rolling	5-10% slope	0.25	0.35	0.5

Topography and vegetation			**Soil texture**		
			Open sandy loam	**Clay and silt loam**	**Tight clay**
	Hilly	10-30% slope	0.3	0.5	0.6
Pasture	Flat	0-5% slope	0.1	0.3	0.4
	Rolling	5-10% slope	0.16	0.36	0.55
	Hilly	10-30% slope	0.22	0.42	0.6
Cultivated	Flat	0-5% slope	0.3	0.5	0.6
	Rolling	5-10% slope	0.4	0.6	0.7
	Hilly	10-30% slope	0.52	0.72	0.82

4.2. Interceptor Drain (Catch Drain)

The interceptor drains run parallel to the main canal. The drains intercept the overland flow from the uplands above the canal. The interceptor drains will discharge into the rivers or nearby gullies as appropriate:

- ✓ Estimation of catchment area for the interceptor drain
- ✓ Inlet and outlet conditions
- ✓ Protection works

Canal structures

- ❖ Identify the structures in your irrigation system
  - ✓ Drop Structures
  - ✓ Division Boxes /Turnouts
  - ✓ Cross-drainage structures
  - ✓ Measuring structures
  - ✓ Protective structures, Etc
- ➢ Collect appropriate data for the design of the structures (hydrology, geology, detailed topomap, etc)
- ➢ Design your structures (typical designs, hence systematize your work)

5. DESIGN OF IRRIGATION SYSTEM STRUCTURES

5.1 Design of Division Box

The division boxes are used to divert the required amount of water from the parent canal to the branching canal for the specified period of time to irrigate the command area. Normally, gates are provided at the division boxes to control the outflow of water. The function of division boxes is to serve the proportioning of the irrigation water based on the available land downstream.

Basic Consideration of the Design

- ✓ At each division boxes, control gates are provided
- ✓ The basin width of the division boxes is equal to the bed width of the main canal plus some additional width for stabilizing the flow.
- ✓ The proportionality of the division boxes is adjusted with the width of the outlet and the head over the sill is the same on both canals. It follows the continuity equation.

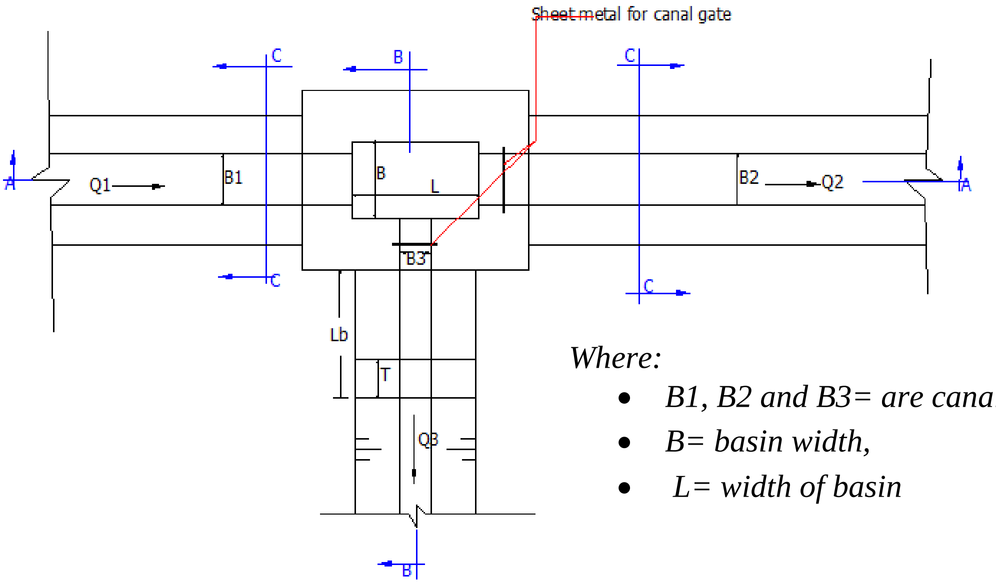
⇒ Width of outlet to tertiary canal, Br = (Qr /Qo) x Bo

Where Qr = Design discharge to tertiary canal

Qo = Design discharge in the main canal

Bo = Main canal bed width

But from construction point of view provide bed widths < 0.25m outlet width.



Where:

- *B1, B2 and B3= are canal bed widths,*
- *B= basin width,*
- *L= width of basin*

Figure 5-1: Typical one-way division box

Figure 5-2: Division Box on field on earthen canal

***Example**: find the minimum bed width for the Tertiary canal capacity of 80 l/s diverted from main canal of Q=240 l/s .Take the bed width of main canal is 0.6m.*

Solution:

Q_r = *Design discharge to tertiary canal =80l/sec*

Q_o = *Design discharge in the main canal = 240l/sec*

B_o = *Main canal bed width = 0.6m*

$\Rightarrow$ *Width of each outlet = (80/240)* 0.6 = 0.20 m*

But from construction point of view provide 0.30 m outlet width.

5.2 Design of Drop Structures

Drop structures are required when the ground slope along which the canals are laid is beyond the recommended limit. A canal given with higher slope than the recommended will be dangerous and will create erosion of the command area and becomes deepen thereby not commanding the irrigable land. Canal of higher slope having higher discharge will make the risk more sever. Therefore, it will be advisable to break the slope length into reasonable lengths so that the recommended slopes can be easily maintained minimizing scouring of the channels. The height of drops should not be greater than 1m and less than 0.5m. If the land slope is too steep the drop spacing will be denser and construction of drops may not be economical. In such cases the canal should be wholly lined with masonry (chutes).

The location of a fall has to be judiciously worked out such that there should be a balance between the quantities of excavation and filling. Further the height of the fall has to be decided, since it is possible to provide larger falls at longer intervals or smaller falls at shorter intervals. It may be observed that the portion of the canal which is running in filling may be able to serve the surrounding area by releasing water by gravity. For the portion of the canal that is running in excavation, if surrounding areas have to be irrigated, it has to be done through pumping.

There are various types of fall structures, some of which are no more provided these days. The most widely used one is the USBR type of drop. The design principle for this type of drop is discussed below:

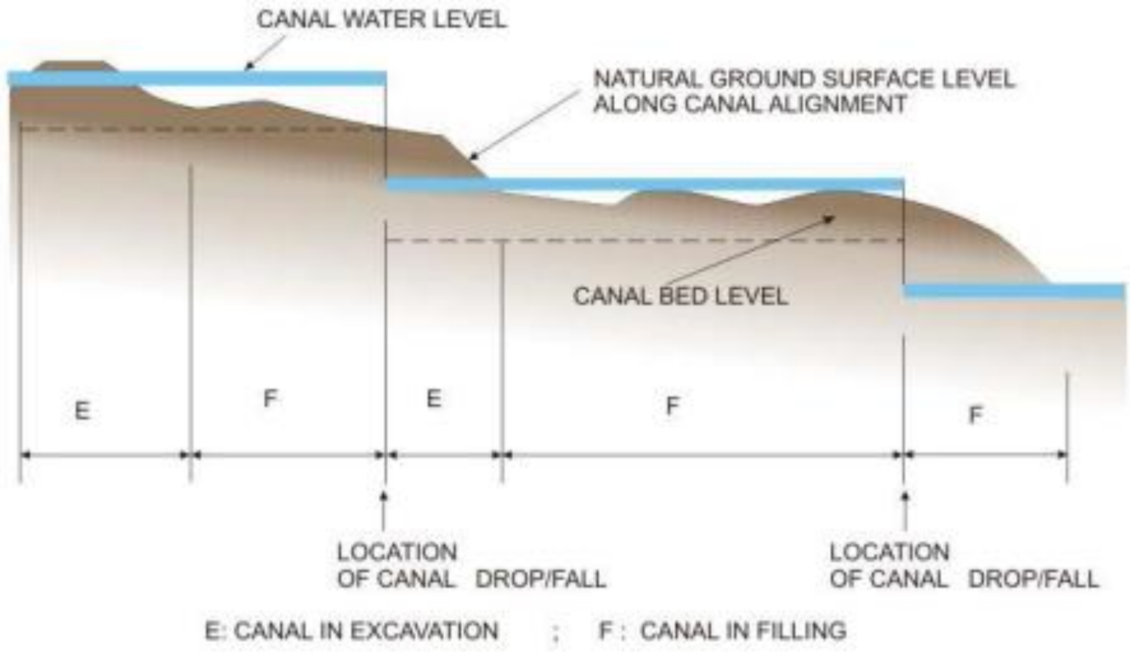


Figure 5-3: Typical location for providing canal drop or fall

1. **Critical flow hydraulics parameters**

   a. Design discharge, Q
   b. Height of drop, H
   c. Width of drop, bc= bed width of main canal
   d. Unit discharge, q =Q/bc
   e. Critical depth, $dc = \frac{q2/3}{g}$

2. **Stilling basin**

   a. Lip height, $a = \frac{dc}{2}$

b. Length, L $L = \left[2.5 + 1.1\frac{d_c}{h} + 0.7\left(\frac{d_c}{h}\right)^3 \right]\sqrt{hd_c}$

c. Width of Basin, $B = \frac{18.46\sqrt{Q}}{Q + 9.91}$

Example: Design a Vertical Drop (U.S.B.R. Type) the given data

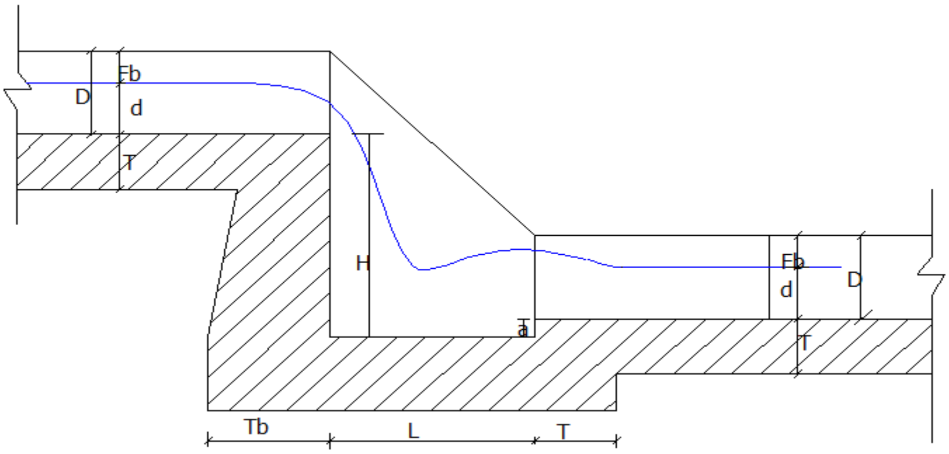


Figure 5-4: typical drop structure

1. Given data:

a. Design discharge = 0.4m3/s

b. Height of drop =1m

c. Canal bed width, B = 0.8m

2. Critical flow hydraulics

a. Width of drop= canal bed width = 0.80m

b. Unit discharge, $q = \frac{Q}{b_c} = \frac{(0.400)}{(0.80)} = 0.500 m^3/\sec/m$

e. Critical depth, $d_c = \left(\frac{q^2}{g}\right)^{1/3} = \left[\frac{(0.500)^2}{9.81}\right]^{1/3} = 0.294m$

3. Stilling basin

a. Lip height, $a = \frac{d_c}{2} = \frac{(0.294)}{2} = 0.147 \rightarrow use\ 0.15m$

$$b.\ Length,\ \ L=\left[2.5+1.1\frac{d_c}{h}+0.7\left(\frac{d_c}{h}\right)^3\right]\sqrt{hd_c}$$

$$=\left[2.5+1.1\frac{(0.294)}{(1.0)}+0.7\left\{\frac{0.294}{(1.0)}\right\}^3\right]\sqrt{1.0*0.294}$$

$$=(3.289)(0.383)=1.54\rightarrow use\,1.6m$$

$$\text{c. Width. } B=\frac{18.46\sqrt{Q}}{Q+9.91}=\frac{18.46\sqrt{(0.400)}}{(0.400)+9.91}=1.13\rightarrow use\,1.20m$$

5.3 Design of Chute structure (Simplified method)

Normally chutes are provided if the numbers of drops are dense with respect of distance. In such case a cute structure will be selected.

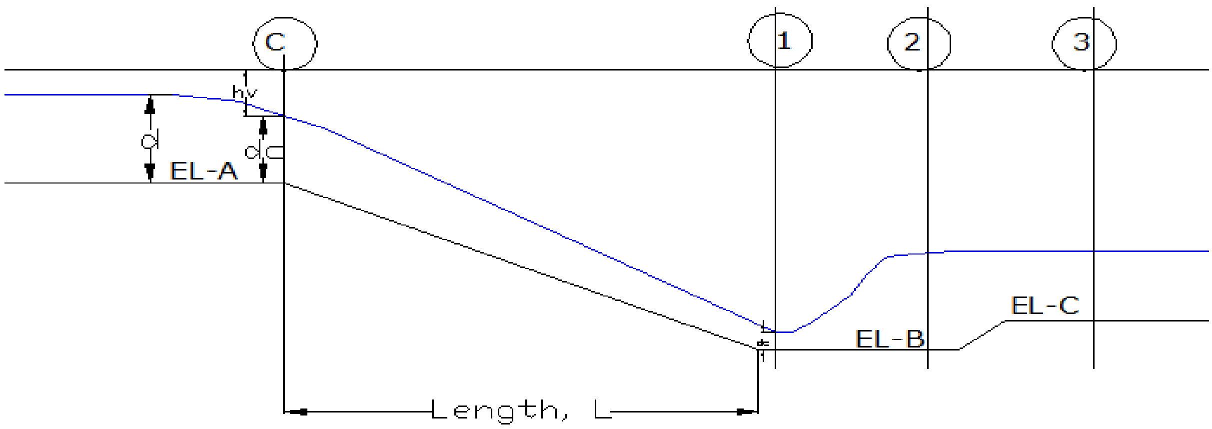


Figure 5-5: typical chute structure

Example: Design a chute for the following given data:

Discharge, Q=0.4m3/s

Elevation difference between upstream and downstream canal bed level = 5m

Length of the chute = 50m

Canal bed width, bc = 0.85m

1. Critical flow hydraulics

$$\text{Unit discharge, } q=\frac{Q}{b_c}=\frac{(0.400)}{(0.85)}=0.470m^3/\sec/m$$

$$\text{Critical depth, } d_c=\left(\frac{q^2}{g}\right)^{1/3}=\left[\frac{(0.47)^2}{9.81}\right]^{1/3}=0.282m$$

$$\text{Critical Velocity, } V_c=\frac{q}{d_c}=\frac{(0.470)}{(0.282)}=1.666m/\sec$$

Velocity head, $h_{vc} = \frac{V_c^2}{2g} = \frac{(1.666)^2}{2x9.81} = 0.141m$

Water area, $A_c = b_c d_c = (0.850)x(0.282) = 0.240m$

Wetted Perimeter, $P_c = b_c + 2d_c = (0.85) + 2x(0.282) = 1.414m$

Hydraulic radius, $R_c = \frac{A_c}{P_c} = \frac{(0.240)}{(1.414)} = 0.1697m$

Water surface slope, $I_c = \left(\frac{nV_c}{R_c^{2/3}}\right)^2 = \left[\frac{(0.017)x(1.666)}{(0.1697)^{2/3}}\right]^2 = 0.00854$

2. Energy at Section (C)

$$Z = EL.A - EL.B = (1800.000) - (1795.000) = 5.00m$$

$$E_c = d_c + h_{vc} + Z = (0.282) + (0.141) + (5.000) = 5.423m$$

3. Energy at Section (1)

Designation	**Results of the calculation**			
Trial number	**1**	**2**	**3**	**4**
Assumed depth, d_1	0.20	0.10	0.105	0.1045
b1 = b	**0.85**	**0.85**	**0.85**	**0.85**
A1 = b1*d1	0.1700	0.0850	0.0893	0.0888
V1 = Q/A1	2.3529	4.7059	4.4818	4.5032
hv1 = V1^2/(2g)	0.2822	1.1287	1.0238	1.0336
P1 = b1 +2*d1	1.2500	1.0500	1.0600	1.0590
R1 = A1/P1	0.1360	0.0810	0.0842	0.0839
I1 = [(ηV1)/(R1^(2/3)]^2	0.0229	0.1828	0.1573	0.1596
Im = (Ic+I1)/2	0.0157	0.0956	0.0829	0.0841
hf1 = Im*L	0.7854	4.7824	4.1460	4.2041
E1 = d1 +hv1 +hf1 E1= Ec = 5.423	1.2676 Too small	6.0111 Too Big	5.2748 a little small	5.3422 o.k.

4. Conjugate depth after jump

Froude number, $F = \frac{V_1}{\sqrt{gd_1}} = \frac{(4.525)}{\sqrt{9.81x(0.104)}} = 4.48$

Conjugate depth, $d_2 = \frac{d_1}{2}\left(\sqrt{1+8F_r^2} - 1\right) = \frac{(0.104)}{2}\left[\sqrt{1+8(4.48)^2} - 1\right] = 0.609m$

5. Stilling basin

a. Length, $L = 4d_2 = 4x(0.609) = 2.436 \rightarrow use\ 2.50m$

b. Width, $B = \frac{18.46\sqrt{Q}}{Q + 9.91} = \frac{18.46\sqrt{(0.400)}}{(0.400) + 9.91} = 1.13 \rightarrow use\ 1.20m$

c. Bottom elevation (EL.C)

$$V_2 = \frac{q}{d_2} = \frac{(0.470)}{(0.609)} = 0.772m/s$$

$$h_{v2} = \frac{V_2^2}{2g} = \frac{(0.772)^2}{2x9.81} = 0.030m$$

$$E_2 = d_2 + h_{v2} = (0.609) + (0.030) = 0.639m$$

$$E_3 = d_3 + h_{v3} = (0.500) + (0.019) = 0.519m$$

$$a = E_2 - E_3 = (0.639) - (0.519) = 0.120m \rightarrow use\ 0.15m$$

$$EL.C = EL.B - a = (1795.000) - (0.15) = 1794.850m$$

5.4 Pipe Culvert (road crossing) Structure

Pipe culvert crossing structure is provided when the irrigation canal crosses the road. To bypass the water a pipe culvert can be designed as below. But it is also possible to construct the canal at the crossing point using masonry and hence, provide a slab cover.

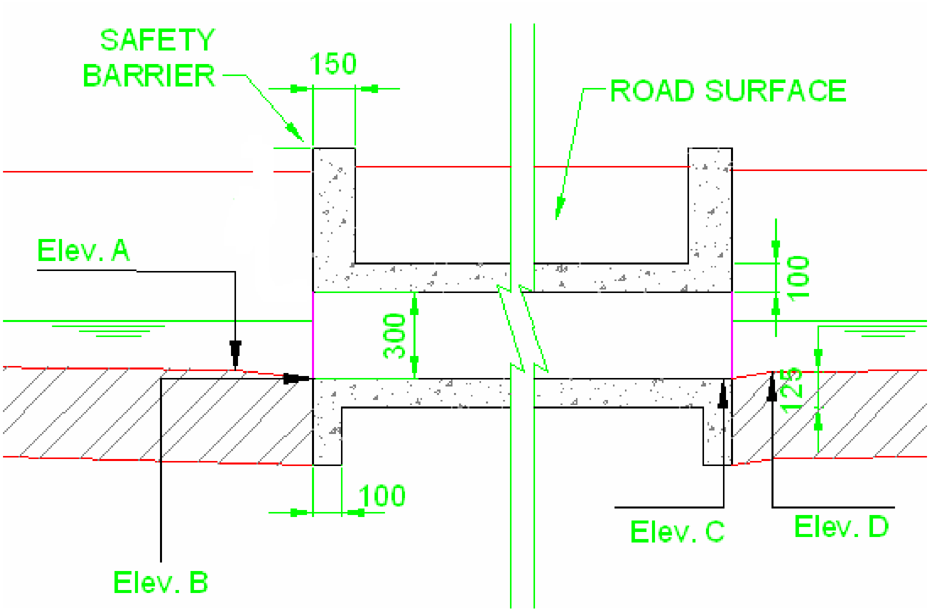


Figure 5-6: Typical road crossing structure

Example: designing of pipe culvert

1. Hydraulic calculation

a. Given Data

Table 5-1: Hydraulic characteristics of the canal

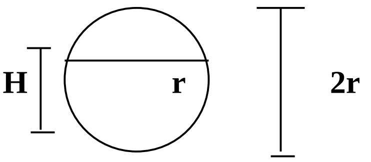
Discharge $Q(m^3/s)$	**Width b(m)**	**Depth d(m)**	**Side slope m**	**Velocity m/sec**	**Velocity head, h_v**	**Bed slope S**	**Roughness n**
0.2	0.4	0.47	1:1	0.44	0.01	0.0007	0.024

b. Flow hydraulics of barrel

Assuming the diameter of the pipe = 0.30m

$$H = 0.80D = 0.80x0.3 = 0.24m.$$

$$\frac{H}{r} = \frac{(0.24)}{(0.15)} = 1.60$$



Refer to table below

Table 5-2: Uniform flow in circular sections flowing partly full

H/r	$\alpha\beta = A/r^2$	**P/r**	$\beta = R/r$	$\alpha\beta^{2/3}$
2.0	3.141	6.283	0.500	1.979
1.9	3.082	5.380	0.572	2.123
1.8	2.978	4.996	0.595	2.105
1.7	2.846	4.692	0.606	2.038
1.6	2.694	4.428	0.608	1.932
1.5	2.527	4.188	0.603	1.802

$$\alpha = \frac{A}{r^2} = 2.694 \rightarrow A = \alpha r^2 = 2.694x0.15^2 = 0.06$$

$$\frac{P}{r} = 4.428 \rightarrow P = 4.428r = 4.428x0.15 = 0.664$$

$$\beta = \frac{R}{r} = 0.608 \rightarrow R = 0.608r = 0.608x0.15 = 0.0912$$

$$V_2 = \frac{Q}{A} = \frac{(0.06)}{(0.06)} = 1m/s$$

$$h_{v2} = \frac{V_2^2}{2g} = \frac{(1)^2}{2x9.81} = 0.004$$

$$I_2 = \left(\frac{nV}{R^{2/3}}\right)^2 = \left[\frac{(0.018)x(1)}{(0.0912^{2/3})}\right]^2 = 0.01$$

Difference in elevation between EL.B and EL.C

$h_f = LxI_2 = (6)x(0.01) = 0.06$, L= width of road (taken to be 6m)

c. Water surface change at the u/s and d/s of the culvert

i. Drop of water surface at the inlet of the culvert

$$\Delta h_1 = 1.5\left(\frac{V_2^2 - V_1^2}{2g}\right) = 1.5\left[\frac{(1)^2 - (0.26)^2}{2x9.81}\right] = 0.06m$$

ii. Rise of water surface at the d/s of canal section

$$\Delta h_2 = 0.3\left(\frac{V_2^2 - V_1^2}{2g}\right) = 0.3\left[\frac{1^2 - (0.24)^2}{2x9.81}\right] = 0.01m$$

a. Elevation

Invert Elevation at u/s canal = 661.85

Water surface elevation at u/s canal =661.85+d1

=661.85+0.24

=662.09

Water surface at the culvert inlet = (Water surface elevation at u/s canal)- Δh_1

=662.09-0.01=662.08

Invert elevation at the culvert inlet = (Water surface at the culvert inlet) –d_2

=662.08–0.24 =661.84

Invert elevation at the culvert outlet = (invert elevation at the culvert inlet) -h_f

=661.84–0.06=661.77

Water surface elevation at the culvert outlet = (Invert elevation at the culvert outlet) +d_2

= 661.77+0.24=662.01

Water surface elevation at the d/s canal = (Water surface elevation at the culvert outlet) + Δh_2

=662.01+0.01 = 662.02

Invert elevation at the d/s canal = (Water surface elevation at the d/s canal)-d1

= 662.02-0.24=661.78

2. Structural Design

a. Considered Data

Depth of soil, H = (1.00) m, at least this depth of soil cover has to be maintained.

Unit weight of soil, ϭs = 1.9ton/m3

Load of vehicle, P= (5.600) ton

b. Load

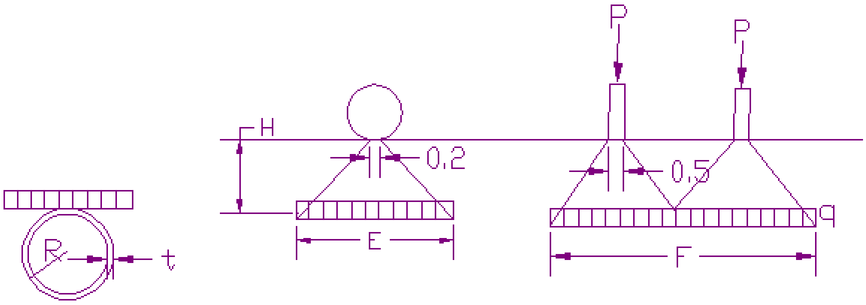


Figure 5-7: Distribution of load over pipe culvert

i. Dead load

Soil: W1 = бs *H = 1.90*1= 1.9ton/m2

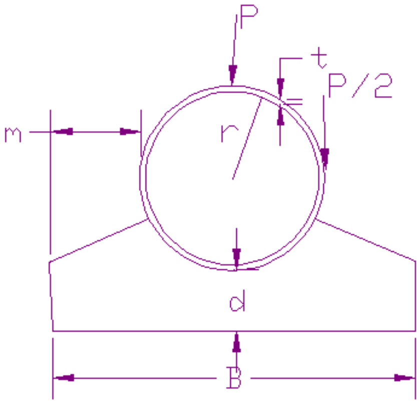
ii. Live load

E = 0.20 + 1.75H = 0.20 + 1.75(1.00) = (1.950) m

F = 2.25 + 1.75H = 2.25 + 1.75 (1.00) = (4.000) m

$$W_2 = \left(\frac{2P}{EF}\right)(1+i) = \left[\frac{2(5.6)}{(1.95)(4.00)}\right]\left[1+(0.0)\right] = 1.436 ton/m^2$$

Where, i: impact factor



Impact factor of the various fill depth

Depth of fill H (m)	Impact factor, *i*
0.0 - 0.3	0 - 0.3
0.3 - 0.6	0.2
0.6 - 0.9	0.1
Over 0.9	0

iii. Total load

W = w1 + w2 = (1.900) + (1.436) = 3.336 tan/m^3

C. Moment

Maximum bending moment

R= 0.5(D+ t) = 0.5[(0.3) + (0.05)] =0.175

M= kWR^2= (0.314) (3.336) $(0.175)^2$ =0.032

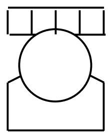
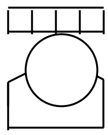
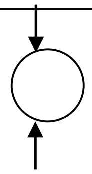
Where, W: uniform load (ton/m^2)

R: radius of culvert (m)

t: Wall thickness (m)

k: load coefficient due to bedding

Table 5-3: Load coefficient due to bedding

Angle of bedding α(deg).	**K**		**Bedding material**		**Remark**
	Granular	**Concrete**	**Granular**	**Concrete**	
90 120 180	0.314 0.275 0.250	0.303 0.243 0.220			

ii. Minimum resisting moment

$$A_1 = \frac{\pi D^2}{4} = \frac{3.14x(0.3)^2}{4} = 0.071m^2$$

$$A_2 = \frac{\pi(D+2t)^2}{4} = \frac{3.14[(0.3)+2x(0.05)]^2}{4} = 0.1m^2$$

$$W_c = (A_2 - A_1)\sigma_c = [(0.1)-(0.071)]x2.4 = 0.07ton/m^2$$

$$M_r = 0.318QR + 0.239W_cR = 0.318Q(0.175) + 0.239(0.07)(0.175)$$

$$= (0.06)Q + (0.003)$$

Where, бc Unit weight of culvert (ton/m^3)

Q: Required supporting strength (ton/m)

W_c: Weight of culvert (ton/m^2)

d. Required supporting strength

Mr = f*M

Where, F: factor of safety (=1.5)

Mr M

(0.06) Q + (0.003) = 1.5 (0.032) = (0.05)

Q= [(0.05) – (0.003)] / (0.06) = (0.78) ton/m

Concrete pipe with extra –quality usually shows the strength of 2,380 kg/m .It can be assumed that the strength of the pipe is the same that of concrete pipe. Hence, Q=780kg/m < 2,380 kg/m o.k.

However, it is very common to strengthen the pipe by bundling 10cm thick cement mortar conventionally. Details are shown in the drawing Album.

e. Design of bedding

<u>Concrete bedding</u>

$$m = \frac{0.455p'}{b\tau_0} \quad and \quad d = \sqrt{\frac{26.4M_c}{b\sigma_c}}$$

where, $P' = \frac{2}{3}p(safety\ factor = 4)$

$$M_c = \frac{P'}{4}(r+t)\sin\alpha + H(r+t)(1-\cos\alpha)) + \frac{Hd}{2}$$
$$H = 0.455P'$$

Where, H: horizontal stress (ton/m)

σ_c : Allowable stress of concrete (30kg/cm^2)

r: inside radius (cm)

t: wall thickness (cm)

α : Angle of bedding (degree)

d: thickness of the bedding (cm)

τ_0 : Allowable tangential stress of concrete (=3kg/ cm^2)

b: limit length =100cm

p = 3.336 ton/m

r = 15cm

t = 5cm

$$P' = \frac{2}{3}P = \frac{2}{3}x(3.336) = 2.224ton/m$$
$$H = 0.455P' = 0.455x(2.224) = 1.012ton/m$$
$$m = \frac{H}{b\tau_0} = \frac{(1,012)}{(100)(3)} = 3.37 \rightarrow use\ 5cm$$
$$\therefore M_c = \frac{(2,224)}{4}[(15)+(5)]\sin(90^0) + 1,012[(15)+(5)][1-\cos(90^0)] + \frac{(1,012)d}{2}$$
$$= 16180 + 506d.(kg.cm)$$
$$d = \frac{\sqrt{26.4(16,180+506d)}}{(100)(30)} = \sqrt{142.384 + 4.453d}$$
$$d^2 - 4.453d - 142.384 = 0$$
$$\therefore d = 14.36cm \rightarrow use\ 15cm$$

5.5 Design of River crossing structure (Multi span flume)

When the discharging canal crosses Main River or gullies the design of flume is very important to bypass the flow to the required place.

I. Design of Flume

Design a flume having one pier at the center. The span has a length of 7m.

Hydraulic Design of multi-spian Flume structure

For maximum safety, take the longest span, i.e. 7m, flume bed width=0.30m, total canal depth =0.45m.

1. Load analysis

A. Live load: Critical condition, when the canal is full of water.

$$w1 = 0.30*0.45*9.81 = 1.32KN/m$$

B. Dead load: Assume the thickness of the bed slab of the canal is 20cm and thickness of the wall is 10cm.

W2= (0.2*0.4+2*0.1*0.45)24=4.08kN/m

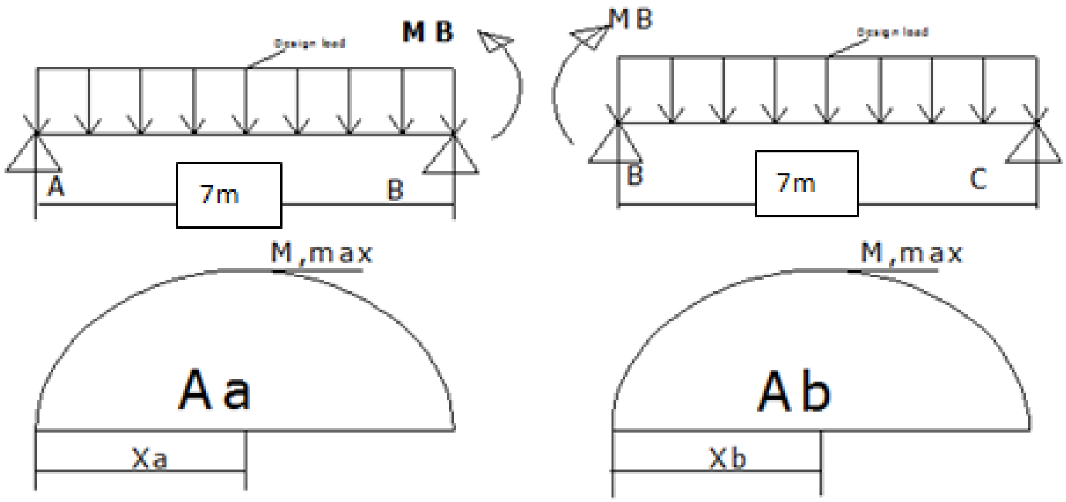
C. Design load:

*Wd=1.3*1.32+1.6*4.08=8.244KN/m*

Since the beam is an indeterminate beam, for analysis use ***three moment equation method***.

$$Ma + 4Mb + Mc = \frac{-6}{L^2}\left(Aa * \bar{X} a + Ab * \bar{X} b\right)$$

Take section at one support, say B:



Load distribution on the slab of flume

$$M,\max = \frac{w*l^2}{8} = \frac{8.244*49}{8} = 50.50KN\ ,\ \bar{X} a = \bar{X} b = L/2 = 3.5m$$

$$Ab = Aa = \frac{2*w*L^2}{3*8}*L = \frac{2*8.244*49}{3*8}*8 = 269.30$$

$$Aa * \bar{X}a = Ab * \bar{X} b = 269.30*3.5 = 942.55$$

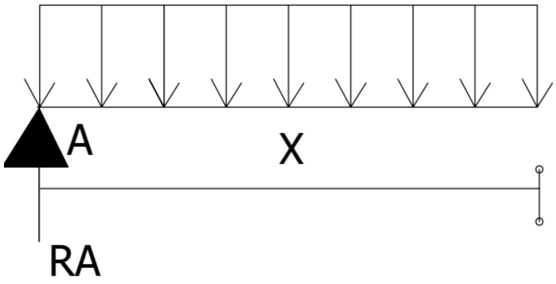
For simply supported beam; Ma=Mc=0.

Then $4*Mb = \frac{-6}{7^2}(2*942.55) = 115.40 \rightarrow Mb = 28.85KN/m$

$$\sum Mb = 0, \quad RA * L + Mb - \frac{w * L^2}{2} \Rightarrow RA = \left(\frac{8.244 * 7^2}{2} - 28.85\right) / 7 = 24.73KN$$

$$\sum Fv = 0, \; w * L = RA + RB \rightarrow RB = 8.244 * 7 - 27.43 = 30.28KN / m$$

Let's take a section at X-distance from support A.



$$Mx = RA * x - w * \frac{x^2}{2}$$

$$\frac{\partial m}{\partial x} = RA - w * x = 0 \rightarrow RA = w * x \rightarrow X = \frac{RA}{w} = \frac{30.28}{8.244} = 3.67m$$

Hence, Moment is maximum at 3.67m from support A.

$$M, \max = RA * x - \frac{w * x^2}{2} = 30.28 * 3.67 - \frac{8.244 * 3.67^2}{2} = 55.61KN - m$$

2. Design for Bending

The following data are known:

$fyk = 420MPa$; $fck = 25Mpa$; $Es = 200{,}000MPa$; $Ec = 26{,}000MPa$

$$fyd = \frac{fyk}{\sigma s} = \frac{420}{1.15} = 365.22MPa \;;$$

$$fcd = \frac{0.67 * fck}{\gamma s} = \frac{0.67 * 25420}{1.5} = 11.17MPa$$

Reinforcement ratio: $\rho = \dfrac{0.0028}{0.0035 + \dfrac{fyd}{Es}} * \dfrac{fcd}{fyd} = 0.0161$

To ensure ductility, $\rho \max = 0.75 * \rho = 0.75 * 0.0161 = 0.0121$

$$\omega \max = \rho \max * \frac{fyd}{fcd} = 0.0121 * \frac{365.22}{11.17} = 0.3956$$

Where: fyk - tensile strength of reinforcement;

fck - Compressive strength of concrete;

fyd - Design strength of reinforcement;

fcd - Design strength of concrete;

Ec - Modulus of elasticity of concrete; and

Es -Modulus of elasticity of steel; Es =200GPa at yield point.

$$\mu = \frac{\omega \max}{1} - \frac{\omega \max^2}{2} = 0.3956 - \frac{0.3956^2}{2} = 0.3714$$

$$\mu = \frac{M \max}{fcd * b * d^2} \Rightarrow d = \sqrt{\frac{50.50*10^6}{11.17*400*0.3714}} = 174.50mm$$

$D = d + \text{cov}er + \frac{\phi used}{2}$, where: D is the total depth, d, calculated depth, and ϕused is the diameter of the bar.

$D = 174.50 + 10 + \frac{16}{2} = 192.50mm$, $D_{calculated}$ (192.50mm) < $D_{assumed}$ (200mm), hence, the assumed thickness is sufficient.

$$\mu = \frac{M \max}{fcd * b * d^2} = \frac{50.5*10^6}{11.17*400*200^2} = 0.282,$$

$$\omega = 1 - \sqrt{1 - 2*\mu} = 1 - \sqrt{1 - 2*0.282} = 0.340$$

$\omega = 0.340 < \omega \max = 0.3956$, this indicates the section is singly reinforced.

Therefore, $As = \omega * \frac{fcd}{fyd} * b * d = 0.340 * \frac{11.17}{365.22} * 200 * 400 = 831.89mm^2$

Area of steel, $as = \frac{\pi * D^2}{4} = \frac{\pi * 16^2}{4} = 201.06mm^2$

Number of bars, $n = \frac{As}{as} = \frac{831.89}{201.06} = 4$

Provide 4φ16mm bars @1266.67mm c/c spacing as main reinforcement.

Canal Wall Design

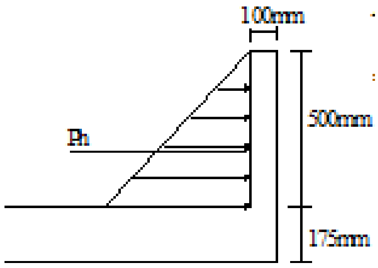
The total force due to water on the canal wall is:

$$Ph = \left(\frac{\gamma * h + 0}{2}\right) * h = \frac{\gamma h^2}{2} = \frac{9.81*0.45^2}{2} = 0.993KN/m$$

Check for shear force for the canal wall thickness

$$V \max = \frac{total - force}{Area} = \frac{0.993}{0.1*1} = 9.93KN/m^2 = 9.93*10^{-3} KN/mm^2$$

Allowable shear stress of C-25 concrete is 3.75N/mm^2. Therefore the thickness of the wall is sufficient for shear.



$$M = Ph * \frac{h}{3} * L = 0.993 * \frac{0.45}{3} * 14$$
$$= 2.085 KN - m$$

$\frac{Mu}{b * d^2 * fck} = \frac{2.085 * 10^6}{14000 * 100 * 25} = 0.0596 < 0.15$; Moment about canal bottom through the canal length: This indicates that the wall thickness is sufficient for bending.

Analysis of the distribution of reinforcement bars for the canal wall

From lever arm curve, $la = 0.95$ corresponding to $\frac{Mu}{b * d^2 * fck}$

Moment arm $Z = la * d = 0.95 * 45 = 42.75 mm$

Area of steel, $As = \frac{Mu}{0.87 * fyk * Z} = \frac{2.085 * 10^6}{0.87 * 420 * 47.5} = 120.13 mm^2$

But minimum reinforcement,

$$= \frac{100 * As}{b * d} \geq 0.15 \Rightarrow As = \frac{0.15 * b * d}{100} = \frac{0.15 * 100 * 1000}{100} = 150 mm^2$$

Use ϕ 10mm bars for vertical reinforcement.

Bar spacing $= \frac{1000 * as}{As} = 1000 * \frac{\pi * 10^2 / 4}{150.00} = 523 mm$, take spacing 525mm.

Number of bars, As/as= 150/78.54 = 1.9 ≈2 bars/meter.

6. ENGINEERING COST ESTIMATION TABLE FORMAT FOR INFRASTRUCTURE SYSTEM

The preparation and subsequent use of bills of quantities on construction projects is the major process involving measurement techniques. The bill of quantities (measurements of work's specification) is prepared from the drawings by the quantity surveyor. It has to be made in accordance with "Standard Technical Specifications Method of Measurements for Construction of Buildings" by BaTCoDA. Normally, it is very essential to develop an excel sheet to compute the earth works and also other items. Here, a sample infrastructure item of works are listed.

Some uses of bill of quantities

- To measure the work contained in the construction or alteration of building works in a systematic and standard manner in order to obtain competitive tenders from contractors
- To assist in the preparation of valuations of work in progress in order to make stage payments to the contractor
- To assist the contractor in planning resources such as materials, labor and plant
- To assist the valuations of variations occurring during the progress of the project
- To assist in the preparation of the final account at the completion of the project

Table 6-1: Cost Summery

Bill No.	Description	Amount in Birr
1	General Items	
2	Headwork Structure	
3	Irrigation and Infrastructure	
4	Access /Inspection road	
	Total	
	VAT (15%)	
	Grand Total	

<u>Note:</u>

i. 10% of the total price will be covered by the user community

ii. Formwork is part of concrete works

iii. Cart away up to 200m downstream and simple site clearing works (removal of grasses, crop root remains and etc) are part of excavation works and during bidding all the contractors shall fill rate with this concept in mind.

Table 6-2: General Items

SN	Description	Unit	Qty	Rate	Total Amount
1	**Preparatory Work**				
1.1	Mobilization	LS			
1.2	Demobilization	LS			
1.3	Provide standard project indicator post using --m*----m flat sheet metal using RHS as column and stiffening starting from the construction time, one at turn from main road and the other at turn to the project (beginning of access road to project)	No			
	Sub total				
2	**Camp (Staff residence, Office, Store, Café, Kitchen, Toilet & Shower)**				
A	**Residential (8m by 4m) & office (6m by 4m) rooms**				
2.1	**Earth Work**				
2.1.1	Excavation for any type of materials (up to a maximum of 1 m depth)	m^3			
2.1.2	Provide and fill hard core with hard basaltic or equivalent stone, well compacted and blinded with crushed stone	m^2			
2.2	**Concrete and Masonry Work**				
2.2.1	Stone masonry work below and above ground level (up to a maximum of 1m below ground and 0.5m above ground)	m^3			
2.2.2	Concrete fill on floor slab C-10 (10cm thick).	m^3			
2.3	**Carpentry and Walling**				
2.3.1	Supply, assemble and fix in position eucalyptus wall post of length 3 m with span length of 1.2m with anti-termite treatment	No			
2.3.2	Supply and fix purlin in Eucalyptus wood size 50 x 70 mm nailed into eucalyptus truss	m			
2.3.3	Supply and fix wall cover in G-32 mm corrugated galvanized iron sheet fixed into zigba wood purlin with dome headed galvanized nails (purlin and ridge cover measured separately)	m^2			
2.3.4	Chip wood wall ceiling	m^2			
2.3.5	Supply and fix 4x5 mm ceiling buttons	m			
2.4	**Carpentry and Roofing**				
2.4.1	Supply, assemble and fix in position eucalyptus roof truss of length 3m span price shall include the application of three coats and external anti-termite treatment as per the drawing	No			
2.4.2	Supply and fix purlin in eucalyptus wood size 50 x 70 mm nailed into eucalyptus truss including three coats of anti - termite external treatment	m			

SN	Description	Unit	Qty	Rate	Total Amount
2.4.3	Supply and fix roof cover in G-32 mm corrugated galvanized iron sheet fixed into Zigba wood purlin with dome headed galvanized nails (purlin and ridge cover measured separately)	m^2			
2.4.4	Supply and fix G-32 mm CIS windows size 1x1.2m with all accessories	No			
2.4.5	Supply and fix G-32 mm CIS doors size 1.0x2.10m with all accessories	No			
2.5	**Finishing**				
2.5.1	Floor screed in cement mortar	m^2			
	Sub total				
3	**Store (4m by 3m)**				
3.1	**Earth Work**				
3.1.1	Excavation for any type of materials up to 1m depth	m^3			
3.1.2	Provide and fill hard core with hard basaltic or equivalent stone, well compacted and blinded with crushed stone	m^2			
3.2	**Concrete and Masonry Work**				
3.2.1	Stone masonry work below and above ground level	m^3			
3.2.2	Concrete fill on floor slab C-10.	m^3			
3.3	**Carpentry and Walling**				
3.3.1	Supply, assemble and fix in position eucalyptus wall post of length 3 m span with anti-termite treatment	No			
3.3.2	Supply and fix wall cover in G-32 mm corrugated galvanized iron sheet fixed into eucalyptus wood purlin with dome headed galvanized nails	m^2			
3.4	**Carpentry and Roofing**				
3.4.1	Supply, assemble and fix in position eucalyptus roof truss of length 3m span with the application of three coats and external anti-termite treatment	No			
3.4.2	Supply and fix purlin in eucalyptus wood size 50 x 70 mm nailed into eucalyptus truss including three coats of anti - termite external treatment	m			
3.4.3	Supply and fix roof cover in G-32 mm corrugated galvanized iron sheet fixed into Zigba wood purlin with dome headed galvanized nails (purlin and ridge cover measured separately)	m^2			
3.4.4	Supply and fix CIS G-32 mm windows size 1x1.2m with all accessories	No			
3.4.5	Supply and fix CIS G-32 mm doors size 1.0x2.10m with all accessories	No			
3.5	**Finishing**				
3.5.1	Floor screed in cement mortar	m^2			
	Sub total				
4	**Cafe & Kitchen (3m by 4m)**				

SN	Description	Unit	Qty	Rate	Total Amount
4.1	**Earth Work**				
4.1.1	Excavation for any type of materials	m^3			
4.1.2	Provide and fill hard core with hard basaltic or equivalent stone, well compacted and blinded with crushed stone	m^2			
4.2	**Concrete and Masonry Work**				
4.2.1	Stone masonry work below and above ground level	m^3			
4.2.2	Concrete fill on floor slab C-10.	m^3			
4.3	**Carpentry and Walling**				
4.3.1	Supply, assemble and fix in position eucalyptus wall post of length 3 m span with anti-termite treatment	No			
4.3.2	Supply and fix wall cover in G-32 mm corrugated galvanized iron sheet fixed into eucalyptus wood purlin with dome headed galvanized nails	m^2			
4.4	**Carpentry and Roofing**				
4.4.1	Supply, assemble and fix in position eucalyptus roof truss of length 3m span with the application of three coats and external anti-termite treatment	No			
4.4.2	Supply and fix purlin in eucalyptus wood size 50 x 70 mm nailed into eucalyptus truss including three coats of anti - termite external treatment	m			
4.4.3	Supply and fix roof cover in G-32 mm corrugated galvanized iron sheet fixed into Zigba wood purlin with dome headed galvanized nails (purlin and ridge cover measured separately)	m^2			
4.4.4	Supply and fix G-32 mm CIS windows size 1x1.2m with all accessories	No			
4.4.5	Supply and fix G-32 mm CIS doors size 1.0x2.10m with all accessories	No			
4.5	**Finishing**				
4.5.1	Floor screed in cement mortar	m^2			
	Sub total				
5	**Shower and Toilet (2.5m by 3m)**				
5.1	**Earth Work**				
5.1.1	Excavation for any type of materials as per the drawing	m^3			
5.2	**Concrete, Masonry and reinforcement Work**				
5.2.1	Stone masonry work	m^3			
5.2.2	Concrete fill on floor slab C-10.	m^3			
5.2.3	Concrete C-20 for cover slab (the cost includes	m^3			
5.3.1	Furnish and install reinforcement bars having φ 12mm (price includes woodwork, formwork and other associated activities)				

SN	Description	Unit	Qty	Rate	Total Amount
5.3.2	Furnish and install reinforcement bars having φ -----mm (price includes woodwork, formwork and other associated activities)				
5.4	**Carpentry and Walling**				
5.3.1	Supply, assemble and fix in position eucalyptus wall post of length 3 m span with anti-termite treatment	No			
5.3.2	Supply and fix wall cover in G-32 mm corrugated galvanized iron sheet fixed into eucalyptus wood purlin with dome headed galvanized nails	m^2			
5.4	**Carpentry and Roofing**				
5.4.1	Supply, assemble and fix in position eucalyptus roof truss of length 3m span with the application of three coats and external anti-termite treatment	No			
5.4.2	Supply and fix purlin in eucalyptus wood size 50 x 70 mm nailed into eucalyptus truss including three coats of anti - termite external treatment	m			
5.4.3	Supply and fix roof cover in G-32 mm corrugated galvanized iron sheet fixed into Zigba wood purlin with dome headed galvanized nails (purlin and ridge cover measured separately)	m^2			
5.4.4	Supply and fix G-32 mm CIS windows size 1x1.2m with all accessories	No			
5.4.5	Supply and fix G-32 mm CIS doors size 1.0x2.10m with all accessories	No			
5.5	**Finishing**				
5.5.1	Floor screed in cement mortar	m^2			
	Sub total				
6	**Guard House (---m by ---m)**				
6.1	**Earth Work**				
6.1.1	Excavation for any type of materials as per the drawing	m^3			
6.2	**Concrete, Masonry and reinforcement Work**				
6.2.1	Stone masonry work	m^3			
6.2.2	Concrete fill on floor slab C-10.	m^3			
6.2.3	Concrete C-20 for cover slab (the cost includes	m^3			
6.2.4	Furnish and install reinforcement bars having φ 12mm (price includes woodwork, formwork and other associated activities)				
6.2.5	Furnish and install reinforcement bars having φ -----mm (price includes woodwork, formwork and other associated activities)				
6.3	**Carpentry and Walling**				
6.3.1	Supply, assemble and fix in position eucalyptus wall post of length 3 m span with anti-termite treatment	No			

SN	Description	Unit	Qty	Rate	Total Amount
6.3.2	Supply and fix wall cover in G-32 mm corrugated galvanized iron sheet fixed into eucalyptus wood purlin with dome headed galvanized nails	m^2			
6.4	**Carpentry and Roofing**				
6.4.1	Supply, assemble and fix in position eucalyptus roof truss of length 3m span with the application of three coats and external anti-termite treatment	No			
6.4.2	Supply and fix purlin in eucalyptus wood size 50 x 70 mm nailed into eucalyptus truss including three coats of anti - termite external treatment	m			
6.4.3	Supply and fix roof cover in G-32 mm corrugated galvanized iron sheet fixed into Zigba wood purlin with dome headed galvanized nails (purlin and ridge cover measured separately)	m^2			
6.4.4	Supply and fix G-32 mm CIS windows size 1x1.2m with all accessories	No			
6.4.5	Supply and fix G-32 mm CIS doors size 1.0x2.10m with all accessories	No			
6.5	**Finishing**				
6.5.1	Floor screed in cement mortar	m^2			
	Sub total				
7	Diversion and Dewatering during construction (this includes for all works from camping to infrastructure)	Ls			
8	Preparation of as built drawing	Ls			
9	Fence Work (wood posts buried with cement concrete and tied with barbed wire at an interval of 1.5 m) 6m by 2.10m double hinged door	m			
	Sub total				
	Total for Preparatory Work				

Table 6-3: Bill of quantity of Infrastructure and drainage system (Right side)

Item	Description	Unit	Qty	Unit Rate (Birr)	Total Cost (Birr)
1	**Main Canal (MC)**				
1.1	**Clearing and Excavation**				
1.1.1	Clearing Bushes, Shrubs, Trees and roots including roots along the canal area and its environs	m^2			
1.1.2	Earth Excavation	m^2			
1.1.3	Soft Rock	m^3			
1.1.4	Random Rock	m^3			
1.15	Hard Rock (Sound rock)	m^3			
1.2	**Concrete Work** *(when bedding is required)*				
1.2.1	Concrete Bedding (C-10)	m^3			
1.2.2.	C-20 concrete for production of slab (including 10 mm dia bar as shown in the working drawing)	m^3			
1.2.2	10 mm dia reinforcement bars	kg			
1.3	**Masonry work**				
1.3.1	Masonry for canal lining with 1:3 ratio	m^3			
1.3.2	Plastering with 1:3 ratio	m^2			
1.4	**Fill and Compaction**				
1.4.1	Backfill and compaction by the excavated material	m^3			
	Sub Total				
2	**Tertiary Canals**				
2.1	**TC-1**				
1	**Clearing and Excavation**				
1.1	Clearing Bushes, Shrubs, Trees and roots including roots along the canal and its environs	m^2			
1.2	Earth excavation	m^3			
1.3	Fill and Compaction with selected material	m^3			
	Sub Total				
2.2	**TC-2**				
1	**Clearing and Excavation**				
1.1	Clearing Bushes, Shrubs, Trees and roots including roots along the canal and its environs	m^2			
1.2	Earth excavation	m^3			
1.3	back fill and Compaction	m^3			
2	*Masonry Work*				
2.1	Stone Masonry	m^3			
2.2	Plastering	m^2			
	Sub Total				
3	**Division Boxes and Turnouts**				
A	**Division Box and Turnout on Main Canal**				
3.1	**Masonry/Stone Work**				
3.1.1	Masonry with 1:3 ratio	m^3			
3.1.2	Plastering with 1:3 ratio	m^3			
3.1.3	Cemented Stone Pitch	m^3			
	Sub Total				

Item	Description	Unit	Qty	Unit Rate (Birr)	Total Cost (Birr)
3.2	**Division box and Turnout Gates on Main Canal**				
3.2.1	4mm Gate sheet metal, (----m by -----m)	No			
3.2.2	4mm Gate sheet metal, (----m by -----m)	No			
3.2.3	Angle Iron (5cm x5cm x5mm thick) for 28 gates	m			
	Sub Total				
B	**Division Box and Turnout on Tertiary Canal**				
3.1	**Masonry/Stone Work**				
3.1.1	Masonry with 1:3 ratio	m^3			
3.1.2	Plastering with 1:3 ratio	m^3			
3.1.3	Cemented Stone Pitch	m^3			
	Sub Total				
3.2	**Division box and Turnout Gates on Tertiary Canal**				
3.2.1	4mm Gate sheet metal, (----m by -----m)	No			
3.2.2	Angle Iron (5cm x5cm x5mm thick) for the gates	m			
	Sub Total				
4	**Drops**				
A	**Drops on Main Canal**				
4.1	**Masonry/Stone Work**				
4.1.1	Earthen Excavation	m^3			
4.1.2	Masonry with 1:3 ratio	m^3			
4.1.3	Plastering with 1:3 ratio	m^3			
4.1.4	Cemented Stone Pitch	m^3			
	Sub Total				
B	**Drops on Tertiary Canal**				
4.2	**Masonry/Stone Work**				
4.2.1	Earthen Excavation	m^3			
4.2.2	Masonry with 1:3 ratio	m^3			
4.2.3	Plastering with 1:3 ratio	m^3			
4.2.4	Cemented Stone Pitch	m^3			
	Sub Total				
5	**CATTLE TROUGH (---- to ----- chainage)**				
5.1	Excavation	m^3			
5.2	Back fill	m^3			
5.3	Hard core	m^3			
5.4	Concrete (C-25)	m^3			
5.5	Masonry with 1:3 ratio	m^3			
5.6	Plastering with 1:3 ratio	m^2			
5.7	Installation of pipe including gates (2 inch PVC)	m			
5.8	12mm reinforcement bar with 20cm spacing c/c	kg			
	Sub Total				
6	**Road crossing (---- to ----- chainage)**				
6.1	Excavation	m^3			
6.2	Back fill	m^3			
6.3	----cm diam RCC concrete pipe	No			

Item	Description	Unit	Qty	Unit Rate (Birr)	Total Cost (Birr)
6.4	Masonry with 1:3 ratio	m^3			
6.5	Plastering with 1:3 ratio	m^3			
	Sub Total				
7	**Footpath crossings (---- to ----- chainage)**				
7.1	Excavation	m^3			
7.2	Back fill	m^3			
7.3	C-20 concrete for production of slab (including ----- mm dia bar as shown in the working drawing)	m^3			
	Sub Total				
Total of Bill for Irrigation and Drainage Infrastructure (Right side)					

7. DRAWINGS

After designing of the structures, the drawings have to be prepared for each structure with the specified scale. The drawings should be clear, easily understandable, and in standard manner. Here are some of the lists of the drawings that have to be included but not limited to:

- ✓ Iirrigation system layout
- ✓ Section and profile of main, secondary and teritary canals
- ✓ Plan and section of Division box, drop, chute, road crossings and drainage crossings
- ✓ Section and profile of catch and collector drains canals

8. REFERENCES

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2. *Different design reports of the region*
3. *Irrigation EngineerPractices by Ministry of Water Resources*
4. *Irrigation Methods, FAO Land and Water Training Manual No 5*
5. *NRCS National Engineering Handbook Part 623, Irrigation, Chapter 4, Surface Irrigation*

Annexes

Annex-1: Manning's roughness coefficient for different canal lining materials

Type of Channel and Description	Roughness coefficient *n*		
	Minimum	Normal	Maximum
A. Excavated earthen channels			
a. Straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
5. With long grass and weeds	0.030	0.040	0.045
b. Winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.033
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.028	0.030	0.035
5. Stony bottom and weedy banks	0.025	0.035	0.040
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest state of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140
B. Lined or built-up channels			
a. Cement			
1. Neat, smooth surface	0.010	0.011	0.013
2. Mortar	0.011	0.013	0.015
b. Concrete			
1. Trowel finish	0.011	0.013	0.015
2. Float finish	0.013	0.015	0.016
3. Finished, with gravel on bottom	0.015	0.017	0.020
4. Unfinished	0.014	0.017	0.020
c. Brick			
1. Glazed	0.011	0.013	0.015
2. In cement mortar	0.012	0.015	0.018
d. Masonry			
1. Cemented rubble	0.017	0.025	0.030
2. Dry rubble	0.023	0.032	0.035

Annex-2: Suggested maximum flow velocities and side slopes for lined and unlined channels

Type of Surface	Maximum Flow Velocities m/sec	Maximum Flow Velocities ft/sec	Side Slopes Range (z)*
Unlined Ditches, seasoned			
Sand	0.3 - 0.7	1.0 - 2.3	3
Sandy loam	0.5 - 0.7	1.6 - 2.3	2-2½
Clay loam	0.6 - 0.9	2.0 - 3.0	1½-2 **
Clays	0.9 - 1.5	3.0 - 5.0	1-2 **
Gravel	0.9 - 1.5	3.0 - 5.0	1-1½
Rock	1.2 - 1.8	4.0 - 6.0	¼-1
Lined Ditches			
Concrete			
Cast-in-place	1.5 - 2.5	5.0-8.2†	¾-1½
Precast	1.5 - 2.0	5.0 - 6.5	0-1½ ††
Brick	1.2 - 1.8	4.0 - 6.0	0-1½ ††
Asphalt			
Concrete	1.2 - 1.8	4.0 - 6.0	1-1½
Exposed membrane	0.9 - 1.5	3.0 - 5.0	1½-2
Buried membrane ‡	0.7 - 1.0	1.6 - 3.3	2
Plastic			
Buried membrane ‡	0.6 - 0.9	2.0 - 3.0	2½

* z is the horizontal unit to one (1) vertical unit.

** Side slopes of 1:1 for small canals in clay and clay loam are common.

† Flows in this velocity range may be supercritical (see definitions) and difficult to control. They are not recommended except for special uses.

†† Small precast and brick channels may have vertical walls (z = 0).

‡ Maximum flow velocities will depend on the cover over the membrane.