DRAINABLE SURPLUS PROBLEMS IN IRRIGATED AREAS

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SYNOPSIS

The constituent elements of the water balance are discussed with special reference to conditions in the Lower Indus Area. Criteria for establishing the drainable surplus are considered, especially in regard to irrigation efficiencies and evaporation losses. Experimental data are quoted in support of the adopted assumptions. A typical calculation of the drainable surplus is presented for areas to be drained by tubewells and the special problems of tile drainage areas are examined.

1. Notation

The following symbols are used in this paper :—

A_r : ratio of the present commanded cultivable area to the measured gross area;
C : constant in infiltration equation;
CCA : commanded cultivable area;
d : depth of water, in inches;
E_p : evaporation from a free-standing, Class A, Bureau of Reclamation evaporation pan, in inches per day;
E_0 : evaporation from a free open water surface, in inches per day;
K : constant in the irrigation losses equation;
K_1 : constant in the canal losses equation;
K_2 : constant in the fallow-land losses equation;
K_3 : constant in the 'never-cultivated' land losses equation;
L_{MC} : total main canal losses, in cusecs;
L_{MB} : total branch and minor canal losses, in cusecs;
MGA : measured gross area;
n : constant in infiltration equation;
Q_c : the maximum consumptive use of a crop, in acre-feet per acre per half-month;
Q_d : dominant discharge;

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Q_f : evaporation losses from fallow-land per square mile of measured gross area, in cusecs per square mile;

Q_{MR} : water applied at watercourse head, in acre-feet per 1,000 acres of commanded cultivable area per half month;

Q_n : total evaporation and evapo-transpiration from 'never-cultivated' land, in cusecs per square mile;

Q_t : $Q_f + Q_n$

t : time, in hours;

x_r : the ratio of the cropping pattern area to 1,000 acres of commanded cultivable area times 0.95.

2. Introduction

Under optimum conditions the water supplied to an irrigated area must always be in excess of that necessary to mature a crop. Part of the excess water is evaporated or transpired from non-crop areas and part passes below the root zone and joins the groundwater. This contribution to the groundwater is called the drainable surplus. To prevent the water table from rising and eventually affecting crop growth the drainable surplus must be removed. The determination of drainable surplus is therefore of prime importance and this paper considers the criteria and the method of calculation which were used to determine drainable surplus in the Southern Zone.

Drainable surplus may be calculated by considering the balance of water entering and leaving an area. Thus :—

INCOME WATER	OUTGOING WATER
Irrigation losses	Rainfall run-off
Canal losses	Down valley flow
Rainfall	Evaporation
Down valley flow	Non-crop evapo-trranspiration

These items are considered in detail in the following sections.

INCOMING WATER

3. Field losses

Field losses are most commonly caused by run-off and deep percolation. For the basin type of irrigation practised in the Southern Zone run-off is primarily due to poor maintenance of field bunds and excessive irrigation applications. Some deep percolation is unavoidable because a crop cannot utilise water reaching its root zone at the same rate at which the water is received; however, excessive deep percolation is due to poor field levelling, excessive single applications, shallow soils underlain by light soils of high permeability, and long irrigation runs.

The magnitude of field losses is commonly expressed in terms of 'field efficiency', the relation between the amount of water supplied to a field and the amount of water beneficially used by the crop in that field.

Willardson and Bishop[1] have recently demonstrated the value of the advance rate number, R, in determining the size of an irrigation application for maximum field efficiency. The advance rate number is the ratio of the time required for the root zone to become fully irrigated with no deep percolation loss and the time required for the water to reach the end of the field. Thus the size of the field, the infiltration rate of its soils, the crop grown and its state of growth, are taken into account when determining the size of the irrigation application.

For an average intake rate ($n = -0.5$ in the infiltration equation, $d = Ct^{n+1}$) the R number must exceed 0.25 for field efficiencies greater than 60 per cent, and when the intake rate is high ($n = -0.3$), the R value must exceed 0.50.

A series of infiltration tests were carried out in Southern Zone on cover and meander-flood plain soils, the most common type of soils in Southern Zone, as part of the Lower Indus Project investigations[2, 3]. Seventy-five ponded 3-day and 200 Musgrave ring 12-hour tests were carried out; accepted results from the two types of tests showed reasonable correlation. The values of n corresponding to the above equation varied from -0.2 for local light soils to -0.44 for local heavy soils. Thus the advance rate number for Southern Zone must not be less than 0.6 for field efficiencies to exceed 60 per cent.

Table 1 gives field efficiency values determined by various research workers and the results of investigations and field experiments carried out in Southern Zone for the Lower Indus Project.

Inattention to the distribution of irrigation water is the prime cause of low field efficiencies.

Under future development, higher cropping intensities, better levelling of fields, improved maintenance of field bunds and improved water management practices will gradually develop, and the field efficiency can be expected to reach 70 to 75 per cent.

4. Watercourse and field channel losses

Watercourse and field channel losses are primarily due to seepage through

TABLE 1.—*Field efficiencies*

Investigator	Crop	Field efficiency Range	Field efficiency Average	Remarks
Meyers and Haise[4] 1959	Various	29—100	66	Level contour border, several fields, seven years period.
Mahida[5] 1957	Various	N. A.	70	Subcontinent, Bombay-Dacca.
LIP[3] 1965	Wheat and oilseeds	74—92	82	Consumptive use experiments, small plots (0.02 acre) well levelled and carefully controlled.
Willardson and Bishop[1] 1967	All		60	Provided that the advance rate number is between 0.6 and 9.0.

N.A.=Not Available

the wetted area of the bed and sides of the channel; a minor proportion of the losses occurs by evaporation from the water surface. The seepage flow may be absorbed by unsaturated surrounding media, evaporated from bare soil of the channel banks and adjacent areas, or transpired by non-crop vegetation growing in these areas. If the surrounding media are or become saturated the seepage flow may be termed percolation. Leakage through poorly constructed channel banks is the most common form of channel loss.

Seepage losses are normally expressed in terms of cusecs per million square feet of wetted area (cusecs/msf). Table 2 summarizes watercourse and field losses determined by various investigators and gives the mean results determined for thirty-three ponded tests carried out as part of the Lower Indus Project investigations.

The results of ponded tests carried out on watercourses in the Southern Zone are detailed in Table 3. The tested reaches were approximately 500 feet long; each test lasted three days and three separate tests were carried out on each watercourse.

Thus, for a watercourse or field channel with a discharge of 2.5 cusecs, a water surface width of 3 feet, an average depth of water of 9 inches and an average length of 10,000 feet, the average total losses are 9.6 per cent of the discharge at the watercourse head, the range being between 4 and 16 per cent.

TABLE 2—*Watercourse and field losses*

Investigator	Losses			Remarks
	Total (cusecs/ msf)	Seepage %	Evaporation %	
Field (prior to 1920)	5.5	..	..	Average of several ponded tests in sub-continent.
Heath (prior to 1920)	..	92	8	Texas, U.S.A.
LIP 1965	4.9	94	6	Average of 33 ponded tests on 11 watercourses distributed throughout Southern Zone.

While the loss by evaporation from the water surface of a channel is only six per cent of the total channel losses, direct evapotranspiration from the banks of the channel together with evapotranspiration of water which has seeped through the banks and collected alongside the channel, are considerable. Losses also occur by overtopping and breaching of the banks of the channel.

For the purposes of calculation an average value of 10 per cent of the watercourse head requirement has been taken to represent watercourse and field channel losses; of this 50 per cent was considered to be lost by evaporation and evapotranspiration and 50 per cent was considered to reach the water-table.

5. Farm losses

The field losses and watercourse/field channels losses are commonly combined and given as farm losses. The term 'farm efficiency' is used to express the effectiveness of water distribution from the watercourse head and is defined as the ratio of the amount of water beneficially used by a crop in a field to the amount of water supplied for it at the watercourse head.

Table 4 gives values of farm efficiencies determined by various investigators compared with values determined from experiments and from data obtained during investigations carried out in the Southern Zone.

TABLE 3.—*Watercourse losses determined by ponded tests, Southern Zone (cusecs/msf)*

Serial No.	Watercourse	Width of water surface (feet)	Seepage losses			Evaporation losses	Total losses	Evap. losses as % of total
	Location by command		Max.	Min.	Normal full supply			
1	Gudu Left Bank ..	2.3	10.2	3.3	8.0	0.3	8.3	4
2	Sukkur Right Bank ..	3.1	3.0	0.3	2.0	0.3	2.3	13
3	Sukkur Right Bank ..	2.2	2.8	0.8	2.5	0.1	2.6	4
4	Sukkur Right Bank ..	4.1	4.9	0.9	5.0	0.3	5.3	6
5	Sukkur Left Bank ..	2.6	8.2	0.9	7.5	0.3	7.8	4
6	Sukkur Left Bank ..	3.6	4.2	0.9	4.0	0.3	4.3	7
7	Sukkur Left Bank ..	3.1	7.5	2.3	5.5	0.1	5.6	2
8	Sukkur Left Bank ..	3.0	7.8	1.7	5.5	0.2	5.7	4
9	Sukkur Left Bank ..	3.0	4.1	1.0	4.0	0.2	4.2	5
10	Ghulam Muhammad Right Bank	3.8	6.0	0.1	4.5	0.2	4.7	4
11	Ghulam Muhammad Left Bank	3.0	4.7	1.7	3.0	0.2	3.2	6
	Mean ..	3.1	..	..	4.7	0.2	4.9	6

TABLE 4.—*Farm efficiencies, basin irrigation*

Investigator	Crop	Farm efficiency	Size of irrigation (inches)	Remarks
Israelsen[7] 1962	Various Various	55 40	2—4 6—8	
Meyers and Haise[1] 1959	Four different crops	40—60	N. A.	California, U.S.A.
	Pasture	24—92	N. A.	On same pasture.
Mahida[5]	Various	60	N. A.	Bombay-Dacca.
LIP[3]	Wheat Cotton	50—57 37—50	N. A. N. A.	Watercourse studies, farmers' fields.
LIP[3]	Wheat and oilseeds	61—83	4	Consumptive-use experiments, small plots (0.02 acres), well levelled and carefully controlled.

The table indicates the wide range of farm efficiencies which can be obtained. The results for one pasture quoted by Meyers and Haise illustrate the importance of the control of water distribution previously discussed. Higher efficiencies are obtained provided that the depth of application is related to the advance rate number, smaller and more frequent irrigation applications will not necessarily in themselves give higher efficiencies.

Summarizing the two previous sections future farming losses for Southern Zone were taken to be as follows :—

If Q_{MR} is the water requirement at watercourse head, then :—

(*i*) Watercourse and field channel losses $= 0.10\ Q_{MR}$ (seepage 50%, evapotranspiration 50%)

(*ii*) Field losses $= 0.90\ Q_{MR} \times (0.30 \text{ to } 0.25) = (0.225 \text{ to } 0.27)\ Q_{MR}$

Farm losses $= (0.325 \text{ to } 0.37)\ Q_{MR}$

(of these losses $(0.275 \text{ to } 0.32)\ Q_{MR}$ moves towards the water-table).

These farm losses are equivalent to a farm efficiency of between 63 and 67.5 per cent. As a value of 67.5 per cent had been accepted for future development in the Northern Zone, this value was also accepted for the Southern Zone to ensure uniformity.

5. Canal losses

Table 5 shows values of canal losses previously used for design purposes in the Southern Zone.

TABLE 5 —*Canal losses*

(*cusecs/msf*)

Source	Losses	Remarks
Buckley	8	1910
Champhekar	8	1930 Sukkur Command
	8	1955 Ghulam Muhammad Command
	12	1960 Gudu Command (Non-perennial canals with greater full supply depths).

In the past many investigators have determined canal losses for individual canals on the subcontinent, but the values vary so widely that they are not suitable for general application.

During the LIP investigations three methods were used to assess canal losses, the inflow—outflow method—using field data, and two indirect methods. These latter involved measuring the water-table profile in the field, assuming aquifer characteristics and determining seepage rates by two analytical solutions, one for 'steady-state' canal flow using flow net analyses and one for 'non-steady state' conditions which occur at the time of canal closure. Each of these analytical solutions assumed fully saturated seepage flow *i.e.*, a shallow water-table. The more direct method of ponded tests could not be used for these larger canals because irrigation supplies could not be interrupted. No attempt was made to assess canal losses for the Gudu Command because at that time these canals were still under construction.

The results of the three methods used and the accepted values for design purposes are given in Table 6. The accepted design values take into account such factors as aquifer characteristics and water-table depth.

TABLE 6.—*Summary of canal losses determined by various methods and accepted design values.* (*cusecs/ msf*)

Barrage Command	Canal Command	Aquifer characteristics: Lateral perm. (10^{-3} ft/sec)	Aquifer characteristics: Specific yield %	Average seepage rates: Inflow/outflow	Average seepage rates: Steady state	Average seepage rates: Non-steady state	Average seepage rates: Mean	Accepted canal losses
Sukkur								
Right Bank	North-west	1.3	10.7	5.6	5.6	5.9	5.7	6
	Kirthar & Warah			4.0	..	2.9	3.5	4
	Rice			2.5	1.8	..	2.2	4
	Dadu			5.1	2.1	2.8	3.3	4
Left Bank	Khairpur F. W.	1.5	13.2	..	..	4.4	4.8	6
	Khairpur F. E.			4.3	..	5.7		
	Rohri Upper (0-300 RD)	1.3	13.3	6.7	..	5.7	6.2	8
	Rohri Lower			4.8	4.3	4.6	4.6	6
	Nara			..	..	4.7	4.7	6
	Jamrao	..	..	..	4.6	5.1	4.9	6
	Mithrao	..	..	..	..	4.6	4.6	6
	Khipro	..	..	..	..	5.1	5.1	6
Ghulam Muhammad								
Right Bank	Kalri-Baghar F. L.	0.7	3.5	..	3.5	..	3.5	4
	Pinyari F. L.			..	3.3	3.4	3.4	4
	Akram Wah			..	3.7	..	3.7	4
Gudu								
Right Bank	All except Pat Feeder	..	..	..	..	..	..	8
	Pat Feeder Extension	..	..	..	..	..	..	4
Left Bank	All	..	..	..	..	..	..	8

In addition to the average six per cent loss by evaporation from the canal-water surface, a series of calculations showed that a further six per cent of the remainder was evapotranspirated by canal-bank vegetation. Thus approximately 88 per cent of total canal losses passed to the groundwater.

7. Rainfall

Excessive rainfall which occurs at intervals of several years was dealt with separately and each area was studied to determine whether or not storm drainage was necessary. Here we are concerned only with normal rainfall and its contribution to groundwater. The contribution of rainfall to the groundwater may be considered in two parts, that portion of the rainfall which falls on fallow land and that which falls on cultivated land. After examining average monthly rainfall records for the Southern Zone it was considered that rain falling on fallow ground could be ignored because, since the amount was small and the initial soil moisture content was so low, movement to the water-table was unlikely, the total precipitation being subsequently evaporated or evapotranspirated.

However, part of the cultivated land will always have a moisture content at or near field capacity while the remainder will have a moisture content between field capacity and the maximum permitted depletion (taken to be midway between the field capacity and the permanent wilting point). At this lowest moisture content the soil was assumed to store 1.5 inches of water per foot of depth and at field capacity it was assumed that all the rainfall less one day's evaporation would pass to the groundwater. For an irrigation rotation of 15 days, two fifteenths of the cultivated area was taken to be at field capacity.

8. Down valley Flow

Down valley flow refers to the gravitational movement of groundwater towards the sea: in the Southern Zone it is extremely small, and for all practical purposes the total flow entering the area in this manner is equal to the flow leaving the area. Thus the contribution of down valley flow to the drainable surplus is negligible and has been ignored in all calculations for drainable surplus.

OUTGOING WATER

9. Evaporation and evapotranspiration from fallow and 'never-cultivated' land

Evaporation and evapotranspiration from cultivated land has already been taken into account in a previous section. However, allowance must be made for evaporation from fallow land, and evaporation and evapotranspiration from land which has 'never' been cultivated. Evaporation from fallow land, which was assumed to have no vegetative cover, depends upon the depth of the water-table—the shallower the water table the greater the evaporation. Various correlation of evaporation rate and water-table depth have been derived from different types of soils and are shown in Figure 1. The correlation recommended by the International Commission of Irrigation and Drainage was accepted for the Southern Zone. Calculations were made for a 7-foot water-table depth for tubewell drainage areas and a 5.5 feet depth for tile drainage areas (the crop water-table depth being 4 feet in the latter case).

The water-table under 'never-cultivated' land was assumed to be stable at 7 feet; half the 'never-cultivated' area was assumed to be covered with vegetation with an evapotranspiration rate of 24 inches a year, the remainder being bare soil with an evaporation rate of 5.6 inches per year. Thus the composite evaporation rate is 14.8 inches per year or an evaporation factor of 0.2 for a free-water surface evaporation rate of 80 inches per year.

DRAINABLE SURPLUS

10. Introduction

Before detailing the method of calculating the drainable surplus it would be helpful to consider how one unit of measured gross area (MGA) is broken down into its various components. Figure 2 shows this breakdown diagramatically.

A_r	is the ratio of present CCA to the measured gross area (MGA);
$0.95\ A_r$ MGA	is the future CCA, allowing 5 per cent for 'never cultivated' land including future development of roads, canals, villages etc.;
$(1\text{-}0.95)\ A_r$ MGA	is the 'never cultivated' land;
$x_r\ 0.95\ A_r$ MGA	is the cropped area, x_r is 0.95 times the ratio of the cropping pattern area to 1,000 acres of CCA, a 5 per cent reduction of optimum cropping pattern being allowed for farming feasibility;
$(1\text{-}x_r)\ 0.95\ A_r$ MGA	is the fallow area;
0.03 MGA	is the portion of the total measured gross area considered to be covered by impermeable surface;
$[(1\text{-}0.95)\ A_r\text{-}0.03)]$ MGA	the portion of 'never-cultivated' land from which evaporation occurs.

All the constituent elements of the drainable surplus were expressed in terms of the measured gross area (MGA) using the above notation. Irrigation, canal, evaporation and evapotranspiration losses and the drainable surplus were calculated in cusecs per square mile MGA. The water requirements, from which the irrigation losses were derived, were calculated per 1,000 acres CCA. To take into account the variations of the various factors which constitute the drainable surplus calculations were made for each half-monthly period.

METHOD OF CALCULATING DRAINABLE SURPLUS

11. Irrigation losses

If Q_{MR} represents the water applied at the watercourse head then the amount lost to the water-table is :—

$$[(0.25 \times 0.90) + 0.05]\, Q_{MR}$$

$$= 0.275\, Q_{MR} \text{ acre-feet per 1,000 acres CCA per half-month (\textit{i.e.}, 67.5 per cent farm efficiency)}$$

$$= 0.00591\, Q_{MR} \text{ cusecs per sq. mile CCA.}$$

Converting this into terms of the gross area, loss to water-table

$$= (0.00591\, Q_{MR}) \times (0.95\, A_r) \times 0.95$$

$$= 0.00533\, A_r\, Q_{MR} \text{ cusecs/sq. mile MGA}$$

$$= K\, A_r\, Q_{MR} \qquad \ldots\ldots\ldots\ldots(1)$$

where A_r is the CCA divided by the measured gross area (MGA), and assuming that five per cent of the CCA is 'never cultivated' and that water availability reduces the usable cultivated area by a further five per cent.

12. Canal losses

If L_{MC} is the total losses from the main canals and L_{MB} the total losses from the minor and branch canals, then the addition to the water-table from canal seepage is :—

$$0.94 \times 0.94\, (L_{MB} + L_{MC}) \text{ cusecs}$$

$$= 0.88\, (L_{MB} + L_{MC})$$

(that is 6 per cent is lost by evaporation and a further 6 per cent of the remainder by evapotranspiration from canal-bank vegetation).

Converting to gross area :—

$$\text{Loss to water-table} = K_1 (L_{MC} + L_{MB}) \qquad \ldots\ldots\ldots\ldots(2)$$

where $K_1 = \dfrac{0.88}{\text{Measured gross area (MGA)}}$

In actual fact a fixed proportion of canal losses cannot be established and applied throughout the year because the change in wetted canal perimeter is not directly proportional to discharge. Large changes in discharge produce relatively small changes in seepage. Moreover, while the losses in branch and main canals can be calculated individually the work involved in carrying out similar calculations for distributaries and minor canals becomes prohibitive. A proportioning method was therefore adopted which although it considerably reduced the volume of the work involved is still sufficiently accurate[6]. It is somewhat complex in description and only an outline of the method is given here.

Firstly each development unit of Southern Zone was subdivided into branch canal commands. The branch requirement at watercourse head was determined as a proportion of the total development unit requirement. This was converted into a flow in terms of cusecs. The losses in the branch canal were calculated from the formula :—

$$Lo_B = KLQ^{\frac{1}{2}}$$

where : Lo_B = Loss in the branch (cusecs)

L = Length of the branch (miles)

Q = the average dominant discharge over length L

K = a constant derived from seepage studies.[6]

In this way the loss in each branch canal at dominant discharge was determined.

To obtain the minor canal loss the total length of minors in the branch command was measured and the ratio of this length to L, the length of the branch canal obtained. Using this ratio a loss ratio 'K_r' was determined from a loss-ratio graph similar to the typical graph shown in Figure 3. These graphs were prepared after a study of several typical branch canal commands involving detailed calculation of losses in all the minor canals and distributaries. Using the loss ratio the minor loss was calculated from the relation :

$$\text{Minor loss} = K_r \times \text{Branch loss}$$

Addition of the branch and minor canal loss gives the total transit losses for the branch canal command. By calculating the losses in this way for each branch command it is possible to obtain the required discharge at the branch head and hence to arrive at the progressive discharge at each offtaking point on the main canals and feeders from head to tail. The losses in the main and feeder canals are calculated by a similar formula to that given for branches and these are allocated against each development unit in proportion to their offtaking discharges.

Calculations carried out thus far only relate to the dominant discharge. The discharge in minor canals may vary considerably from the dominant according to watercourse requirements. To calculate the loss in each half-monthly period the graph in Figure 4 is used in which the ratio of the required discharge for the period to the dominant discharge is plotted against the ratio of required loss to loss at dominant discharge. This graph may be used for minors under all conditions and for larger canals when they flow at discharges greater than design. The losses in the larger canals at flows less than the dominant discharge are taken to be the same as those at the dominant because the level will have to be kept up in these canals in order to command the offtakes. This assumption is conservative.

13. Evaporation losses, fallow land

Fallow acreage per square mile of gross area is $(1-x_r)$ 608 Ar. If E_o is the evaporation from an open water surface in inches per day, then the evaporation from a water-table 5.5 feet deep is $0.1\ E_o$ and for a 7-foot depth to water-table is $0.07\ E_o$ (see Figure 1). Thus, if evaporation loss per square mile of MGA is Q_f, then :—

for 5.5 foot deep water-table :

$$Q_f = 0.1\ E_o (1-x_r)\ 608\ A_r \qquad \text{acre-inches/day/sq. mile MGA}$$
$$= 2.55 (1-x_r)\ A_r\ E_o \qquad \text{cusecs/sq. mile MGA}$$

for 7-foot deep water-table :

$$Q_f = 1.79 (1-x_r)\ A_r\ E_o$$
$$\textit{i.e. } Q_f = K_2 (1-x_r)\ E_o \qquad \ldots\ldots\ldots(3)$$

where $K_2 = 1.79\ A_r$ for for 7-foot deep water-table
$= 2.55\ A_r$ for 5.5-foot deep water-table.

14. Evaporation and evapotranspiration from 'never-cultivated' land

The acreage of 'never-cultivated' land from which evaporation or evapotranspiration occurs is $(0.97-0.95)\ A_r$ 640 per square mile of MGA. Assuming that 50 per cent of the area in question is bare soil, that the remainder is covered in vegetation and, as previously mentioned, that the water-table is stable at 7 feet, then the overall evaporation factor is 0.2 E_o inches per day. Thus, if Q_n is the total evaporation and evapotranspiration then :—

$$Q_n = (0.97—0.95)\ A_r\ 640 \times 0.2\ E_o \text{ acre-inches per day per sq. mile MGA}$$

$$\simeq K_3\ E_o \text{ cusecs/square mile MGA} \qquad \ldots\ldots\ldots(4)$$

15. Summary

The constituent elements described in the previous four sections and which together form the drainable surplus in this particular case, can be summarized and expressed in terms of the water balance as follows :—

INCOMING WATER	OUTGOING WATER
Irrigation losses : $K\ A_r\ Q_{MR}$	Evaporation from fallow land : $K_2\ (1—x_r)\ E_o$
Canal losses : $K_1\ (L_{MC}+L_{MB})$	Evaporation and evapotranspiration from 'never-cultivated' land : $K_3\ E_o$

16. Typical calculation of drainable surplus for a tubewell area

The calculations for drainable surplus for a typical tubewell development unit, SL4, are given in Tables 7 to 10 inclusive. Table 7 details the cropped acreage per 1,000 acres CCA by half-month periods; Table 8 gives the main, branch and minor canal losses; Table 9 sets out the calculation of evaporation losses for a seven-foot deep water-table; and Table 10 shows the calculation of drainable surplus using data abstracted from the other tables.

Rainfall in this area was very small and made no contribution to the drainable surplus.

17. Calculations for tile drains at field level

The drainable surplus for tile drains at field level is a special case because the unit drainage area for tile drainage is so small that a single crop may completely cover the area served by two or more tile drains. Hence when calculating the drainable surplus at field level for a particular crop, allowance must be made for the total deep percolation without reduction for evaporation from fallow land. The method of calculation is therefore as follows :—

If Q_c is the maximum crop consumptive use in acre-feet per acre per half-month, then the total losses from the water supply are :—

TABLE 7.—*Cropped acreage per* 1,000 *acres CCA*
(*Development Unit* SL4)

Acres CCA	..	400	120	50	20	400	230	120	70	10	20	20	20	
Half-months	..	C	SF	SG	Ca	W	WO	WF	O	G	SO	SP	WP	Total
Jan. I	..	..	..	..	18	400	230	120	70	10	..	..	20	868
Jan. II	..	..	..	..	17	400	216	120	70	10	..	..	20	853
Feb. I	..	..	..	..	16	400	158	120	70	10	..	..	17	791
Feb. II	..	..	..	..	16	400	115	120	70	10	..	..	3	734
Mar. I	..	..	9	..	17	400	115	120	70	10	..	..	..	741
Mar. II	..	..	19	..	18	200	58	84	70	10	..	..	..	459
Apr. I	..	..	28	..	18	..	..	36	70	10	..	..	..	162
Apr. II	..	..	37	..	18	..	..	..	70	10	..	3	..	138
May I	..	150	46	..	18	..	..	..	70	10	..	17	..	311
May II	..	350	46	..	18	..	..	..	70	10	..	20	..	514
June I	..	400	46	..	18	..	..	..	70	10	3	20	..	567
June II	..	400	46	19	18	..	..	..	70	10	17	20	..	600
July I	..	400	46	44	18	..	..	..	70	10	20	20	..	628
July II	..	400	46	50	18	..	..	..	70	10	20	20	..	634
Aug. I	..	400	46	50	18	..	..	..	70	10	20	20	..	634
Aug.. II	..	400	46	50	18	..	..	..	70	10	20	20	..	634
Sep I	..	400	46	50	18	..	..	..	70	10	20	20	..	634
Sep. II	..	400	37	50	18	..	..	36	70	10	20	17	..	658
Oct. I	..	400	28	32	18	..	43	84	70	10	20	3	..	708
Oct. II	..	350	19	7	18	66	101	120	70	10	20	..	3	784
Nov. I	..	150	9	..	18	333	158	120	70	10	17	..	17	902
Nov. II	..	..	..	..	18	400	172	120	70	10	3	..	20	813
Dec. I	..	..	..	..	18	400	216	120	70	10	..	..	20	854
Dec. II	..	..	..	..	18	400	230	120	70	10	..	..	20	868

C = Cotton
SF = Summer Fodder
SG = Sorghum and Millet
Ca = Sugarcane
W = Wheat
WO = Winter Oilseeds
WF = Winter Fodder
O = Orchards
G = Gardens
SO = Oilseeds
SP = Summer Pulse
WP = Winter Pulse

TABLE 8.—*Canal losses*

Half-monthly	Minor and branch		Main canals		
	L_{MB}	L_{mb}	F	L_{MC}	L_{mc}
	(1)	(2)	(3)	(4)	(5)
Jan. I	416	0.342	1.0	793	0.651
Jan. II	431	0.354	1.0	793	0.651
Feb. I	432	0.355	1.0	793	0.651
Feb. II	409	0.336	1.0	793	0.651
Mar. I	380	0.312	1.0	793	0.651
Mar. II	354	0.291	1.0	793	0.651
Apr. I	374	0.307	1.0	793	0.651
Apr. II	460	0.378	1.0	793	0.651
May I	464	0.381	1.012	803	0.659
May II	479	0.393	1.0	793	0.651
June I	479	0.393	1.0	793	0.651
June II	464	0.381	1.010	800	0.657
July I	472	0.388	1.032	818	0.672
July II	483	0.397	1.052	834	0.685
Aug. I	514	0.422	1.125	890	0.731
Aug. II	523	0.429	1.140	903	0.741
Sep. I	505	0.415	1.100	871	0.715
Sep. II	478	0.392	1.0	793	0.651
Oct. I	502	0.412	1.0	793	0.651
Oct. II	488	0.401	1.055	836	0.686
Nov. I	494	0.406	1.0	793	0.651
Nov. II	488	0.401	1.0	793	0.651
Dec. I	476	0.391	1.0	793	0.651
Dec. II	474	0.389	1.0	793	0.651

Notes.—Column 1. Branch and minor canal losses in cusecs (L_{MB}).

Column 2. Contribution to drainable surplus by branch and minor canals losses in cusecs per sq. mile MGA ($K_1 \times L_{MB} = L_{mb}$).

Column 3. Factor for converting main canal losses at dominant discharge to the half-monthly discharge loss values

$$F = \frac{(Q_{MR})^{\frac{1}{2}}}{(Q_d)^{\frac{1}{2}}}$$

Column 4. Main canal losses in cusecs (L_{MC}) derived from losses at dominant discharge multiplied by factor in column 3

$$(L_{MC} = Lq_d \times F)$$

Column 5. Contribution to drainable surplus by main canal losses in cusecs per sq. mile MGA ($L_{mc} = K_1 L_{MC}$)

where Q_{MR} = discharge in cusecs at the module

Q_d = dominant discharge in cusecs.

TABLE 9.—*Evaporation losses from drainable surplus (depth to water-table 7 ft.)*

Half months			1	2	3	4	5	6	7	8
			E_p	E_o	x_r	$1-x_r$	$K_2(1-x_r)$	Qf Col. (5) .(2)	Qn K_3.(2)	Qt Col. (6)+ (7)
			(ins/day)					*(cusecs/sq. mile)*		
Jan.	I	..	..	0.08	0.825	0.175	0.389	0.022	0.058	0.080
Jan.	II	..	0.14	0.10	0.810	0.190	0.423	0.029	0.073	0.102
Feb.	I	..	0.18	0.13	0.751	0.249	0.554	0.050	0.094	0.144
Feb.	II	..	0.23	0.16	0.697	0.303	0.674	0.076	0.116	0.192
Mar.	I	..	0.32	0.22	0.704	0.296	0.658	0.102	0.160	0.262
Mar.	II	..	0.37	0.26	0.436	0.564	1.254	0.228	0.189	0.417
Apr.	I	..	0.47	0.31	0.154	0.846	1.881	0.408	0.225	0.633
Apr.	II	..	0.50	0.33	0.131	0.869	1.933	0.447	0.240	0.687
May	I	..	0.57	0.37	0.295	0.705	1.568	0.406	0.269	0.675
May	II	..	0.54	0.35	0.488	0.512	1.139	0.279	0.254	0.533
June	I	..	0.50	0.33	0.539	0.461	1.025	0.237	0.240	0.477
June	II	..	0.49	0.32	0.570	0.430	0.956	0.214	0.232	0.446
July	I	..	0.44	0.31	0.597	0.403	0.896	0.195	0.225	0.420
July	II	..	0.48	0.33	0.602	0.398	0.885	0.204	0.240	0.444
Aug.	I	..	0.46	0.32	0.602	0.398	0.885	0.198	0.232	0.430
Aug.	II	..	0.33	0.23	0.602	0.398	0.885	0.143	0.167	0.310
Sep.	I	..	0.35	0.25	0.602	0.398	0.885	0.155	0.182	0.337
Sep.	II	..	0.33	0.23	0.625	0.375	0.834	0.134	0.167	0.301
Oct.	I	..	0.33	0.23	0.673	0.327	0.727	0.117	0.167	0.284
Oct.	II	..	0.25	0.18	0.745	0.255	0.567	0.071	0.131	0.202
Nov.	I	..	0.18	0.13	0.857	0.143	0.318	0.029	0.094	0.123
Nov.	II	..	0.17	0.12	0.772	0.228	0.507	0.043	0.087	0.130
Dec.	I	..	0.13	0.09	0.811	0.189	0.420	0.027	0.065	0.092
Dec.	II	..	0.12	0.08	0.825	0.175	0.389	0.022	0.058	0.080

TABLE 10.—*Calculation of drainable surplus*

Half-month	1	2	3	4	5	6	7
		Cusecs per sq. mile MGA					
	Q_{MR} a. ft/1,000 Acs	$K A_r Q_{MR}$	Qt	L_{mb}	Total (2+4—3)	L_{mc}	Drainable surplus
Jan. I ..	153.16	0.720	0.080	0.342	0.982	0.651	1.633
Jan. II ..	185.28	0.871	0.102	0.354	1.123	0.651	1.774
Feb. I ..	192.70	0.906	0.144	0.355	1.117	0.651	1.768
Feb. II ..	142.38	0.669	0.192	0.336	0.813	0.651	1.464
Mar. I ..	82.35	0.387	0.262	0.312	0.437	0.651	1.088
Mar. II ..	42.77	0.201	0.417	0.291	0.075	0.651	0.726
Apr. I ..	47.33	0.222	0.633	0.307	0.104	0.651	0.547
Apr. II ..	180.32	0.848	0.687	0.378	0.539	0.651	1.190
May I ..	264.32	1.242	0.675	0.381	0.948	0.659	1.607
May II ..	221.44	1.041	0.533	0.393	0.901	0.651	1.552
June I ..	240.33	1.130	0.477	0.393	1.046	0.651	1.697
June II ..	263.86	1.240	0.446	0.381	1.175	0.657	1.832
July I ..	274.65	1.281	0.420	0.388	1.249	0.672	1.921
July II ..	285.94	1.344	0.444	0.397	1.297	0.685	1.982
Aug. I ..	326.77	1.536	0.430	0.422	1.528	0.731	2.259
Aug. II ..	336.58	1.582	0.310	0.429	1.701	0.741	2.442
Sep. I ..	312.40	1.468	0.337	0.415	1.546	0.715	2.261
Sep. II ..	220.33	1.036	0.301	0.392	1.127	0.651	1.778
Oct. I ..	179.91	0.846	0.284	0.412	0.974	0.651	1.625
Oct. II ..	290.65	1.366	0.202	0.401	1.565	0.686	2.251
Nov. I ..	161.26	0.758	0.123	0.406	1.041	0.651	1.692
Nov. II ..	156.15	0.734	0.130	0.401	1.005	0.651	1.656
Dec. I ..	140.03	0.658	0.092	0.391	0.957	0.651	1.608
Dec. II ..	136.18	0.640	0.080	0.389	0.949	0.651	1.600
Total ..	4836.89						

$$\frac{0.325}{0.675}\ Q_c = 0.481\ Q_c$$

The total supply is $1.481\ Q_c$.

Evaporation and evapotranspiration from the watercourse supply $= 0.05 \times 1.481\ Q_c$.

Thus deep percolation $= (0.481 - 0.05 \times 1.481)\ Q_c$
$= 8.78\ Q_c$ cusecs per square mile MGA ....(5)

This calculation is made for the acreage of each crop in each area where tile drains were proposed.

CONCLUSIONS

18. General

The paper describes a method of calculating drainable surplus in tubewell drainage areas based as far as possible on data derived from field experiments, which was used for the 28 development units into which Southern Zone was divided. Inevitably the method depended upon a number of assumptions: where possible these were based on observation of field conditions or study of typical areas, but, nevertheless, some pure assumptions had to be made. Further field experiments and study will permit refinement of these assumptions.

Despite these limitations the method is considered to be basically sound, and to provide a reasonable estimation of drainable surplus. It represents a considerable advancement on previous calculations.

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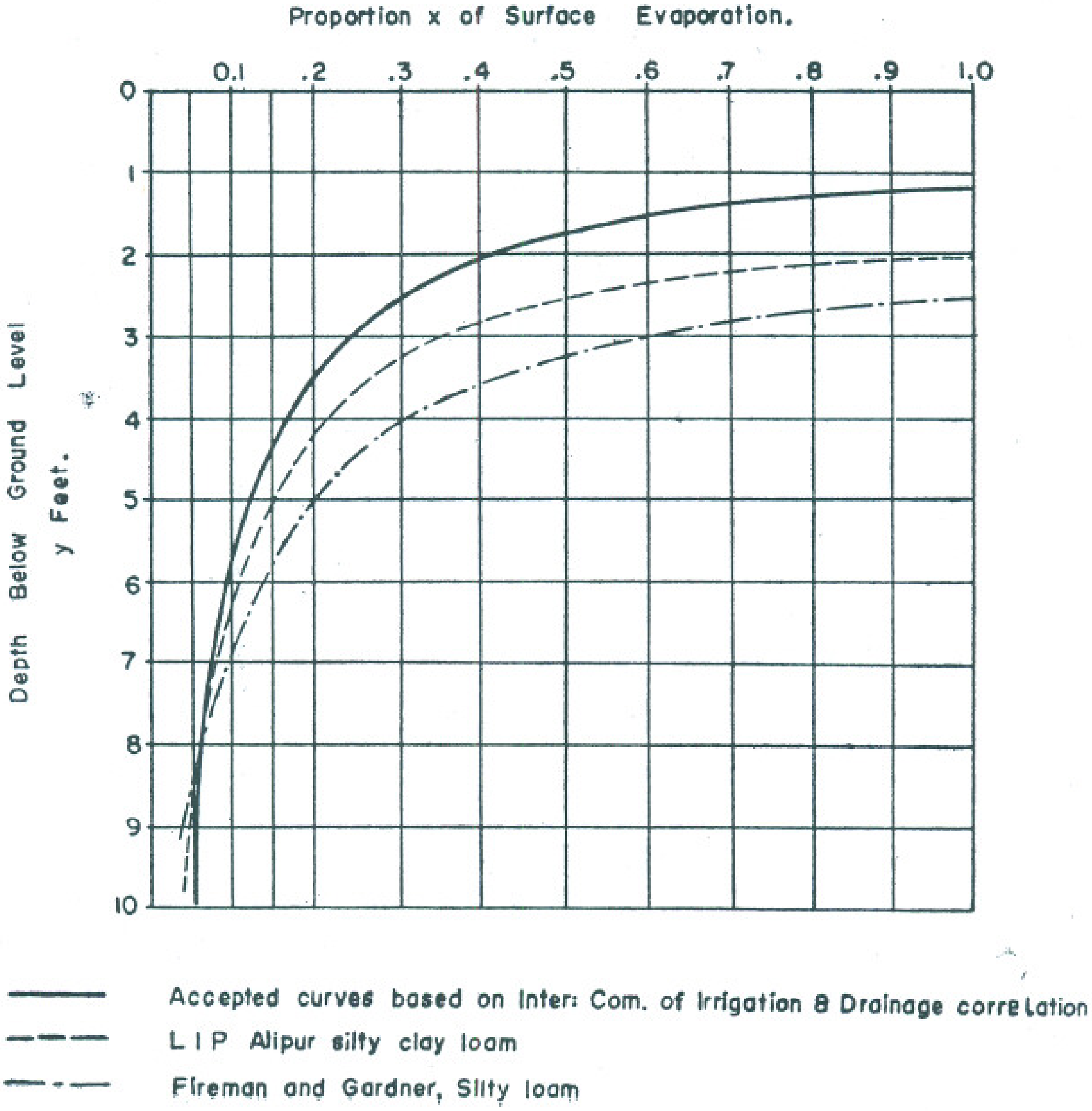
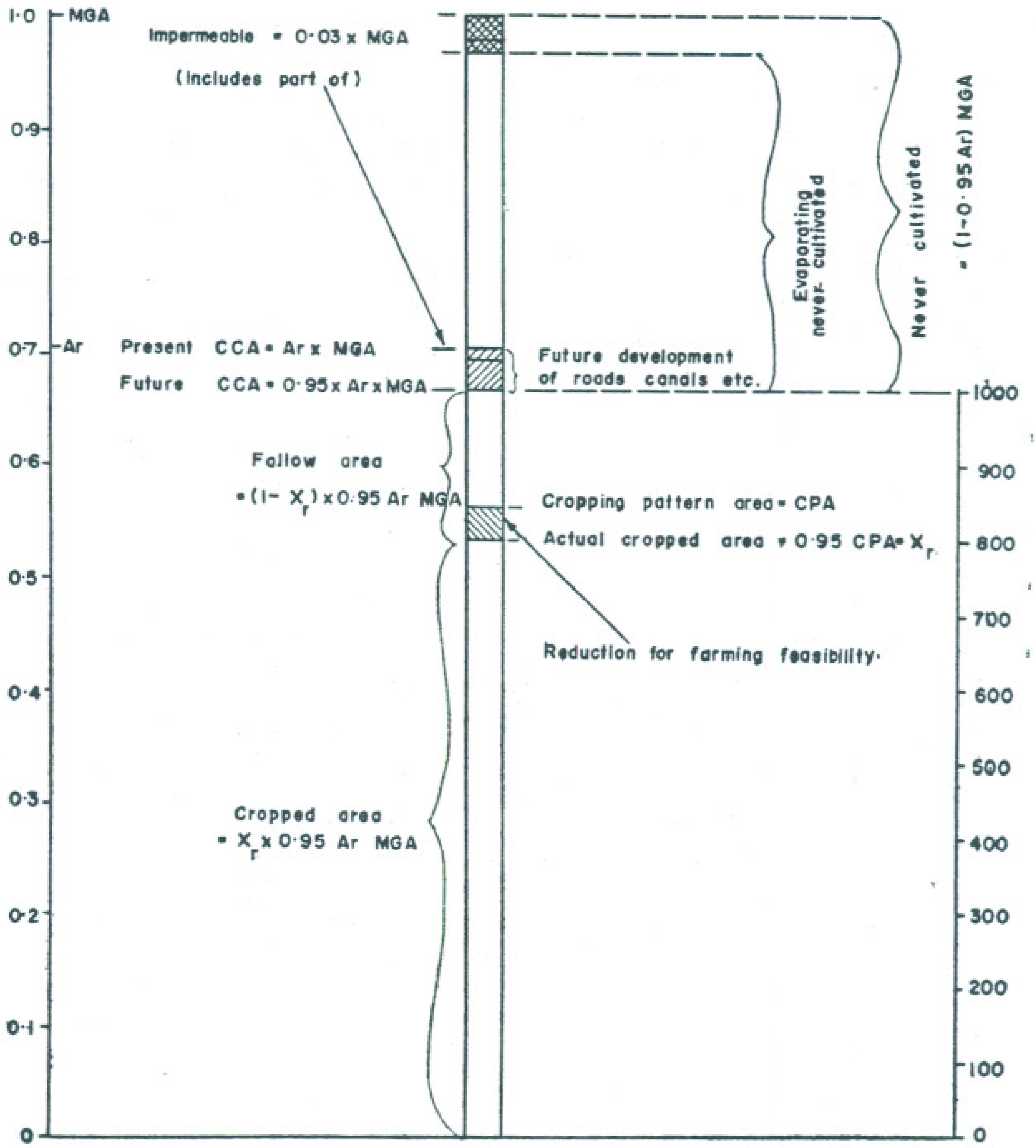
EVAPORATION FROM BELOW GROUND LEVEL.

Figure: 1



SCHEMATIC DIVISION OF TOTAL AREA.

Figure:2



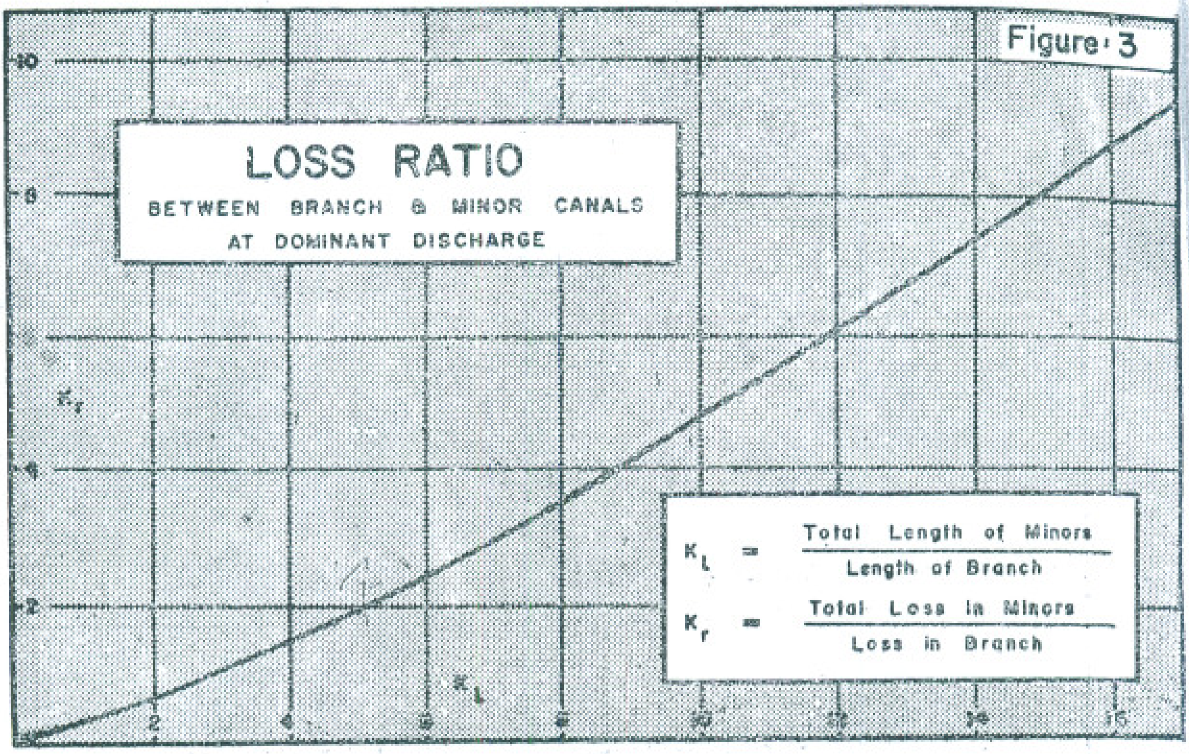


Figure: 3

LOSS RATIO

BETWEEN BRANCH & MINOR CANALS AT DOMINANT DISCHARGE

K_L = Total Length of Minors / Length of Branch

K_r = Total Loss in Minors / Loss in Branch

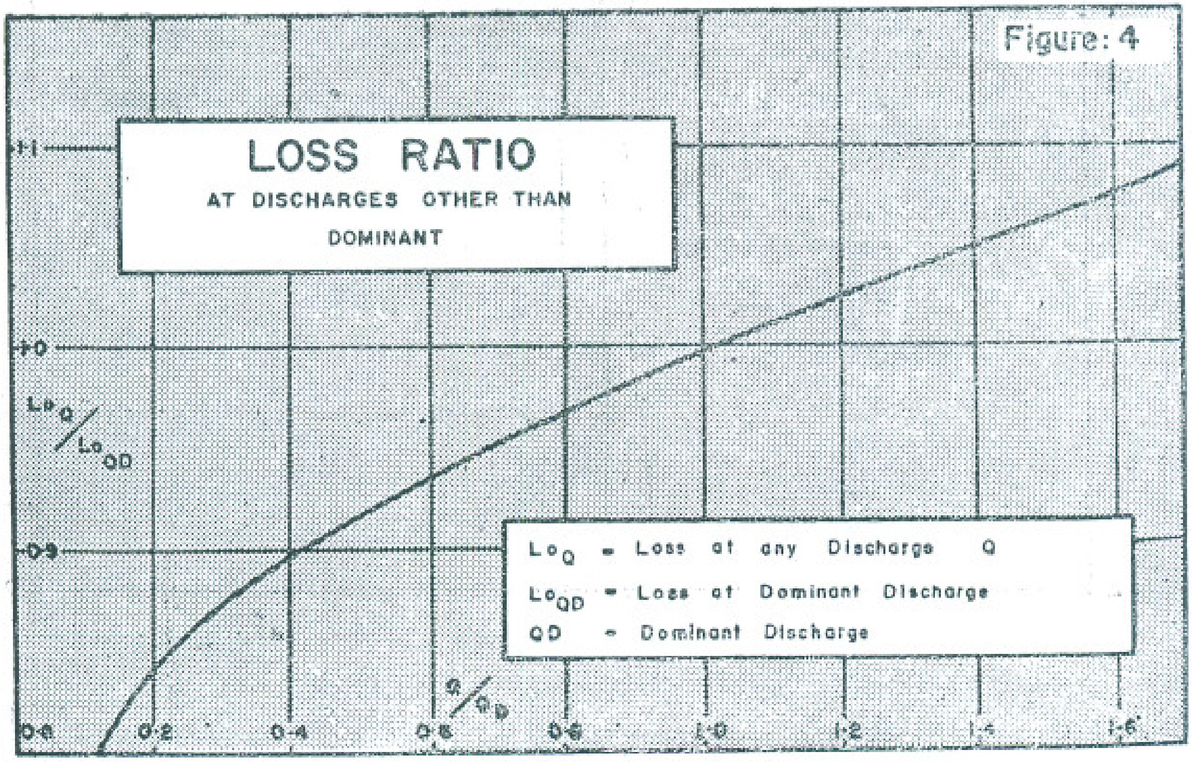


Figure: 4

LOSS RATIO

AT DISCHARGES OTHER THAN DOMINANT

Lo_Q = Loss at any Discharge Q

Lo_{QD} = Loss at Dominant Discharge

QD = Dominant Discharge