A PRACTICAL GUIDE TO IRRIGATION CANAL DESIGN

By

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Planning or improving an irrigation project requires a close coordination of the activities such as land classification, estimation of irrigation diversion requirement, determination of sources of available water, design of storage reservoir, design of distribution works, economic analysis of the project and water management. However, this paper deals with the estimation of irrigation water requirement and the design of irrigation canals. Some guidelines are presented in the design of earth canal to efficiently carry the irrigation diversion requirement.

Irrigation Diversion Requirement

Irrigation diversion requirement is the total quantity of water diverted from a source for evapotranspiration, percolation, farm waste, farm ditch loss and conveyance loss in main canal and lateral minus effective rainfall in the field. Figure 1 shows a typical canal irrigation network and the associated terms in irrigation diversion requirement.

Evapotranspiration also known as consumptive use refers to the portion of water which evaporates from water or soil surface in the field and from transpiration of the plants. According to a study by Ongkingco of the University of the Philippines, College of Agriculture, evapotranspiration measurements in the humid tropic have shown considerable consistency with an average value between 4 and 6 mm/day when advective energy (energy brought in by wind from drier areas) is relatively small. Higher average rates of 6 to 8 mm/day have been obtained during dry season when advective energy is not negligible.

Percolation on the other hand, is the quantity of water lost due to the downward movement of water through a depth of soil and is influenced by soil texture. Factors affecting the rate and amount of percolation are as follows:

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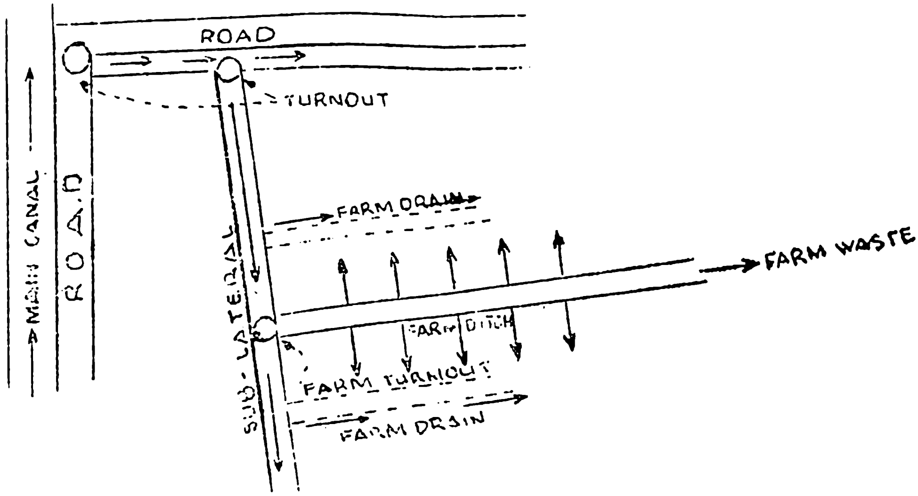

FIG. 1. *Illustration of terms pertaining to irrigation diversion requirement.*

1) soil texture and structure in layer of the soil profile—soil with less percolation are fined texture and have massive structure; coarse-textured soil and with columnar structure have higher percolation rate
2) soil permeability—permeable soils tend to have more percolation; less permeable soils have less percolation
3) depth of impervious layer—shallow soils tend to have less percolation while deep soils have more percolation
4) depth of water table—shallow water table tends to induce less percolation; deep water table, more percolation

The average percolation rates after land soaking for the three generalized soil types as suggested by the National Irrigation Administration are as follows:

Soil Texture	*Percolation Rate* *Amm/day)*
sandy	2.5 — 8
loamy	1.5 — 2.5
clayey	1.0 — 1.5

Effective rainfall is defined as the total rainfall minus that amount which cannot be stored or used in the paddy field.

The water loss components which are larger in quantity, goes to non-productive purposes. The components of the water losses are 1) farm waste, 2) farm ditch loss and 3) conveyance loss.

Farm waste is defined as the water lost in the farm due to seepage, percolation and leakages in paddy ditches, over-application of irrigation water, scheduled and unscheduled drainage and spillage.

Farm ditch loss is the portion of water lost due to seepage, percolation and leakages in the slope surface of the canals.

Conveyance loss is the amount of water lost in canal due to seepage, percolation along the wetted perimeter of canals and leakages through canals holes and gates and illegal diversion. It also includes evaporation from water surface and transpiration from weeds in canal bed and banks. This loss is limited to main canals and laterals only.

As you will note, the water losses are largely dependent on seepage. According to Darcy, the seepage discharge depends on the type of soil and on hydraulic gradient. The soil factor is represented by the seepage coefficient which expresses the soil's capacity to transmit liquid. The value of this coefficient depends, also, on the moisture content of soil and the temperature. Representative values are on Table 1.

For a better understanding of each term, the components of the diversion requirement are presented in the following equations:

1) Evapotranspiration = Evaporation + Transpiration

2) Crop Water Requirement = Crop Water Requirement + Percolation

3) Irrigation Requirement = Crop Water Requirement + Farm Waste — Effective Rainfall

4) Farm Turnout Requirement = Irrigation Requirement + Farm Ditch Loss

5) Diversion Requirement = Farm Turnout Requirement + Conveyance Loss in Main Canal & Lateral

Irrigation Efficiency

This is usually defined as the ratio of the irrigation water consumed by crops of an irrigated area to the water diverted from the source. When measured at the farm headgate it is called "farm irrigation efficiency" or "farm delivery efficiency" when measured at

TABLE 1

Water Losses By Seepage From Earth Channels

Type of soil	*Seepage loss ($m^3/m^2/day$)*
Impervious clay loam	0.07-0.10
Medium clay loam, impervious layer below the channel bottom not exceeding 60-90 cm in depth	0.10-0.15
Clay loam, silty soil	0.15-0.23
Clay loam with gravel, sandy clay loam, gravel cemented with clay particles	0.23-0.30
Sandy loam	0.30-0.45
Sandy soil	0.45-0.55
Sandy soil with gravel	0.55-0.75
Pervious gravelly soil	0.75-0.90
Gravel with some earth	0.90-1.80

Remarks: (1) The area, m^2, in this table is the wetted perimeter alone one metre of the channel. (2) All the values in this table are quite general; the soil type definitions give large soil groups and the experiments on which they are based ignored such important factors as the shape of the channel, the depth of an impervious layer and the depth of the ground water surface. The values are to be considered as general information only.

the source of water supply, it is called "water conveyance and delivery efficiency" or "over efficiency".

Separation of the various components of irrigation efficiency is necessary to evaluate the efficiency of the various section of the system. The product of the components efficiency terms give the overall efficiency of the system.

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An area of 10,500 hectares is being foreseen as an irrigable area. The requirement for evapotranspiration is assessed at 6 mm/day and the same for percolation is 2 mm/day. Assuming additional ten percent of the requirement is also provided. This additional ten percent will serve as a flexibility factor to cover the possible changes in water requirement on account of one or more of the following factors:

1) denser planting with fertilizer application

2) future variation in paddy cultivation practices

3) variation in farm side

Assuming an 80% distribution efficiency and 75% conveyance efficiency, what would be the corresponding diversion requirement.

1) crop water require = Evapotranspiration + Percolation
= 6 mm/day + 2 mm/day
= 8 mm/day

2) crop water requirement with provision for flexibility factor = 8 mm/day + 10 x 2 mm/day
= 8.8 mm/day

3) overall efficiency = conveyance efficiency x distribution efficiency
= 0.8 x 0.75
= 0.60

4) overall efficiency = crop water requirement with *flexibility factor* diversion requirement

Thus, irrigation diversion requirement = 8.8 mm/day / 0.60
= 14.67 mm/day

5) $Q = \dfrac{A\,d}{T}$ where A = irrigable area

d/t = irrigation diversion requirement

Q = 10,500 ha x 14.67 mm/day = 17.83 cms

This discharge requirement at source should be 17.83 cms and must be less than the water supply available at source. If not, the irrigable area has to be reduced to meet the availability of water supply.

Hydraulics of the Irrigation Canal

Canals and laterals are designed to meet the peak irrigation diversion requirement. Assuming the flow in the canal to be steady uniform flow, the Manning's equation can be applied. The discharge can be expressed as

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

where

Q = discharge in canal (cms)
n = Manning's roughness
R = hydraulic radius defined as the ratio of area to to wetted perimeter (m)
S = longitudinal slope

Values of Manning's roughness are presented in Table 2 for different type of channels. Since this value cannot be measured, much is left to the personal judgment of the designer.

TABLE 2

Values of n *In Manning's Equation*

Type of Channel	*Condition* *Excellent*	*Good*	*Fair*	*Poor*
Artificial channels				
1 Earth channel, straight, regular	0.017	0.020	0.023	0.025
2 Earth channel, excavated by floating excavator	0.023	0.028	0.030	0.040
3 Channel, cut in rock, straight, regular	0.023	0.030	0.033	0.035
4 Channel, cut in rock, not straight, irregular	0.035	0.040	0.045	
5 Channel, blasted in rock, vegetation on the sides	0.025	0.030	0.035	0.040
6 Earth bottom, sides with rubble stones	0.028	0.030	0.033	0.035
7 Bending channel, low velocity of flow	0.20	0.025	0.028	0.030
Natural channels				
1 Clean, straight, no sand banks, no holes	0.025	0.028	0.030	0.033
2 As 1 with some vegetation and gravel	0.030	0.033	0.035	0.040
3 Bending, clean, some sand banks and holes	0.033	0.035	0.040	0.045
4 As 3, shallow water, less regular	0.040	0.045	0.050	0.055
5 As 3 but with some vegetation and stones	0.035	0.040	0.045	0.050
6 As 4 but with some rocky sections	0.045	0.050	0.055	0.060
7 Slow-flowing reach, much vegetation and deep holes	0.050	0.060	0.070	0.080
8 Much high and dense vegetation	0.075	0.100	0.125	0.150
Line channels				
1 Masonry lining, without binding mortar	0.025	0.030	0.033	0.035
2 As 1 but with mortar	0.017	0.020	0.025	0.030
3 Pneumatically applied concrete lining	0.014	0.016	0.019	0.021
4 Concrete lining, very smooth	0.010	0.011	0.012	0.013
5 Ordinary concrete lining, cast in steel frame	0.013	0.014	0.014	0.015
6 As 5 but in timber frame	0.015	0.016	0.016	0.018

The discharge at a given cross-section in the canal is not only dependent on the roughness, n, the longitudinal slope and cross-sectional area, but also on its shape as expressed by its hydraulic reduce. For maximum discharge, with a given roughness and longitudinal slope, the cross-section has to have a shape with maximum hydraulic radius. Such a cross-section is called a hydraulically optimum cross-section.

Of all the cross-sectional shapes possible, semi-circular and circular shapes have the maximum hydraulic radius. In most cases, however, e.g. earth canals, this shape is impractical and it is therefore customary to build earth canals with trapezoidal cross-section.

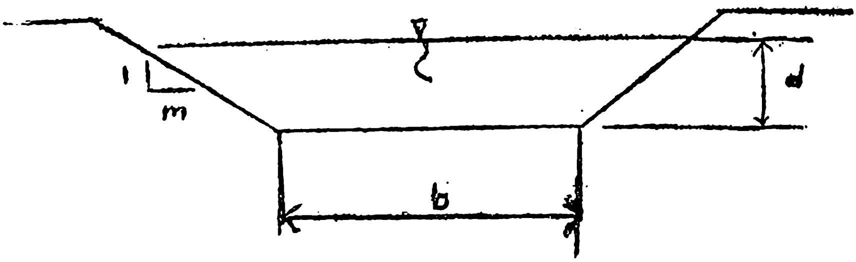
Relationships between the dimensions of a hydraulically optimum trapezoidal channel cross-section are on Table 3.

TABLE 3

Relationships Between The Dimensions Of Hydraulically Optimum Trapezoidal Channel

CROSS-SECTIONS

m	b/d	$Pd = d/\sqrt{A}$	$Pb = /\sqrt{A}$	$P_B = B/\sqrt{A}$	$Pd = 2/\sqrt{A}$	$Pp = P/\sqrt{A}$	$Pr = R/\sqrt{A}$
0.00	2.0000	0.7071	1.4142	1.4142	0.7071	2.8284	0.3536
0.50	1.2361	0.7590	0.9382	1.6972	0.8486	2.6352	0.3795
0.58	1.1521	0.7598	0.8574	1.7567	0.8784	2.6321	0.3799
1.00	0.8284	0.7396	0.6127	2.0919	1.0460	2.7044	0.3698
1.25	0.7016	0.7158	0.5022	2.2917	1.1459	2.7939	0.3579
1.50	0.6056	0.6891	0.4173	2.4846	1.2423	2.9021	0.3446
1.75	0.5309	0.6621	0.3515	2.6689	1.3345	3.0206	0.3311
2.00	0.4721	0.6361	0.3003	2.8444	1.4222	3.1446	0.3180
2.50	0.3852	0.5887	0.2268	3.1702	1.5851	3.3971	0.2944
3.00	0.3246	0.5485	0.1780	3.4690	1.7345	3.6467	0.2742
4.00	0.2462	0.4853	0.1195	4.0019	2.0010	4.1213	0.2426
5.00	0.1979	0.4386	0.0868	4.4728	2.2364	4.5597	0.2193
6.00	0.1654	0.4027	0.0666	4.8990	2.4495	4.9661	0.2013



The relationships given in Table 3 are expressed in the following equations:

$$\frac{b}{d} = 2\ [1 + m^2)^{1/2} - m]$$

$$P_d = \frac{d}{A^{1/2}} = \frac{1}{[2\ (1 + m^2)^{1/2} - m]^{1/2}}$$

$$P_b = \frac{b}{A^{1/2}} = \frac{2\ 1\ (1 + m^2)^{1/2} - m\ 1}{[2\ (1 + m^2)^{1/2} - m]^{1/2}}$$

$$P_B = \frac{B}{A^{1/2}} = \frac{2(1 + m^2)^{1/2}}{[2\ (1 + m^2)^{1/2} - m]^{1/2}}$$

$$P_a = \frac{a}{A^{1/2}} = \frac{(1 + m^2)^{1/2}}{[2\,(1 + m^2)^{1/2} - m]^{1/2}} = \frac{P_B}{2}$$

$$P_p = \frac{P}{A^{1/2}} = 2\,[2\,(1 + m^2)^{1/2} - m]^{1/2} = {}^{2}/P_d$$

$$P_r = \frac{R}{A^{1/2}} = \frac{1}{2\,[\,2\,(1 + m^2)^{1/2} - m]^{1/2}} = \frac{1}{P_p} = P_d/_2$$

Side slopes of the trapezoidal section are determined by the stability of the bank material. Recommended side slopes in earth canals are exhibited in Table 4.

Another design criteria in earth canal is the permissible velocity. Permissible velocity is the velocity at which the flow does not cause

TABLE 4

U.S. Bureau of Reclamation Recommendations for Side Slopes in Earth Channels

Type of soil	*Side slope*	
	In channels up to 1.20 m deep	*In channels deeper than 1.20 m*
Turf	1:0	
Hard clay	1:0.5	1:1
Clay loam and silty loam	1:1	1:1.5
Sandy loam	1:1.5	1:2
Sand	1:2	1:3

scour. Most investigators who have determined empirical values for the permissible velocity have related to it the soil texture.

Fortier and Scobey determined the permissible velocities in existing channels for various soils. Their results are shown in Table 5.

TABLE 5

Permissible Mean Velocity

Type of Soil	*Permissible mean velocity (m/sec)*	
	Clean water	*Water containing colloids*
Very fine sand	0.45	0.75
Sandy loam	0.55	0.75
Silty loam	0.60	0.90
Alluvial silt, without colloids	0.60	1.00
Dense clay	0.75	1.00
Hard clay, colloidal	1.10	1.50
Very hard	1.80	1.80
Fine gravel	0.75	1.50
Medium and coarse grave	1.20	1.80
Stones	1.50	1.80

The following points about the figures given in Table 5 should be noted.

(1) 0.15 m/sec may be added to these values when the depth of the water is more than 1.0 m, and 0.15 m/sec should be subtracted when the water contains very coarse suspended sediments.

(2) For high and infrequent discharges of short duration, up to 30% may be added to the values given provided that the specified values are ont exceded with continous and frequent flows.

The problem of canal location is similar to highway location, but the solution may be more since the slope of the canal bottom must be downgrade. Within the limitation of the topography, the exact route of a canal is determined by the slopes that can be tolerated. Excessive slope may result in a velocity sufficient to cause erosion of the bed material. On the other hand, gradual slope may result in velocities so that growth of aquatic plants will reduce the hydraulic efficiency of canal and suspended material in the water may be deposited.

Free board must be provided above the design water level as a precaution against accumulation of sediment, reduction in hydraulic efficiency by plant growth, wave actions, settlement of the bank and flow in excess of design values. Usually free board is about 40% of the maximum depth but not less than 30 cm.

Let us consider the irrigation diversion requirement of 17.83 cms. from the previous section. From the soil survey, the soil is classified as clay loam and silty loam, so that the permissible velocity is 0.60 to 0.90 m/sec. (Table 5). The average value of .75 m/sec. is used in the design. The side slope of 1:1 is adapted and Manning's roughness is 0.025.

Using the continuity equation,

$$Q = AV \text{ where V is the permissible velocity}$$

$$\text{then, } A = Q/V = 17.83 \text{ cms}/0.75 \text{ m/sec.}$$

$$= 23.77 \text{ m}^2$$

Referring to Table 4, for a hydraulically optimum cross-section with side slope of 1:1, we have the ratio of base width to depth (b/d) = 0.8284,

$$p_d = d/A^{1/2} = 0.7396$$

and

$$p_b = b/A^{1/2} = 0.6127$$

Therefore,

$$d = 3.61 \text{ m} \qquad b = 2.99$$
$$A = bd + md^2 = 23.77 \text{ m}^2$$
$$P = b + 2d\,(1 + m^2)^{1/2} = 13.20 \text{ m}$$
$$R = 1.80 \text{ m}$$

With the permissible velocity, the calculated hydraulic radius and the roughness coefficient, the permissible velocity can occur at one and only longitudinal slope. This slope can be calculated using Manning's formula

$$V = \frac{R^{2/3} \quad S^{1/2}}{n} \qquad \text{or } S^{1/2} = \frac{nV}{R^{2/3}}$$

$$S^{1/2} = \frac{0.025 \text{ x } 0.75}{1.80^{2/3}} \quad ; \quad S = 0.0002$$

This longitudinal slope must conform with the ground profile of the canal layout, if not a series of water drops should be provided.

REFERENCES

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