USER MANUAL **UM 44**

USER'S MANUAL FOR DESIGN OF DRAINAGE SYSTEM FOR STEADY AND UNSTEADY STATE

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ABSTRACT

Using Dupuit (1863) Forchheimer (1930) assumptions Donman has derived equation for drain spacing for steady state condition of discharge. The similar equation using equivalent depth (d) in place of depth to impervious layer (D) has been obtained by Hooghout for steady state condition of recharge.

The Boussinesq-equation which describes the position of watertable under non steady state of recharge, has been solved by Glover Glover assumed an initial horizontal groundwater table as a result of an instantaneous recharge of rainfall or irrigation. Dumm solved the same equation for the initial watertable corresponding to the shape of Fourth degree parabola. This equation which is known as Glover Dumm equation was modified by placing d in place of D to account for flow convergence in the vicinity of drains. This substitution also made the equation applicable to pipe drainage.

The Boussinesq-equation was further solved in this report for the constant and continuous recharge, constant recharge during a restricted period and intermittent recharge conditions. Computer programs are prepared for steady and unsteady state condition using Hooghouts and Glover, Dumm, Glover Dumm and Modified Glover Dumm equations respectively. Separate programs are also prepared for the condition of constant and continuous recharge, constant recharge during a restricted period and intermittent recharge. The computer program developed are interactive type and can be easily used by field engineers.

1.0 INTRODUCTION

Plants require oxygen as well as water for their growth. During waterlogged condition oxygen diffusion is unable to sustain root or microbial requirements of plants for any length of time. In the absence of sufficient oxygen, substance such as alcohol and cyanide may be formed in the plant tissues and plant growth is curtailed. The allowable groundwater table is closely related to the root system of the crop concerned.

It is a well known phenomenon that when an area is irrigated excessively the groundwater level rises. When the water table reaches a height, which is within the capillary lift of the soil, the soil moisture is brought to the surface where it evaporates. Salts, which were originally present in the irrigation water or which were dissolved in the rising groundwater, get concentrated on the land surface by the so called 'tea kettle effect'. This causes soil salinity and some times alkalinity which are harmful to plant growth.

According to Kovda (1977) both the intensity of groundwater evaporation and salt accumulation processes attain their maximum in arid climate conditions when the groundwater levels reaches a depth of 1.5-2.5 m below ground surface. When a saline water table rises and remains in the root zone longer than about 48 hours, resulting in an abnormally high saline moisture condition, agricultural production is usually seriously affected.

2.0 PARAMETERS FOR SUB SURFACE DRAINAGE

The design calculation for any water table problem requires knowledge of

a) Soil permeability (if there is more than one layer, the permeability of each layer must be found),

b) The thickness of each layer of soil and the depth to impermeable layer,

c) The minimum depth at which the water table is to be controlled,

d) The design drainage coefficient which is the amount of water that must be removed in a given period.

e) The recommended period of disposal

2.1 Soil Permeability

For most drain-spacing equations, details of soil permeability and depth to the impermeable layer are required. Generally speaking a layer is deemed to be impermeable if its permeability is less than 1/10th of the upper layer.

A number of tests for determining the insitu hydraulic conductivity below a water table have been developed. The tests which have been found to be most adaptable use are Guelph permeameter, auger hole and piezometer test procedure. All these procedures measure the rate of change of water level in a hole or the difference of water level elevation with time under unit hydraulic gradient. Hydraulic conductivity and transmissivity of aquifer comprising of gravel and gravelly materials are determined by pumping test. The well pumping method is an expensive test and is used mainly for determining the suitability of an area to be drained by pumping rather than by drains.

2.2 Depth to Impermeable Layer

The effect of depth to impermeable layer below drain on required spacing of drains has been studied by Galvin (1979). The results have been presented in Table 1 for value of drainage coefficient = 0.1 m/day, permeability = .9 m/day, and required maximum height of water level midway between drains = 0.5 m.

TABLE 1: EFFECT OF DEPTH TO IMPERMEABLE LAYER ON DRAIN SPACING

Depth of impermeable layer below Drains (meters)	Spacing (meters)		
	50 mm pipe	100 mm pipe	200 mm pipe
0	9.5	9.5	9.5
0.5	15.5	15.9	16.2
1	18.7	19.4	20.0
2	22.0	23.4	24.8
3	22.7	26.9	29.6

These results show that while the size of drain has very little effect, the depth of the impermeable layer below the drain depth has a major effect on the spacing. In fact the drain spacing can be double if the impermeable layer is 1 meter below the drain level and still further increased as the depth to the impermeable layer increase. Thus, it is quite obvious that substantial savings can be achieved where the existence of a deep impermeable layer is known. The information about the existence of impermeable layer is a prerequisite for rational design (Drainage manual, 1995).

2.3 Desirable Depth of the Water Table

The aim of drainage installation is the removal of excess water and salt from the soil for providing a favorable root zone for plant growth. In any irrigation planning it is essential requirement that water table should be controlled so that it does not enter the root zone to cause water logging and salinization.

The water table positions that a drainage system is required to maintain are primarily related to soil type, climate, crops, cropping intensity and water management. Most crops grow best with a water table which is below their normal root zone. However, crops will not be adversely affected by a higher water table for a short period (FAO, 1980).

The water table depths suggested by FAO (1980) for steady state and transient drainage design are given in Tables below.

TABLE 2: SUGGESTED IRRIGATED SEASON WATER TABLE DEPTHS FOR DRAIN SPACING DESIGN USING STEADY STATE FORMULA

Crops	Water table depth in m below ground surface fine textured (permeable) soil	light textured soil
Field Crops	1.2	1.0
Vegetables	1.1	1.0
Tree Crops	1.6	1.2

TABLE 3: SUGGESTED IRRIGATION SEASON WATER TABLE DEPTHS FOR DRAIN SPACING DESIGN USING TRANSIENT FORMULA

Crops	Water table depth in m below ground surface fine textured (permeable) soil	light textured soil
Field Crops	0.5	0.9
Vegetables	0.9	0.9
Tree Crops	1.4	1.1

2.4 Drainage Coefficient

The design requirement expresses the agricultural function of the drainage system in terms that can be used as input information for any of the drain spacing equation (Bouwer, vide Jan Van Schilfgaarde, 1974). Distinction should be made between the drainage requirement (also known as drainage criterion) which is the total desired drainage intensity for a given field or region and the design requirement (also known as design criterion) which is the difference between the drainage requirement and the existing natural drainage intensity of a given field. Thus the design requirement expresses the drainage deficiency of a field to be absorbed by the drainage system. Drainage criteria can be evaluated for a steady state condition, a falling water table, salinity control or trafficability of the soil depending on the main function of the drainage system. The steady state drainage criterion depends essentially on the rainfall pattern and the effect of water table position on crop yield. This effect is difficult to evaluate because it is affected by a number of factors (like stage of growth, soil fertility level, temperature) and crop yield is not directly dependent on water table position, but on O_2 and CO_2 diffusion rates in the soil. These diffusion rates depend on the soil water content which is not uniquely related to water table position. Fields within the same soil or climatic region may have different degree of natural drainage because of difference in surface drainage, water table depth, artesian pressure in ground water, ground water inflow, ground water out flow and leaking irrigation canals etc.

In humid areas drainage coefficient is used in design of drain. Drainage coefficient is the depth of water drained off from a given area in 24 hours, found by experience with many installed drainage system. Drainage coefficient are selected with respect to the degree of protection to be provided for various crops. For average small drainage project the drainage coefficient would range from 6 to 25 mm.

An empirical way of adjusting the design requirement to the natural drainage intensity of a field has been suggested (Table 4) by Van Someren for Dutch condition (Vide Schilfgaarde, 1974). The high water table conditions prior to artificial drainage is taken as the basis for adjusting the drainage coefficient.

Table 4: EXAMPLE OF ADOPTION OF DRAINAGE COEFFICIENT TO NATURAL DRAINAGE CONDITION OF FIELD

Minimum water table depth below field surface, observed to occur several time (three for example) per critical season prior to aritificial drainage (cm)	Drainage Coefficient (m/day)		
	Grass land dmin=30 cm	Cultivated land dmin=40 cm	Orchard dmin=60 cm
	(dmin=depth to water table below ground surface midway between the drains)		
0	7	7	7
10	7	7	7
20	3	5	6
30	No drainage	No drainage	6
40	No drainage	No drainage	4
50	No drainage	No drainage	3
60	No drainage	No drainage	1
70	No drainage	No drainage	No drainage

The drainage coefficient can be found from a ground water balance equation as follows (FAO, 1980):

$$Q_s = R_f + S_c + S_i - D_n$$

where,

Q_s = Water to be removed by the on farm drainage system which is the design drainage rate or drainage coefficient,

R_f = On farm recharge to the groundwater i.e. leaching water, rainfall and deep percolation resulting from excessive water application,

S_c = Seepage from canals,

S_i = Groundwater flow into the area including artesian inflow,

D_n = Natural drainage which is equal to groundwater flow out of the area to be drained.

Distinction must be made between the recharge rate required for salinity control, which should be considered as the minimum required sub surface drainage rate and the rate required for the removal of deep percolation losses from over irrigation. Generally the value of R_f to be used is the highest of the two rates.

2.5 Deep Percolation

Bureau of Reclamation makes use of deep percolation in estimating the drain spacing. When drainage problem exists on an operating project and drains are being planned, the build up i the water table due to irrigation application can best be determined by field measurement. The water table depth should be measured at several locations in the area to be drained on the day before and on the day after several irrigation application. The average build up shown by these two measurements should be used in the spacing computation.

In the planning stage of new project's or on the operating projects where the measured build up is not available, the amount of deep percolation must be estimated from each irrigation application. The build-up is computed by dividing the amount of deep percolation by the specific yield of the material in the zone where the water table is expected to fluctuate. Table 5 shows deep percolation as a percentage of the irrigation net input of water into the soil. These percentages are based on various soil textures and infiltration rates of the upper root zone soils. By knowing the infiltration rate, hydraulic conductivity of the soil in the root zone, the percolation rate can be known. Making use of the relationship between the hydraulic conductivity and specific yield build up can be calculated.

Table 5. APPROXIMATE DIP PERCOLATION FROM SURFACE IRRIGATION (PERCENT OF NET INPUT)

By texture

Texture	Percent	Texture	Percent
LS	30	CL	10
SL	26	SiCL	6
L	22	SC	6
SiL	18	C	6
SCL	14		

By infiltration rate

Inf.rate, in/h	Deep percolation percent	Inf.rate, in/h	Deep percolation percent
0.05	3	1.00	20
.10	5	1.25	22
.20	8	1.50	24
.30	10	2.00	28

.40	12	2.50	31
.50	14	3.00	33
.60	16	4.00	37
.80	18		

2.6 Drainable Porosity

Representative drainable porosity values for use in transient state equations are difficult to be measured accurately. Whenever possible and practical, the drainable porosity should be determined from measurement of drain discharge and draw down of existing drains or pilot drains. Where field drain tests can not be made the following procedure has been recommended (FAO, 1980).

A limited number of representative undisturbed soil samples for laboratory determination of drainable porosity should be collected. The drainable porosity may be estimated from soil moisture release characteristics of each soil. The values determined should be correlated with soil structure and texture obtained from the soil profile. The value arrived at should be compared with empirical curves developed elsewhere relating drainable porosity with such factors as hydraulic conductivity, soil texture and soil structure and provisional value of drainable porosity for the various soil types in the area should be established.

The values of drainable porosity of soils having different structure and texture are presented in Table 6 which can be used where first approximation of drainable porosity is needed.

Table 6. DRAINABLE POROSITY VALUES* AS RELATED TO SOIL TEXTURE AND STRUCTURE

Texture	Structure	Drainable porosity

Clay Heavy clay loam	Massive, very fine of fine columnar	1 - 2 %
Clay Clay loam Silty clay Sand clay loam	Very fine or fine prismatic, angular blocky or platy	1 - 3%
Clay Silty clay Sandy clay Slty clay loam Clay loam Silty loam Silt Sandy clay loam	Fine and medium prismatic, angular blocky and platy	3 - 8%
Light clay loam Silt Silt loam Very fine sandy loam Loam	Medium prismatic and subangular blocky	6 - 12%
Fine sandy loam Sandy loam	Coarse subangular block and granular fine crumb	12 - 18%
Loamy sand Fine sand	Medium crumb Single grain	15 - 22%
Medium sand	Single grain	22 - 26%
Coarse sand Gravel	Single grain	26 - 35%

* Based on data from the Water and Power Resources Service (formerly Unitmd States Bureau of Reclamation).

2.7 Tolerance Limit

In arid zones water and salts are the main environmental factors influencing plant growth. The first effect of excess water in soil is to replace air in the soil pores with water leading to an oxygen deficit. For normal growth of the plant a minimum oxygen content is essential. Also transport of gases in the soil is seriously disturbed as gas diffusion mainly takes place in air filled pores. The limited exchange of gases will not only decrease the Oxygen content but also increase the Carbon dioxide content. Low O_2 concentrations and high CO_2 concentration have direct effect on root anatomy. The plant stage is also of importance for the degree of damage done to plants under conditions of excess water. By flooding during the initial growth stages of barley, plants were completely killed, but plants survived when flooded during the later stages. It is well known that perennial plants can withstand long periods of water logging during the dormant phase without any harm the soil type may well influence the reaction of crops under conditions of excess water. From experience and experiments it is well known that higher water tables can be tolerated in sandy soils than in loamy or clayey soils.

2.8 Period of Disposal

Recommended period of disposal for different crops based on tolerance limit of crops to ponding as per the Indian standard code (IS 8835 - 1978) are as given in following table

Tab 3. PERIOD OF DISPOSAL FOR SOME CROPS

Name of crop	Period of disposal
Paddy	7 to 10 days
maize, Bajra and	3 days

other similar crops	
Sugarcane and	
banana	7 days
Cotton	3 days
Vegetables	1 days

2.9 Plant Tolerance to Waterlogging

Not much work in India has been done on the relative tolerance of crop plants to waterlogging. A list of tolerance to Oxygen deficit is given in Table 8 (Cannon 1925). This will be supplemented by data on tolerance to excess CO_2, tolerance to permanent high water table and tolerance to waterlogging (VanHoorn, 1958; Butijn, 1961; Dhawan 1958).

Table 8. Relative tolerance of plants under Oxygen deficit, high ground water levels based on laboratory experiment and field tests.

	to O deficit (lab.expt.)	to excess CO (lab.	to high ground water levels (field tests)	to waterlogging (practical experience
Highly tolerant	rice willow sugar cane	citrus	sugar cane potato broad beans	plum strawberry several grasses
Medium tolerant	oats barley onion cotton citrus soya apple	apple tomato sunflower	sugar beet wheat barley oats peas cotton	citrus banana apple pear blackberry
Sensi-tive	maize peas	tobacco	maize	peach cherry

beans	respberry
tobacco	date palm
	olive

3. STEADY STATE DRAINAGE EQUATIONS

Using Darcy's law, and equation of continuity the drain spacing equations are derived. In the potential theory, in order to get Laplace's partial differential equation, these two are combined. The solution of partial differential equation yields spacing equations and detailed information about the flow system.

In the Dupuit-Forchheimer (D-F) theory (Dupuit 1863; Forchheimer 1930), simple assumptions are made and, results are obtained using Darcy's law and the equation of continuity, without solving Laplace's equation. However application of D-F theory, also known as horizontal flow theory should be restricted to conditions where the flow region is of large horizontal extent relative to its depth.

The D-F assumptions states that For small inclinations of the free water surface, all streamlines in a gravity flow system are horizontal; and the velocity along these streamlines is proportional to the slope of the free water surface but is independent of the depth (Stuyt, 1991).

3.1 Principles of the Hooghoudt equation

If the drain is placed above the impervious layer, the flow lines will not be parallel and horizontal as given in D-F assumptions, but will converge towards the drain (radial flow). In this case flow lines are longer than they are in the case of parallel, horizontal ones.

Hooghoudt (1940) has developed an equation for flow to drains as shown in Figure 1. If the horizontal flow above drain level is neglected, the flow equation for a uniform soil is

$$h = \frac{qL}{K} F_H \qquad ..(1)$$

$$F_H = \frac{(L-D\sqrt{2})^2}{8DL} + \frac{1}{\pi} \ln \frac{D}{r_o * \sqrt{2}} + f(D,L) \qquad ..(2)$$

where H is for Hooghoudt; r_o is the radius of the drains; and f(D,L) is a function of D and L, generally small compared with the other terms in this equation therefore, it may be ignored in practice (Labye 1960).

$$h = \frac{qL}{K} \left(\frac{(L-D\sqrt{2})^2}{8DL} + \frac{1}{\pi} \ln \frac{D}{r_o * \sqrt{2}} \right) \qquad ..(3)$$

In this equation the first term represents the head loss due to horizontal flow, and the second term head loss due to radial flow near the drain.

$$h_h = \frac{qL}{K} \left(\frac{(L-D\sqrt{2})^2}{8DL} \right) \qquad ..(4)$$

and

$$h_r = \frac{qL}{K} \left(\frac{1}{\pi} \ln \frac{D}{r_o * 2^{0.5}} \right) \qquad ..(5)$$

In Hooghoudt's equation, horizontal flow exists only if the drain spacing L exceeds $(D\sqrt{2})$, in which case horizontal flow is taken over a distance of $(L-D\sqrt{2})$ instead of L. Radial flow is restricted to the region within a distance $(D\sqrt{2})/2$ from both sides of the drains. The horizontal flow component increases with the drain spacing L, and the radial flow component increases with the depth of the impervious layer.

The head loss caussed due to the convergence of flow lines to a pipe drain can be simulated by replacing the pipe drains by vertically-walled ditches, in conjunction with a reduction of the depth to the impermeable layer (D). This results in the following equation.

$$q = \frac{8 K_a d h + 4 K_b h^2}{L^2} \qquad ..(6)$$

where K_a and K_b are hydraulic conductivity below and above the drain level, h is the height of water table above drain level at mid point, q is drain discharge rate per unit area and L is the spacing of drains.

3.2 Hooghoudt table

The equivalent depth (d) is a function of L, D and r. d-tables for r =0.1 m and various values of D and L were made by Hooghout. It is clear from the table that the value of d increases with D until D approximates at D = L/4, independent of the value of L. For higher values of D the flow pattern is no longer affected by the depth of impermeable layer.

3.3 Nomograph methods

The Hooghoudt table is applicable only for the drain diameter of 0.2 m. For other diameters of drain Van Beers has given two nomographs. The Nomograph given in Fig 2 has the advantage that d can be determined for all values of drain dia (r_o) and u. Nomograph calculates the d value according to following formula

$$d = \frac{D}{\frac{8D}{\pi L} \ln \frac{D}{u} + 1} \qquad ..(7)$$

The nomograph given in Fig 3 takes into account the radial flow near the drain by reducing the drain spacing by a factor

$$L = L_o - C \qquad ..(8)$$

where L_o is the drain spacing without radial flow and C the correction term for radial flow; C is defined as

$$L = \sqrt{\frac{8KDh}{q}} \qquad ..(9)$$

and

$$C = D \ln \left(\frac{D}{u}\right) \qquad ..(10)$$

The nomograph has the advantage of also being applicable to solve the non-steady-state Glover-Dumm equation.

4. NON STEADY STATE DRAINAGE EQUATIONS: GLOVER-DUMM

Drainage equations describing the watertable in equilibrium with rainfall or irrigation water do not represent actual field situation, because watertable constantly moves through the soil in areas with periodic irrigations or high intensity rainfalls. An equation that describes the movement of the watertable through the soil could provide a more accurate method of design. Such a movement of the watertable through the soil is called a non-steady state or transient condition.

The non-steady state of drainage was studied in the U.S.A. by States Bureau of Reclamation, particularly Gover (Dumm 1954), in the Netherland by Kraijenhoff van de Leur (1958) and Maasland

(1959). The equation that is widely used for non-steady state flow problems is based on the Dupuit-Forchheimer conditions. This equation describes - as an approximation - horizontal flow in a vertical prism in a flow region, bounded above by the free groundwater surface and below by an impermeable layer.

According to conservation of mass the changes of flow in the x-direction must equal the change in the quantity of water stored in the column considered. The change of storage is defined as follows

$$\Delta S = \mu \, \Delta h \qquad ..(11)$$

ΔS = change in water stored per unit surface area during time step

μ = the effective porosity of the soil

Δh = change in watertable level during time step

The effective porosity, also referred to as 'drainable porosity', represents the total fraction of the soil volume which are drained as the watertable moves down. The use of a constant value for μ, however, is a simplification of actual conditions because the volume of water which is drained from a soil increases gradually with an increase of suction. The result of this simplification is difficult to assess but the accuracy of the approximate solutions is found to be good enough for practical purposes.

Combining Darcy's law with the continuity equation yields,

$$\frac{\delta h}{\delta t} = \frac{KD}{\mu} \frac{\delta^2 h}{\delta x^2} + \frac{R}{\mu} \qquad ..(12)$$

where

KD = transmissivity of the aquifer (m^2/day)

R = recharge rate per unit surface area (m/day)

h = hydraulic head as a function of x and t (m)

x = horizontal distance from a reference point, e.g. ditch (m)

t = time (days)

μ = drainable pore space

Equation 12 is called the Boussinesq-equation which describes the position of the watertable under non-steady recharge. When the recharge rate R equals zero, we get

$$\frac{\delta h}{\delta t} = \frac{KD}{\mu} \frac{\delta^2 h}{\delta x^2} \quad ..(13)$$

This is the equation (13) which must be solved for the non-steady state case of the moving watertable.

4.1 Principles of the Glover-Dumm equation

The initial horizontal groundwater table at a certain height above drain level was assumed by Glover to obtain the solution for equation (13). The initial horizontal watertable is due to an instantaneous recharge to the groundwaterby rainfall or irrigation. Subsequent solutions were obtained by assuming other initial shapes for the watertable. The initial and boundary conditions for which Equation (13) must be solved are:

1) initial horizontal watertable at t=0, $h = R/\mu = h_o$

$0 < x < L$

2) water level in drains remains at zero level = drain level

$t > 0$, $h = 0$, at $x=0$ and at $x = L$

where

R_i = instantaneous recharge per unit surface area (m)

h_o = height above drain level of the initial horizontal watertable (m)

Equation 13 was solved for these boundary conditions by a Fourier series in terms of a sine series

$$h(x,t) = \frac{4h_0}{\pi} \sum_{n=1,3,5..}^{\infty} \frac{1}{n} e^{-n^2 \alpha t} \sin \frac{n \pi x}{L} \quad ..(14)$$

where

$$\alpha = \frac{\pi^2 K D}{\mu L^2} \quad ..(15)$$

where α is the reaction factor (per day). The larger α is, faster the drainage system responds (small L and large K and D).

Equation 14 gives the shape of the watertable at any time t at any location x. As height of the watertable midway between the drains is considered x = L/2 is substituted into Equation 14

$$h(L/2,t) = \frac{4h_0}{\pi} \sum_{n=1,-3,5...}^{\infty} \frac{1}{n} e^{-n^2 \alpha t} \quad ..(16)$$

if $\alpha t \gg 0.2$

$$h_t = \frac{4\ h_0}{\pi} e^{-\alpha\ t} = 1.27\ e^{-\alpha\ t} \quad ..(17)$$

Dumm 1960 assumed initial water table having shape of a fourth degree parabola

$$h_t = \frac{4\ h_0}{\pi} e^{-\alpha\ t} = 1.16\ e^{-\alpha\ t} \quad ..(18)$$

Above two equations have a difference that the shape factor $4/\pi$ is changed from 1.27 to 1.16.

Putting the value of α in equation (18) and solving

$$L = \pi \left(\frac{K\ D\ t}{\mu}\right) \left(\ln 1.16 \frac{h_0}{h_t} \right)^{-\ 0.5} \quad ..(19)$$

Equation (19) is called Glover-Dumm equation.

The radial resistance of the flow towards drains not reaching an impermeable layer is accounted for by replacing D by the Hooghoudt d. This substitution, makes Glover-Dumm equation applicable to pipe drainage. It is justified because the flow paths for steady-state and transient flow may be considered at least similar, though not identical. As a result, equation 19 changes into

$$L = \pi \left(\frac{K\,d\,t}{\mu}\right) \left(\ln 1.16 \frac{h_o}{h_t} \right)^{-0.5} \qquad ..(20)$$

Above equation is called the modified Glover-Dumm equation it is particularly used to calculate the drain spacing in irrigated areas. It requires the determination of three soil properties K, D and μ, and size of the drains and a drainage criterion.

Instead of a water-table elevation/discharge criterion, as used for steady-state equations, the Glover-Dumm equation requires as criterion a predetermined water table draw down in a certain period of time (ho /ht), at what rate the watertable midway between the drains has to drop after an irrigation to be at the required new depth before the next irrigation starts.

4.2 Derivation Of Unit Step Response Function

The shape of water table at any location mid way between the drain is given by equation (16) and (15)

If h_o = 1. (m) in eq (16) the unit response is given by

$$k(t) = \frac{4}{\pi} \sum_{n=1,-3,5...}^{\infty} \frac{1}{n} e^{-n^2 \alpha t} \qquad ..(21)$$

let time span is discretised by uniform time step τ. The total response for (t- τ) period will be given by

$$K(t) = \frac{4}{\pi}\int_{0}^{t} \sum_{n=1,-3,5...}^{\infty} \frac{1}{n} e^{-n^2 \alpha (t-\tau)} d\tau \qquad ..(22)$$

let $t-\tau = v$ hence $-d\tau = dv$

at $\tau = 0$, $v = t$ and at $\tau = t$, $v = 0$. Therefore, equation (22) changes to

$$K(t) = \frac{4}{\pi}\int_{t}^{0} \sum_{n=1,-3,5...}^{\infty} \frac{1}{n} e^{-n^2 \alpha v} (-dv) \qquad ..(23)$$

Solution of equation (23) gives the unit step response function or discrete kernel coefficient as below

$$K(t) = \frac{4}{\pi} \sum_{n=1,-3,5...}^{\infty} \frac{1}{n^3 \alpha} (1 - e^{-n^2 \alpha t}) \qquad ..(24)$$

4.2.1 Height of water table after t days

Let R be the recharge intensity and μ be the effective porosity then the height of initial watertable is R/μ. Therefore from equation (24) the height of water table at the end of day t is given by $(K(t) - K(t-1))$, or

$$K(t) = \frac{R}{\mu} [\frac{4}{\pi} \sum_{n=1,-3,5...}^{\infty} \frac{1}{n^3 \alpha} (1 - e^{-n^2 \alpha t})$$

$$- \frac{4}{\pi} \sum_{n=1,-3,5...}^{\infty} \frac{1}{n^3 \alpha} (1 - e^{-n^2 \alpha (t-1)})] \qquad ..(25)$$

4.2.2 Discharge rate of drain

The discharge of drain (m/day) per unit surface area at time t is found by using Darcy's law

$$q_t = \frac{-2KD}{L}(dh/dx)_{x=0} \qquad ..(26)$$

Differentiating equation (14) with respect to x gives the following equation

$$dh/dx = \frac{4h_o}{\pi} \sum_{n=1,3,5..}^{\infty} \frac{1}{n} e^{-n^2\alpha t} \left(-\frac{n\pi}{L}\right) \cos \frac{n\pi x}{L} \qquad ..(27)$$

Therefore putting x = 0

$$dh/dx = \frac{4h_o}{L} \sum_{n=1,3,5..}^{\infty} e^{-n^2\alpha t} \qquad ..(28)$$

Substituting equation (28) into equation (26)

$$q_t = \frac{-2KD}{L} \frac{4h_o}{L} \sum_{n=1,3,5..}^{\infty} e^{-n^2\alpha t} \qquad ..(29)$$

rearranging above equation and substituting α the

$$q_t = \frac{8R\alpha}{\pi^2} \sum_{n=1,3,5..}^{\infty} e^{-n^2\alpha t} \qquad ..(30)$$

Solving equation similar to the way equation (21) is solved. The discharge intensity of a parallel drainage system is found as below

$$q_t = \frac{8R\alpha}{\pi^2} \sum_{n=1,3,5..}^{\infty} (1- e^{-n^2\alpha t})/n^2 \qquad ..(31)$$

The drain discharge at the end of t days is given by

$$q_t = \frac{8R\alpha}{\pi^2} \sum_{n=1,3,5..}^{\infty} (1- e^{-n^2 \alpha t})/n^2 -$$

$$\frac{8R\alpha}{\pi^2} \sum_{n=1,3,5..}^{\infty} (1- e^{-n^2 \alpha (t-1)})/n^2 \qquad ..(32)$$

4.2.3 Condition of recharge

(1) Constant and Continuous recharge

The height of water table and discharge rate of drain can be found using equation ((24)* R) and equation (31) respectively.

(2) Constant recharge during a restricted period

The height of water table for constant recharge during a restricted period can be found using equation (25) and the drain discharge is given by equation (32).

(3) Intermittent recharge

The height of water table for the condition of Intermittent recharge is given by

$$h_m = \sum_{\gamma=1}^{m} h(\gamma)\, R(m - \gamma + 1) \qquad .(33)$$

$$h_m = \frac{1}{\mu\alpha} [R_m K(1) + R_{m-1} K(2) + ...R_1 K(m)] \qquad ..(34)$$

where K(2) = K(2) - K(1) and so on.

The discharge rate of drain is given by following equation

$$Q_m = \sum_{\gamma=1}^{m} q(\gamma)\, R(m - \gamma + 1) \qquad ..(35)$$

$$Q_m = [R_m q(1) + R_{m-1} q(2) + ...R_1 q(m)] \qquad ..(36)$$

where q(2) = q(2) - q(1) and so on.

5.0 REMARKS

This report is a user manual for design of subsurface drainage system. In this report computer programs are prepared for steady state using Hooghouts equation and unsteady state condition using Glover, Dumm, Glover Dumm and Modified Glover Dumm equations. Separate programs are also prepared for the condition of constant and continuous recharge, constant recharge during a restricted period and intermittent recharge.

The design of a drainage system in any area should be followed by its economical analysis. Keeping this aspect into consideration the economical analysis of drainage project are also included in this report. The graphics subroutines also included in the program. The computer programs developed and included in this report are of interactive type and are given in Appendix 1. All these programs are clubbed together as one and can be easily used by field engineers.

References

1. Drainage manual (1994). Draft published by National Institute of Hydrology.

2. Stuyt L.M. (1991). Subsurface flow to drains and wells. Lecture note for International course on Land drainage at ILRI, Wageningen, The Netherlands.

3. Mishra G.C. (1993). Application of Discrete Kernels in Groundwater flow problems, ISIAM 92, p405-410, Feb 4-7, 1993.

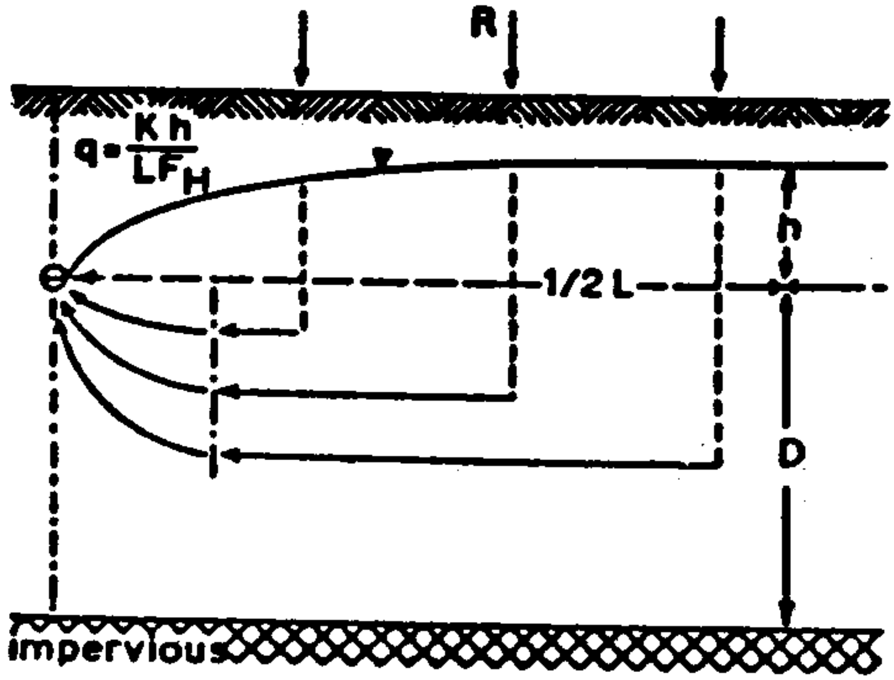

FIG. 1 FLOW TO DRAIN

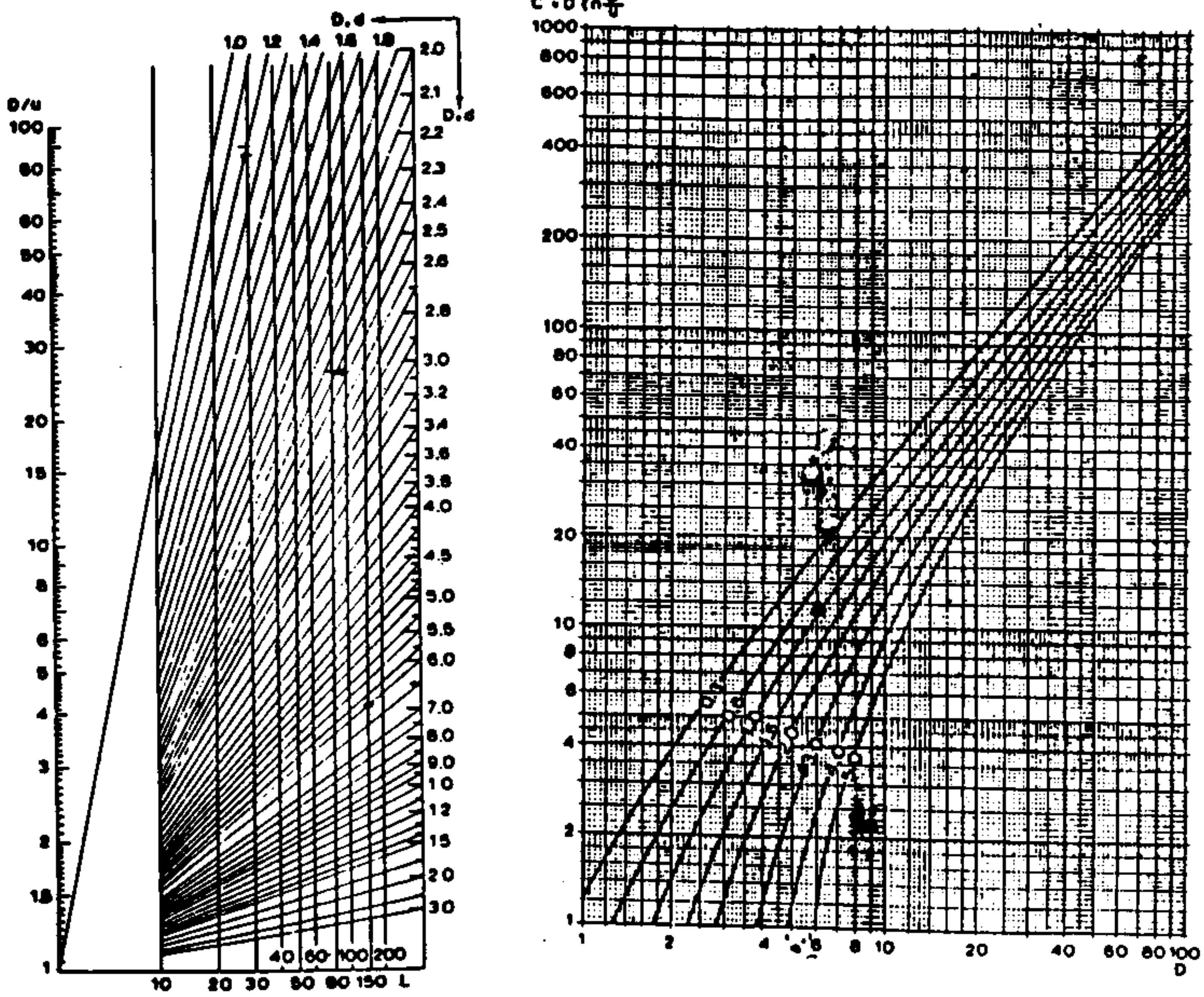

FIG.2 NOMOGRAPH (VAN BEERS)

```
C***********************************************************************
C       THIS PROGRAMME CALCULATES THE DRAIN SPACING FOR BOTH UNSTEADY
C       AND STEADY FLOW
C***********************************************************************
$large
$debug
        INCLUDE 'Fgraph.Fi'
        INCLUDE 'Fgraph.fd'
        INTEGER*2 oldcolor, status
        INTEGER*4 oldbgd
        CHARACTER*2 str
        RECORD/ rccoord/ curpos

        DIMENSION Z(100),S(100),SUM(100),SUMC(100)
        DIMENSION SUMG(100),SUMQ(100)

        OPEN(UNIT=1,FILE='UB2.DAT')
        OPEN(UNIT=2,FILE='UB2.OUT')

        status=setvideomode( $TEXTC40)
        CALL CLEARSCREEN( $GCLEARSCREEN)
        CALL outtext('text color/monocrome attributes:20')
        CALL outtext( 'back:2' //str // 'fore:4')

        oldbgd=setbkcolor(2)
        oldcolor = settextcolor (4)
        WRITE (str,'(I2)' ) 1
        CALL settextposition( 23,5,curpos)
        CALL CLEARSCREEN( $GCLEARSCREEN)
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*)

        WRITE(*,*) '  PROGRAMME TO CALCULATE DRAIN SPACING
     1  '
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*) '  UNDER STEADY STATE AND UNSTEADY STATE
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*)'           DRAINAGE   CRITERIA     '
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*)
        WRITE(*,*) '       (PRESS ENTER TO CONTINUE)
        READ(5,*)
        CALL CLEARSCREEN( $GCLEARSCREEN)

        status=setvideomode( $TEXTC80)
        CALL outtext('text color/monocrome attributes:1')
        CALL outtext( 'back:3' //str // 'fore:1')

        oldbgd=setbkcolor(3)
        oldcolor = settextcolor (1)
```

```
      WRITE (str,'(I2)' ) 1
      CALL settextposition( 23,5,curpos)
      CALL CLEARSCREEN( $GCLEARSCREEN)

c     REAL HL,HL1,HL2,AS
c     DIMENSION HL(1),HL1(1),HL2(1)

C     OPEN(UNIT=1,FILE='UM.DAT',STATUS='OLD')
C     OPEN(UNIT=2,FILE='UM.OUT',STATUS='UNKNOWN')

C*********************************************************************

      WRITE(*,*)
      WRITE(*,*)
      write(*,*)'      STEADY STATE DRAINAGE CRITERIA
     1                          <PRESS 1 THEN ENTER TO CONTINUE>'
      WRITE(*,*)
      WRITE(*,*)
      write(*,*)'      UNSTEADY STATE DRAINAGE CRITERIA
     1                        - <PRESS 2 THEN ENTER TO CONTINUE>'
      WRITE(*,*)
      WRITE(*,*)
      write(*,*)'     DRAIN DISCHARGE FOR INTERMITTANT RECHARGE
     1                          <PRESS 3 THEN ENTER TO CONTINUE>'
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)'    DRAIN DISCHARGE FOR CONSTANT RECHARGE FOR RESTRICTE
     1                        <PRESS 4 THEN ENTER TO CONTINUE>'
      WRITE(*,*)
      WRITE(*,*)
      WRITE(*,*)'     ECONOMIC ANALYSIS OF DRAINAGE PROJECT
     1                          <PRESS 5 THEN ENTER TO CONTINUE>'
      READ(*,*)NCHA
      CALL CLEARSCREEN( $GCLEARSCREEN)
      IF (NCHA.EQ.1) GO TO 200
      IF (NCHA.EQ.2) GO TO 100
      IF (NCHA.EQ.3) GO TO 1000
      IF (NCHA.EQ.4) GO TO 1500
      IF (NCHA.EQ.5) GO TO 1600

C*********************************************************************

C     PROGRAM TO FIND THE SPACING OF FIELD DRAINS WITH UNSTEADY STATE

100   WRITE(*,*)'                        UNSTEADY STATE CRITERIA
      write(*,*)
      WRITE (5,'('' DEPTH TO IMPERVIOUS LAYER FROM GROUND SURFACE (DA)(
     1).:''$)')
      READ *,DA

      WRITE (5,'('' LOCATION OF DRAIN FROM GROUND SURFACE (Dd)(m):''$)
      READ *,Dd

      D=DA-Dd

      WRITE (5,'('' DEPTH TO IMPERVIOUS LAYER BELOW DRAIN(D).(m).:''$)'
      WRITE(5,*)D

      WRITE (5,'('' HYDRAULIC CONDUCTIVITY OF SOIL (HK)(m/day)..:''$)'
      READ *,HK
```

```
 WRITE (5,'('' TYPE OF CROP GROWN IN AREA.(Give Name).......:''$)
 READ(*,'(A12)')CROP

 WRITE(*,*)
 WRITE(*,*)'   WATER REQUIREMENT OF SOME CROPS'
 WRITE(*,*)
 WRITE(*,*)'   WHEAT ..................= 0.42 m '
 WRITE(*,*)'   BARLEY AND GRAM.........= 0.3 m '
 WRITE(*,*)'   POTATO, BAJRA, SORGHUM = 0.5 m '
 WRITE(*,*)'   RADDISH.................= 0.4 m '
 WRITE(*,*)'   MAIZE...................= 0.625 m '
 WRITE(*,*)'   PEAS....................= 0.15 m '
 WRITE(*,*)'   COTTON..................= 0.4 m '
 WRITE(*,*)'   GROUNDNUT...............= 0.5 m '
 WRITE(*,*)'   TIL.....................= 0.25 m '
 WRITE(*,*)'   ARHAR...................= 0.33 m '
 WRITE(*,*)'   BARSEEM.................= 0.9 m '
 WRITE(*,*)
 WRITE(*,*)'      PRESS ENTER TO CONTINUE  '
 READ(*,*)

 WRITE (5,'('' TOTAL WATER REQUIREMENT OF CROP (m) (WR) ....:''$)')
 READ *,WR

 WRITE(*,*)
 WRITE(*,*)' NUMBER OF IRRIGATIONS FOR SOME CROPS'
 WRITE(*,*)
 WRITE(*,*)'   WHEAT ..................= 5 TO 7 '
 WRITE(*,*)'   BARLEY AND GRAM.........= 3 TO 4 '
 WRITE(*,*)'   POTATO..................= 8 TO 10 '
 WRITE(*,*)'   BAJRA AND SORGHUM.......= 4 TO 7 '
 WRITE(*,*)'   RADDISH.................= 6 TO 7 '
 WRITE(*,*)'   MAIZE...................= 4 TO 5 '
 WRITE(*,*)'   PEAS....................=   '
 WRITE(*,*)'   COTTON..................= 5 TO 6 '
 WRITE(*,*)'   GROUNDNUT................= 4 TO 6 '
 WRITE(*,*)'   TIL......................= 2  '
 WRITE(*,*)'   ARHAR....................= 2 TO 3 '
 WRITE(*,*)'   BARSEEM..................= WEEKLY '
 WRITE(*,*)
 WRITE(*,*)'      PRESS ENTER TO CONTINUE
 READ(*,*)

 WRITE (5,'('' NUMBER OF IRRIGATIONS FOR THE CROP SELECTED ABOVE (
1N):''$)')
 READ *,N

 WRITE (5,'('' IRRIGATION INTERVAL (DAYS) (RI)..............:''$)'
 READ *,RI

 WRITE(*,*)
 WRITE(*,*)' TOLERENCE PERIOD OF SOME CROPS TO WATERLOGGING'
 WRITE(*,*)
 WRITE(*,*)'  WHEAT, BAJRA,MAIZE,COTTON
1                       AND SIMILAR CROPS.........= 3 days '
 WRITE(*,*)'  VEGETABLES................= 1 days '
 WRITE(*,*)'  SUGARCANE AND BANANA......= 7 days '
 WRITE(*,*)'  PADDY.....................= 7 TO 10 days '
 WRITE(*,*)
```

```
      WRITE(*,*)'        PRESS ENTER TO CONTINUE
      READ(*,*)

      WRITE (5,'('' MAXIMUM PERIOD ALLOWED FOR DISPOSAL (DAY) (T):''$)')
      READ *,T

      DIW=(WR/N)

      WRITE (5,'('' DEPTH OF IRRIGATION WATER GIVEN PER IRRIGATION (m)
     1(DIW):''$)')
      WRITE(5,*)DIW

      WRITE (5,'('' PERCENTAGE OF WATER PERCOLATING INTO SOIL (FRACTION)
     1(P):''$)')
      READ *,P

      R=(DIW*P)

      WRITE (5,'('' PERCOLATION OR RECHARGE INTO THE SOIL (GROUND) (R) (
     1m):''$)')
      WRITE(5,*)R

      WRITE (5,'('' STORAGE COEFFICIENT (EFFECTIVE POROSITY) (PHI)
     1..:''$)')
      READ *,PHI

      dh=R/PHI

      WRITE (5,'('' INSTANT RISE OF WATER TABLE dh=(R/PHI)  (m)..:''$)')
      WRITE(5, *)dh
      WRITE(*,*)
      WRITE (5,'('' POSITION OF STATIC WATER TABLE BELOW SOIL (WT) (WEAT
     1HER IT IS                 AT DRAIN LEVEL OR ABOVE IT (IF AT DRAI
     2N LEVEL WT=Dd):''$)')
      READ *,WT

      HI = Dd-WT

      WRITE (5,'('' INITIAL HEIGHT OF WATER TABLE ABOVE DRAIN (HI=Dd-WT)
     1 (m):''$)')
      WRITE(5, *)HI

      H=HI+dh

      WRITE (5,'('' TOTAL HEIGHT OF WATER TABLE ABOVE DRAIN AT t=0 H=(HI
     1+dh)(m):''$)')
      WRITE(5, *)H
      write(*,*)
      WRITE(*,*)'   IF WATER TABLE IS WITHIN 1 m FROM SOIL SURFACE DRAIN
     1AGE IS                    REQUIRED IF NOT CHANGE DEPTH OF DRAIN
     2FROM GROUND SURFACE'
      WRITE(*,*)
      WRITE(5, '('' DO YOU WANT TO CHANGE DEPTH OF DRAIN FROM GROUND SUR
     1FACE (Dd)                 (IF YES TYPE 1)...............
     2:''$)')
      READ (5,*) NCHA
      IF (NCHA.EQ.1) GO TO 4

      WRITE(5, '('' DO YOU WANT TO CHANGE INITIAL HEIGHT OF WATER TABLE
     1 OR DEPTH                 OF DRAIN AT TIME t=0 (IF BOTH TYPE 1,
```

```
     2IF ONLY DEPTH TYPE 2                              IF NONE TYPE 3):''$)')
        READ(5,*) NCHA
        IF (NCHA.EQ.1) GO TO 5
        IF (NCHA.EQ.2) GO TO 6
        IF (NCHA.EQ.3) GO TO 7
 5      write(*,*)

        WRITE(*,*)'    IF INITIAL WATER TABLE IS AT DRAIN LEVEL AND IRRIGAT
     1ION IS ONLY INPUT THEN      R/PHI WILL GIVE TOTAL HEIGHT AT t=0, IF
     2 THERE ARE OTHER SOURCES OF RECHARGE   PRESENT (ADD ALL SUCH DEPTH
     3S TO GET INI. WATER TABLE HEIGHT AT t=0)'
        WRITE(*,*)
        WRITE (5,'('' TOTAL NEW HEIGHT OF WATER TABLE ABOVE DRAIN AT TIME
     1t= 0 (m) :''$)')
        READ *,H
        WRITE(*,*)
 6      WRITE (5,'('' DEPTH OF DRAIN BELOW SOIL (IT SHOULD BE BELOW 1 m)
     1 (Dd) (m):''$)')
        READ *,Dd

 7      WRITE (5,'('' MAX PERMISSIBLE HEIGHT OF WATER TABLE BELOW SOIL AT
     1THE END                        OF 3 DAYS IS (Dm).(m).......:''$)')
        READ *,Dm

        HC=(Dd-Dm)

        WRITE (5,'('' HEIGHT OF WATERTABLE ABOVE DRAIN LEVEL AFTER 3 DAYS
     1 (HC):''$)')
        WRITE(5,*)HC

C       ********************************************************************
        PAI=3.141592654
C       ********************************************************************

C       GLOVER SOLUTION

        HL=PAI*SQRT(HK*D*T/PHI)/SQRT(ALOG(1.27323*H/HC))

C       ********************************************************************

C       GLOVER DUMM EQUATION

        HL1=PAI*SQRT(HK*D*T/PHI)/SQRT(ALOG(1.16*H/HC))

C       ********************************************************************

        WRITE (5,'('' DRAIN SPACING INITIAL WATERTABLE HORIZONTAL(GLOVER)
     1 (HL)...:''$)')
        WRITE (5,*)HL

        WRITE (5,'('' DRAIN SPACING INITIAL WATERTABLE 4D PARABOLA GLOVER
     1 DUMM (HL1):''$)')
        WRITE (5,*)HL1

C***************************************************************************

C       MODIFIED GLOVER DUMM EQUATION

C       ASSUME A DRAIN SPACING (L) AND READ FROM NOMOGRAPH THE d VALUE
C       CORRESPONDING TO AK AND L,
```

```
      COF=PAI*SQRT(HK*T/PHI)/SQRT(ALOG(1.16*H/HC))

      WRITE (5,'('' COEFF HL2=COF * SQRT d (COF)..................:''$)')
      WRITE (5,*) COF

C***********************************************************************
C      VAN BEERS HAS GIVEN TWO NOMOGRAPHS FOR CALCULATION OF d FOR ANY
C       PE DIAMETER, NOMOGRAPH ONE GIVES RELATIONSHIP BETWEEN D/u AND
C        NOMOGRAPH2 BETWEEN C (CORRECTION FACTOR) AND D. HOOGHOUT TABLE
C       VES d FOR PIPE DIA OF 0.2 M ONLY
C*****  ****************************************************************
      RITE(*,*)
      RITE(5, '('' (NOMOGRAPH1 & HOOGHOUT TABLE OR NOMOGRAPH2, TYPE 1
     OR 2):''$)')
      READ(5,*) NCHA
      IF (NCHA.EQ.1) GO TO 10
      IF (NCHA.EQ.2) GO TO 20

C***********************************************************************

C      NOMOGRAPH D/U VER L (AFTER VAN BEERS) AND HOOGHOUT TABLE
      WRITE(*,*)
10    WRITE(5, '('' DRAIN DIAMETER (DIA)...........................:''$)')
      READ(5,*) DIA

      AK =2*D/(PAI*DIA)

30    WRITE(5, '('' D U RATIO (AK).................................:''$)')
      WRITE(5,*) AK

      WRITE (5,'('' ASSUMMED SPACING (AS)..........................:''$)')
      READ(5,*) AS

      TCOF=((((8*D)/(PAI*AS))*ALOG(AK))+1)
      DI=D/TCOF

      WRITE(5, '('' EQUIVALENT DEPTH (DI).(m)......................:''$)')
      WRITE(5,*) DI

C     WRITE (5,'('' ASSUMED SPACING VER D U RATIO FROM NOMOGRAPH,
C    1EQUIVALENT DEPTH (DI) IS READ AS.....................:''$)')
C     READ *,DI

      HL2=PAI*SQRT(HK*DI*T/PHI)/SQRT(ALOG(1.16*H/HC))

      WRITE (5,'('' DRAIN SPACING FROM MODIFY GLOVER DUM EQ (HL2):''$)')
      WRITE (5,*)HL2

      WRITE(5, '('' DO YOU WANT TO CHANGE DRAIN DIA (IF YES TYPE 1) DO Y
     1OU WANT TO CHANGE           DRAIN SPACING (TYPE 2), DO YOU WANT TO
     2 STOP PROGRAMME (TYPE 3):''$)')
      READ(5,*) NCHA
      IF (NCHA.EQ.1) GO TO 10
      IF (NCHA.EQ.2) GO TO 30
      IF (NCHA.EQ.3) GO TO 90
C     STOP

C***********************************************************************
C      NOMOGRAPH C VER D (AFTER VAN BEERS)
```

```
20        Q (R/T)

          WRITE(5, '('' DRAINAGE COEFFICIENT.(WATER TABLE TO BE LOWERED WITH
     1IN                              3 DAY) (dh/T) (m/day) (Q)...:''$)')
          WRITE(5,*) Q

          HLO=SQRT(8*HK*D*H/Q)

          WRITE (5,'('' DRAIN SPACING WITHOUT RADIAL FLOW (HLO)......:''$)')
          WRITE (5,*) HLO

40        WRITE(5. '('' DRAIN DIAMETER (DIA)...........................:''$)'
          READ(5,*) DIA

          AK =2*D/(PAI*DIA)

          WRITE(5, '('' D U RATIO (AK).................................:' $)')
          WRITE(5.*) AK

          C=D*ALOG(AK)

          WRITE(5, '('' CORRECTION TERM FOR RADIAL FLOW (C)..........:''$)')
          WRITE(5.*) C

          HL3=HLO-C

          WRITE (5,'('' DRAIN SPACING FOR DESIGN (HL3)...............:''$)')
          WRITE (5,*)HL3

          WRITE(5, '('' DO YOU WANT TO CHANGE DRAIN DIA (IF YES TYPE 1), TO
     1STOP PROGRAMM  TYPE 2:''$)')
          READ(5.*) NCHA
          IF (NCHA.EQ.1) GO TO 40
          IF (NCHA.EQ.2) GO TO 90
          STOP
C         END
C***********************************************************************

C         PROGRAM TO FIND THE SPACING OF FIELD DRAINS WITH STEADY STATE
C         BY USING HOOGHOUTS EQUATION

C         **************************************************************

200       WRITE(*,*)'                         STEADY STATE CRITERIA
          WRITE(*,*)

          WRITE (5,'('' DEPTH TO IMPERVIOUS LAYER FROM GROUND SURFACE (DA)(m
     1).:''$)')
          READ *,DA

          WRITE (5,'('' LOCATION OF DRAIN FROM GROUND SURFACE (Dd)(m):''$)')
          READ *,Dd

          D=DA-Dd

          WRITE (5,'('' DEPTH TO IMPERVIOUS LAYER BELOW DRAIN (D)(m)...:''$)')
          WRITE(5,*) D
```

```
      WRITE(5, '(" HYDRAULIC CONDUCTIVITY OF SOIL (m/day).......:"$)')
      READ *,HK

C     WRITE (5,'(" INITIAL HEIGHT OF WATER TABLE ABOVE DRAIN (m):"$)')
C     WRITE(5, *)H

      WRITE (5,'(" ALLOWABLE DEPTH OF WATER TABLE BELOW GROUND SURFACE
     1                                AFTER 3 DAYS (Dm)(m):"$)')
      READ *,Dm

      HC=Dd-Dm

      WRITE (5,'(" HEIGHT OF WATER LEVEL ABOVE DRAIN AFTER 3 DAYS (HC
     1:"$)')
      WRITE(5,*)HC

      WRITE (5,'(" TYPE OF CROP GROWING IN THE AREA.(Give Name).:"$)
      READ(*,'(A12)')CROP
      WRITE(*,*)
      WRITE(*,*)'   WATER REQUIREMENT OF SOME CROPS'
      WRITE(*,*)
      WRITE(*,*)'   WHEAT ..................= 0.42 m '
      WRITE(*,*)'   BARLEY AND GRAM.........= 0.3 m '
      WRITE(*,*)'   POTATO, BAJRA, SORGHUM = 0.5 m '
      WRITE(*,*)'   RADDISH.................= 0.4 m '
      WRITE(*,*)'   MAIZE...................= 0.625 m '
      WRITE(*,*)'   PEAS... ................= 0.15 m '
      WRITE(*,*)'   COTTON..................= 0.4 m '
      WRITE(*,*)'   GROUN   T...............= 0.5 m '
      WRITE(*,*)'   TIL.....................= 0.25 m '
      WRITE(*,*)'   ARHAR...................=      m '
      WRITE(*,*)'   BARSEEM.................= 0.9 m '
      WRITE(*,*)
      WRITE(*,*)'      PRESS ENTER TO CONTINUE  '
      READ(*,*)

      WRITE (5,'(" TOTAL WATER REQUIREMENT OF CROP (m) (WR) ....:"$)
      READ *,WR

      WRITE(*,*)
      WRITE(*,*)' NUMBER OF IRRIGATIONS FOR SOME CROPS'
      WRITE(*,*)
      WRITE(*,*)'   WHEAT ..................= 5 TO 7 '
      WRITE(*,*)'   BARLEY AND GRAM.........= 3 TO 4 '.
      WRITE(*,*)'   POTATO..................= 8 TO 10 '
      WRITE(*,*)'   BAJRA AND SORGHUM.......= 4 TO 7 '
      WRITE(*,*)'   RADDISH.................= 6 TO 7 '
      WRITE(*,*)'   MAIZE...................= 4 TO 5 '
      WRITE(*,*)'   PEAS....................-   '
      WRITE(*,*)'   COTTON..................= 5 TO 6 '
      WRITE(*,*)'   GROUNDNUT...............= 4 TO 6 '
      WRITE(*,*)'   TIL.....................= 2   '
      WRITE(*,*)'   ARHAR...................= 2 TO 3 '
      WRITE(*,*)'   BARSEEM.................= WEEKLY '
      WRITE(*,*)
      WRITE(*,*)'      PRESS ENTER TO CONTINUE
      READ(*,*)

      WRITE (5,'(   NUMBER OF IRRIGATIONS FOR THE CROP SELECTED ABOVE
```

```
1(N)...:''$)')
   READ *,N

   WRITE (5,'('' IRRIGATION INTERVAL (DAYS) (RI)..............:''$)')
   READ *,RI

   DIW=(WR/N)

   WRITE (5,'('' DEPTH OF IRRIGATION WATER GIVEN PER IRRIGATION (m
1(DIW):''$)')
   WRITE(5,*)DIW

   WRITE (5,'('' PERCENTAGE OF WATER PERCOLATING INTO SOIL (FRACTI
1(P):''$)')
   READ *,P

   R=(DIW*P)

   WRITE (5,'('' PERCOLATION OR RECHARGE INTO THE SOIL (GROUND) (R
1):''$)')
   WRITE(5,*)R

C
C  WRITE (5,'('' STORAGE COEFFICIENT (PHI)......................:''$)
C  READ *,PHI

   WRITE(*,*)
   WRITE(*,*)' TOLERENCE PERIOD OF SOME CROPS TO WATERLOGGING'
   WRITE(*,*)
   WRITE(*,*)'  WHEAT, BAJRA,MAIZE,COTTON
1                 AND SIMILAR CROPS.........= 3 days '
   WRITE(*,*)'  VEGETABLES.................= 1 days '
   WRITE(*,*)'  SUGARCANE AND BANANA.......= 7 days '
   WRITE(*,*)'  PADDY......................= 7 TO 10 days '
   WRITE(*,*)
   WRITE(*,*)'      PRESS ENTER TO CONTINUE  '
   READ(*,*)
   WRITE (5,'('' MAXIMUM PERIOD ALLOWED FOR DISPOSAL (DAY) (T)
1.:''$)')
   READ *,T

   Q=R/T

   WRITE(5, '('' DRAINAGE COEFFICIENT (m/day).................:''$)')
   WRITE(5,*) Q

   WRITE(5, '('' DO YOU WANT TO CHANGE DRAINAGE COEFFICIENT (IF YES
1TYPE 1, IF NO TYPE 2):''$)')
   READ(5,*) NCHA
   IF (NCHA.EQ.1) GO TO 15
   IF (NCHA.EQ.2) GO TO 16

15 WRITE(5, '('' DRAINAGE COEFFICIENT (m/day).................:''$)')
   READ(5,*) Q

16 WRITE(5, '('' DRAIN DIAMETER (DIA) (m)....................:''$)')
   READ(5,*) DIA

60 PAI=3.141592654
```

```
        AK =2*D/(PAI*DIA)

50      WRITE(5, '('' D U RATIO (AK)................................:''$)')
        WRITE(5,*) AK

        WRITE (5,'('' ASSUMMED DRAIN SPACING (HL)..................:''$)')
        READ(5,*) HL

        TCOF=((((8*D)/(PAI*HL))*ALOG(AK))+1)
        DI=D/TCOF

        WRITE(5. '('' EQUIVALENT DEPTH (DI).(m).................... ''$)
        WRITE(5,*) DI

C*************************************************************************

C       HOOGHOUDT EQUATION

        HL = SQRT((8.*HK*DI*HC  + 4.*HK*(HC*HC))/Q)

C*************************************************************************

        WRITE(5. '('' DRAIN SPACING (HL)............................:''$)')
        WRITE(5,*) HL

        WRITE(5, '('' CHANGE ASSUMED SPACING OR EQUIVALENT DEPTH (IF YES
     1TYPE 1                    IF NO TYPE 2)               ......
     2:''$)')
        READ(5,*) NCHA
        IF (NCHA.EQ.1) GO TO 50
        IF (NCHA .EQ.2) GO TO 14

14      WRITE(5. '('' DRAIN DIAMETER.................................:''$)
        READ(5,*) DIA
        RO=DIA/2.

70      WRITE(5, '('' DRAIN SPACING (HL)............................:''$)')
        READ(5,*) HL

        COFF = (Q*HL/HK)
        HORZ  = ((HL-D*SQRT(2))**2)/(8.*D*HL)
        RADIAL = ALOG(D/(SQRT(2)*RO))/PAI
        HC = COFF*(HORZ+RADIAL)

        WRITE(5, '('' ALLOWABLE HEIGHT ABOVE DRAIN...................:''$)')
        WRITE(5,*) HC

        WRITE(5, '('' CHANGE DRAIN SPACING (IF YES TYPE 1, TYPE 2 TO CONTI
     1NUE)....:''$)')
        READ(5,*) NCHA
        IF (NCHA.EQ.1) GO TO 70

        WRITE(5, '('' DO YOU WANT TO CHANGE DEPTH OF DRAIN BELOW SOIL (IF
     1YES TYPE 1                TO STOP PROGRAM TYPE 2).:''$)')
        READ(5,*) NCHA
        IF (NCHA.EQ.1) GO TO 80
        IF (NCHA.EQ.2) GO TO 90

80      WRITE (5,'('' NEW DEPTH OF DRAIN BELOW SOIL (Dd) (m).......:''$)')
        READ *,Dd
```

```
      D=DA-Dd

      WRITE(5, '('' DEPTH TO IMPERVIOUS LAYER BELOW DRAIN.(m)....:''$)')
      WRITE(5,*) D

      WRITE (5,'('' MAX HEIGHT OF WATER TABLE BELOW SOIL ALLOWED AFTER
     1 3 DAYS IS (Dm).(m):''$)')
      READ *,Dm

      HC=Dd-1

      WRITE (5,'('' HEIGHT ABOVE DRAIN AFTER 3 DAYS (HC).........:''$) ')
      WRITE(5,*)HC

      WRITE(5, '('' DO YOU WANT TO FIND THE NEW SPACING OF DRAIN (IF Y
     1                        TYPE 1, TO STOP PROGRAM TYPE 2)...
     2:''$)')
      READ(5,*) NCHA
      IF (NCHA.EQ.1) GO TO 60
      IF (NCHA.EQ.2) GO TO 90

C*********************************************************************
C       PROGRAMME CALCULATES HEIGHT OF WATER TABLE AND CORRESPONDING
C       DRAIN DISCHARGE FOR INTERMITTENT RECHARGE
C*********************************************************************
1000    WRITE(*,*)' INTERMITTENT RECHARGE'
        WRITE(*,*)
        WRITE(5, '('' HAVE YOU PREPARED DATA FILE UB2.DAT (IF YES type 1)
     1: ''$)')
        READ(5,*) NCHA
        IF (NCHA.EQ.1) GO TO 107

107     PAI=3.141592654
C       READ(1,*)N
C       READ(1,*)(Z(J),S(J),J=1,N)

        WRITE (5,'('' DEPTH TO IMPERVOIUS LAYER FROM GROUND SURFACE (DA)
     1:''$)')
        READ *,DA

        WRITE (5,'('' DEPTH OF DRAIN FROM GROUND SURFACE (Dd)......:''$)')
        READ *,Dd

        D=DA-Dd

        WRITE (5,'('' DEPTH TO IMPERVIOUS LAYER FROM DRAIN (D).....:''$)')
        WRITE(5,*)D

        WRITE(5, '('' DRAIN DIAMETER (DIA)..........................:''$)')
        READ(5,*) DIA

        AK =2*D/(PAI*DIA)

        WRITE(5, '('' D U RATIO (AK)................................:''$)')
        WRITE(5,*) AK

        WRITE (5,'('' DRAIN SPACING (L..............................:''$)')
        READ *,L
```

```
TCOF=((((8*D)/(PAI*L))*ALOG(AK))+1)
DI=   TCOF

WRITE(5, '('' EQUIVALENT DEPTH (DI).(m).....................:''$)')
WRITE(5,*) DI

WRITE (5,'('' HYDRAULIC CONDUCTIVITY (HK)..................:''$)')
READ *,HK

WRITE (5,'('' STORAGE COEFFICIENT (PHI)....................:''$)')
READ *,PHI

AL=(PAI*PAI*HK*DI)/(PHI*L*L)

WRITE (5,'('' ALPHA (AL)...................................:''$)')
WRITE (5,*) AL

COF=(4)/(PAI*AL)

WRITE (5,'('' COEFFICIENT (COF)............................:''$)')
WRITE (5,*) COF

COFG=8/(PAI**2)

WRITE (5,'('' COEFFICIENT (COFG)...........................:''$)')
WRITE (5,*) COFG

READ(1,*)N
READ(1,*)(Z(J),S(J),J=1,N)
WRITE(2,12)

FORMAT(1X,'DATE',2X,'CT VALUES',2X,'SUM CT',2X,'HT OF WT',2X,'GT V
ALUES'2X,'SUM GT',2X'DIS. RATE')

SUM3=0.
SUM7=0.

DO J=1,N
SUM1=0.
SUM2=0.
SUM5=0.
SUM6=0.

DO I=1,100,2
SUM1=SUM1+((1-EXP(-(I**2)*AL*Z(J)))/(I**3))*SIN(PAI*I/2)
SUM5=SUM5+((1-EXP(-(I**2)*AL*Z(J)))/(I**2))
IF(J.EQ.1)THEN
SUM2=0.
SUM6=0.

ELSE
SUM2=SUM2+(((1-EXP(-(I**2)*AL*Z(J-1)))/(I**3)))*SIN(PAI*I/2)
SUM6=SUM6+(((1-EXP(-(I**2)*AL*Z(J-1)))/(I**2)))
ENDIF
ENDDO
SUM(J)=(SUM1-SUM2)*COF
SUMG(J)=(SUM5-SUM6)*COFG

S(J)=S(N+1-J)
```

```
        if(S(J).eq.0.)THEN
        SUMC(J)=0.
        SUMQ(J)=0.
C       SUM7=0.
        ELSE

        SUMC(J)=(SUM(J)*S(J))/PHI
        SUM3=SUM3+SUMC(J)
        SUMQ(J)=(SUMG(J)*S(J))
        SUM7=SUM7+SUMQ(J)
        ENDIF

        WRITE (2,11)J,SUM(J),SUMC(J),SUM3,SUMG(J).SUMQ(J),SUM7
        ENDDO
11      FORMAT(I4,2X,7F9.4)

        go to 90

C**********************************************************************
C       PROGRAMME CALCULATES HEIGHT OF WATER TABLE AND CORRESPONDING
C       DRAIN DISCHARGE FOR CONSTANT RECHARGE DURING A RESTRICTED
C       PERIOD (CRRP)
C**********************************************************************
1500    WRITE(*,*)' CONSTANT RECHARGE FOR RESTRICTED PERIOD'
        WRITE(*,*)

C       DIMENSION SUM(100),SUMG(100)

        OPEN(UNIT=2,FILE='CRRP.OUT')

        PAI=3.141592654

        WRITE (5,'(''  DEPTH TO IMPERVIOUS LAYER FROM GROUND SURFACE (Da)
     1:''$)')
        READ *,DA

        WRITE (5,'('' DEPTH OF DRAIN FROM GROUND SURFACE (Dd)......:''$)')
        READ *,Dd

        D=DA-Dd

        WRITE (5,'('' DEPTH TO IMPERVIOUS LAYER FROM DRAIN (D).....:''$)')
        WRITE(5,*)D

        WRITE(5, '('' DRAIN DIAMETER (DIA)........................:''$)')
        READ(5,*) DIA

        AK =2*D/(PAI*DIA)

        WRITE(5, '('' D U RATIO (AK)..................................:''$)')
        WRITE(5,*) AK

        WRITE (5,'('' DRAIN SPACING (L)............................:''$)')
        READ *,L

        TCOF=(((8*D)/(PAI*L))*ALOG(AK))+1)
        DI=D/TCOF

        WRITE(5, '('' EQUIVALENT DEPTH (DI).(m).....................:''$)')
        WRITE(5,*) DI
```

```
      WRITE (5,'('' HYDRAULIC CONDUCTIVITY OF SOIL (HK)..........:''$)')
      READ *,HK

      WRITE (5,'('' STORAGE COEFFICIENT (PHI)....................:''$)'
      READ *,PHI

C*****************************************************************

      AL=(PAI*PAI*HK*DI)/(PHI*L*L)

      WRITE (5,'('' ALPHA (AL).......................................:''$
      WRITE (5,*) AL

      WRITE (5,'('' CONTINUOUS RECHARGE RATE (R)...................:''$
      READ *,R

      COF=(4*R)/(PAI*PHI*AL)

      WRITE (5,'('' COEFFICIENT (COF).............................:''$
      WRITE (5,*) COF

      COFG=(8*R)/(PAI**2)

      WRITE (5,'('' COEFFICIENT (COFG)..........................  ''$)
      WRITE (5,*) COFG

      WRITE (5,'('' TIME IN DAYS (N)..............................:''$)
      READ *,N

      WRITE(2,13)

13    FORMAT(1X,'DATE',2X,'HT OF WT',2X'DIS. RATE')

      DO J=1,N,1
      SUM1=0.
      SUM2=0.
      SUM5=0.
      SUM6=0.

      DO I=1,100,2

      SUM1=SUM1+((1-EXP(-(I**2)*AL*(J)))/(I**3))*SIN(PAI*I/2)
      SUM5=SUM5+((1-EXP(-(I**2)*AL*(J)))/(I**2))

      IF(J.EQ.1)THEN
      SUM2=0.
      SUM6=0.

      ELSE
      SUM2=SUM2+(((1-EXP(-(I**2)*AL*(J-1)))/(I**3)))*SIN(PAI*I/2)
      SUM6=SUM6+(((1-EXP(-(I**2)*AL*(J-1)))/(I**2)))

      ENDIF
      ENDDO
      SUM(J)=(SUM1-SUM2)*COF
      SUMG(J)=(SUM5-SUM6)*COFG

      WRITE (2,18)J,SUM(J),SUMG(J)
      ENDDO
```

```
18      FORMAT(I4,2X,3F9.4)
c       STOP
c       END
        go to 90

C**********************************************************************
C       ECONOMIC ANALYSIS OF DRAINAGE SYSTEM
C**********************************************************************

1600    WRITE(*,*)'  ECONOMICAL ANALYSIS'
        WRITE(*,*)
        PAI=3.141592654

C       FIELD DRAIN
C       ***********

31      WRITE (5,'('' DEPTH OF FIELD DRAIN FROM GROUND SURFACE (Dd)(m)
     1 :''$)')
        READ *,Dd

        WRITE (5,'('' TOTAL LENGTH OF FIELD DRAIN (FDL)(m).........:''$)'
        READ *,FDL

        WRITE (5,'('' DIAMETER OF FIELD DRAIN (FDD) (m)............:''$)'
        READ *,FDD

        WRITE (5,'('' TOP WIDTH OF FIELD DRAIN (TWT)(m)............:''$)'
        READ *,TWT

        WRITE (5,'('' BOTTOM WIDTH OF FIELD DRAIN (BWT)(m).........:''$)'
        READ *,BWT

        FDD=(TWT+BWT)/2

        EWD=Dd*FDD*FDL
        WRITE (5,'('' VOL OF EARTH WORK FOR DIGGING FIELD DRAIN (EWD) (cu
     1m) :''$)')
        WRITE(5,*)EWD

        EWF=(Dd*FDD*FDL)-(PAI*FDD*FDD/4)
        WRITE (5,'('' VOL OF EARTH WORK FOR FILLING FIELD DRAIN (EWF) (cu
     1m) :''$)')
        WRITE(5,*)EWF

        WRITE(*,*)
        write(*,*)' COST OF EARTH WORK (CPWD RATES FOR DIGGING): Rs 17.4/
     1cu.m'
        write(*,*)' COST OF EARTH WORK (CPWD RATES FOR FILLING): Rs 11.4/
     1cu.m'
        WRITE(*,*)

        CEWDF=17.4*EWD
        WRITE (5,'('' COST OF EARTH WORK FOR DIGGING FIELD DRAIN (CEWDF)
     1(Rs) :''$)')
        WRITE(5,*)CEWDF

        CEWFF=11.4*EWF
        WRITE (5,'('' [illegible] OF EARTH WORK FOR FILLING FIELD DRAIN (CEWFF)
     1(Rs) :''[illegible]
        WRITE [illegible]
```

```
      F1=CEWDF+CEWFF
      WRITE (5,'('' TOTAL COST OF EARTH WORK FOR FIELD DRAIN INSTALLATIO
     1N (F1) (Rs):''$)')
      WRITE(5,*)F1

      WRITE (5,'('' COST OF FIELD DRAIN PIPE (FDC)(Rs/m).........:''$)')
      READ *,FDC

      TFDC=FDC*FDL
      WRITE (5,'('' TOTAL COST OF FIELD DRAIN PIPE (TFDC)(Rs)....:''$)')
      WRITE(5,*)TFDC

      TCIF=F1+TFDC
      WRITE (5,'('' TOTAL COST OF FIELD DRAIN INSTALLATION (TCIF) (Rs)
     1:''$)')
      WRITE(5,*)TCIF

      ***********************************************************************
      WRITE(5, '('' DO YOU WANT TO PERFORM COST ANALYSIS FOR COLLECTOR
     1DRAIN (IF YES                TYPE 1, IF NO TYPE 2): ''$)')
      READ(5,*) NCHA
      IF (NCHA.EQ.1) GO TO 32
      IF (NCHA.EQ.2) GO TO 33
      ***********************************************************************

      COLLECTOR DRAIN
      ****************

?     WRITE (5,'(''.DEPTH OF COLLECTOR DRAIN FROM GROUND SURFACE (CDd)
     1(m):''$)')
      READ *,CDd

      WRITE (5,'('' TOTAL LENGTH OF COLLECTOR DRAIN (CDL) (m)......:''$)
      READ *,CDL

      WRITE (5,'('' DIAMETER OF COLLECTOR DRAIN (CDD) (m).......   '$)')
      READ *,CDD

      WRITE (5,'('' TOP WIDTH OF COLLECTOR DRAIN (TWC)(m).........:''$)')
      READ *,TWC

      WRITE (5,'('' BOTTOM WIDTH OF COLLECTOR DRAIN (BWC)(m).....:''$)')
      READ *,BWC

      CDD=(TWC+BWC)/2

      EWCD=CDd*CDD*CDL
      WRITE (5,'('' VOL OF EARTH WORK FOR DIGGING COLLECTOR DRAIN (EWCD)
     1(cu.m):''$)')
      WRITE(5,*)EWCD

      EWCF=(CDd*CDD*CDL)-(PAI*CDD*CDD/4)
      WRITE (5,'('' VOL OF EARTH WORK FOR FILLING COLLECTOR DRAIN (EWCF)
     1(cu. m):''$)')
      WRITE(5,*)EWCF

      WRITE(*,*)
      write(*,*)' COST OF EARTH WORK (CPWD RATES FOR DIGGING : Rs 17.4/
     1cu.m'
```

```
      write(*,*)' COST OF EARTH WORK (CPWD RATES FOR FILLING): Rs 11.4/
     1cu.m'
      WRITE(*,*)

      CEWDC=17.4*EWCD
      WRITE (5,'('' COST OF EARTH WORK FOR DIGGING COLLECTOR DRAIN (CEWD
     1C) (Rs) :''$)')
      WRITE(5,*)CEWDC

      CEWFC=11.4*EWCF
      WRITE (5,'('' COST OF EARTH WORK FOR FILLING COLLECTOR DRAIN (CEWF
     1C) (Rs) :''$)')
      WRITE(5,*)CEWFC

      C1=CEWDC+CEWFC
      WRITE (5,'('' TOTAL COST OF EARTH WORK FOR COLLECTOR DRAIN INSTALL
     1ATION (C1)(Rs):''$)')
     , WRITE(5,*)C1

      WRITE (5,'('' COST OF COLLECTOR DRAIN PIPE PER UNIT LENGTH (CDC)(
     1s/m).....:''$)')
      READ *,CDC

      TCDC=CDC*CDL
      WRITE (5,'('' TOTAL COST OF COLLECTOR DRAIN PIPE (TCDC)(RS):''$)'
      WRITE(5,*)TCDC

      TCIC=C1+TCDC
      WRITE (5,'(''TOTAL COST OF COLLECTOR DRAIN INSTALLATION (TCIC) (F
     1:''$)')
      WRITE(5,*)TCIC

C     ***************************************************************
33    WRITE(5, '('' DO YOU WANT TO PERFORM COST ANALYSIS FOR INSPECTION
     1 HOLES ( IF YES                TYPE 1, IF NO TYPE 2)
     2: ''$)')
      READ(5,*) NCHA
      IF (NCHA.EQ.1) GO TO 34
      IF (NCHA.EQ.2) GO TO 35
C     ***************************************************************
C     INSPECTION HOLE
C     ***************

34    WRITE (5,'('' TOTAL DEPTH OF MAIN HOLE (DMH) (m)              :''$)'
      READ *,DMH

      WRITE (5,'('' TOTAL LENGTH OF MAIN HOLE (HML) (m)             :''$)'
      READ *,HML

      WRITE (5,'('' TOTAL WIDTH OF MAIN HOLE (WMH) (m)              :''$)'
      READ *,WMH

      EWMH=DMH*HML*WMH
      WRITE (5,'('' TOTAL VOLUME OF EARTH WORK FOR DIGGING MAIN HOLE (E
     1MH) (cu.m):''$)')
      WRITE(5,*)EWMH

      WRITE(*,*)
      write(*,*)' COST OF EARTH WORK (CPWD RATES FOR DIGGING): Rs 17.4/
     1cu.m'
```

```
      WRITE(*,*)
      WRITE (5,'('' COST OF EARTH WORK FOR MAIN HOLE PER UNIT VOLUME (CE
     1WMH) (Rs/cu.m) :''$)')
      READ(5,*)CEWMH

      CEWMHI=EWMH*CEWMH
      WRITE (5,'('' COST OF EARTH WORK FOR MAIN HOLE (TCEWMHI) (Rs)
     1:''$)')
      WRITE(5,*)CEWMHI

      WRITE (5,'('' TOTAL NUMBER OF MAIN HOLES (HN) (m)          :''$)')
      READ *,HN

      TCEWMH=HN*CEWMHI
      WRITE (5,'('' TOTAL COST OF EARTH WORK FOR MAIN HOLE (TCEWMH) (Rs)
     1:''$)')
      WRITE(5,*)TCEWMH

      BWMH=EWMH-(DMH*(HML-0.2)*(WMH-0.2))
      WRITE (5,'('' VOLUME OF BRICK WORK FOR MAIN HOLE (BWMH) (cu. m)
     1:''$)')
      WRITE(5,*)BWMH
      WRITE(*,*)
      write(*,*)'  COST OF BRICKWORK (1:4) (CPWD RATE) = Rs 917/cu.m.'
      WRITE(*,*)
      WRITE (5,'('' COST OF BRICK WORK FOR MAIN HOLE (CBWMH) (Rs/cu.m)
     1:''$)')
      READ(5,*)CBWMH

      TCBWMH=BWMH*CBWMH
      WRITE (5,'('' TOTAL COST OF BRICK WORK FOR MAIN HOLE (TCBWMH) (Rs
     1:''$)')
      WRITE(5,*)TCBWMH

      AP=(5*DMH*(HML-0.2))+(4*(HML-0.2)*0.1)
      WRITE (5,'('' AREA OF PLASTER FOR MAIN HOLE (AP)  (sq.m)   :''$ ')
      WRITE(5,*)AP
      WRITE(*,*)
      write(*,*)'  COST OF PLASTER (1:4) (CPWD RATE) = Rs 29.95/ sq.m.'
      WRITE(*,*)

      WRITE (5,'('' COST OF PLASTER FOR MAIN HOLE (CP)  (Rs/sq.m)
     1:''$)')
      READ(5,*)CP

      TCP=AP*CP
      WRITE (5,'('' TOTAL COST OF PLASTER FOR MAIN HOLE (TCP)  (Rs)
     1:''$)')
      WRITE(5,*)TCP

      TCMHC=TCEWMH+TCBWMH+TCP
      WRITE (5,'('' TOTAL COST OF MAIN HOLE CONSTRUCTION (TCMHC)  (Rs)
     1:''$)')
      WRITE(5,*)TCMHC
      ***********************************
      WRITE (5,'('' DO YOU WANT TO CONTINUE. (YES TYPE 1, NO TYPE 2)
     1:''$)')
      READ(5,*) NCHA
      IF (NCHA.EQ.1) GO TO 35
      IF (NCHA.EQ.2) GO TO 39
```

```
    ***********************************
    TFC1=TCIF+TCIC+TCMHC
    WRITE (5,'('' TOTAL COST OF DRAIN INSTALLATION (FIXED COST) (TFC1
   1(Rs):''$)')
    WRITE(5,*)TFC1

    TOHC1=TFC1*0.1
    WRITE (5,'('' TOTAL OVERHEAD CHARGES (ENGINEERING CHARGES (10%of
   1TFC1 (Rs)) :''$)')
    WRITE(5,*)TOHC1

    TOHC2=TFC1*0.1
    WRITE (5,'('' TOTAL COST OF GRAVEL FILTER (10%of TFC1 (Rs)):''$)')
    WRITE(5,*)TOHC2
    WRITE(*,*)

    TFC=TFC1+TOHC1+TOHC2

    WRITE (5,'('' FIXED COST TOTAL COST OF DRAIN INSTALLATION  (TFC)
   1(Rs):''$)')
    WRITE(5,*)TFC

    WRITE (5,'('' TOTAL AREA UNDER STUDY (TA) (ha)                :''$)'
    READ(5,*)TA

    CTPH=TFC/TA
    WRITE (5,'('' COST OF DRAIN INSTALLATION PER ha  (CTPH)    :''$)
    WRITE(5,*)CTPH

    WRITE (5,'('' TOTAL LIFE OF DRAINAGE SYSTEM (TL) (Years,      $)'
    READ(5,*)TL

    WRITE (5,'('' RATE OF INTEREST FOR PRESENT ANALYSIS (RI) (FRACTIO
   1N) :''$)')
    READ(5,*)RI

    TAR=((TFC*(RI*((1+RI)**TL)))/(((1+RI)**TL)-1))
    WRITE (5,'('' TOTAL RECOVERY PER YEAR (TAR) (Rs/year)          '$)'
    WRITE(5,*)TAR

    WRITE (5,'('' MAINTENANCE COST PER YEAR (FRACTION)(HMANC) (10 % OF
   1FIXED COST                 MAY BE ASSUMED)                :''$)')
    READ(5,*)HMANC

    AMC=TFC*HMANC
    WRITE (5,'('' ANNUAL MAINTENANCE COST OF SYSTEM (AMC) (Rs)
   1:''$)')
    WRITE(5,*)AMC

    TAC=TAR+AMC
    WRITE (5,'('' TOTAL ANNUAL COST OF DRAINAGE SYSTEM (TAC) (Rs)
   1:''$)')
    WRITE(5,*)TAC

    ********************************************

    WRITE(5, '('' DO YOU WANT TO CHANGE THE DEPTH OF DRAIN (FIELD OR
   1 COLLECTOR)                IF YES TYPE 1. IF NO TYPE 2): ''$)')
    READ(5,*) NCHA
    IF (NCHA.EQ.1) GO TO 31
```

```
      IF (NCHA.EQ.2) GO TO 36

36    WRITE(5, '('' DO YOU WANT TO CALCULATE THE ANNUAL BENEFITS FROM D
     1AINAGE SYSTEM              (IF YES type 1) TO STOP PROGRAMM TYPE
     22): ''$)')
      READ(5,*) NCHA
      IF (NCHA.EQ.1) GO TO 37
      IF(NCHA.EQ.2) GO TO 90

37    WRITE (5,'('' ADDITIONAL AREA BROUGHT UNDER CULTIVATION (AR1) (ha
     1:''$)')
      READ(5,*)AR1

      WRITE (5,'('' AVERAGE PRICE OF PRODUCE (Rs/Tons) or (Rs/kg) (A
     1  :''$)')
      READ *,AP1

      WRITE (5,'('' ADDITIONAL YIELD FROM CULTIVATION IN THIS AREA (
     1                          (Tons/ha) or (kg/ha)        :''$)
*     READ(5,*)AY1

      HNR1=(AR1*AY1*AP1)
      WRITE (5,'('' ADDITIONAL RETURN (BENEFITS) FROM DRAINAGE P  JECT
     1(HNR1) (Rs):''$)')
      WRITE(5,*)HNR1

      WRITE (5,'('' ADDITIONAL AREA BROUGHT UNDER IRRIGATION US    W
     1FROM DRAIN (AR2) (ha):''$)')
      READ(5,*)AR2

      WRITE (5,'('' ADDITIONAL YIELD FROM IRRIGATION (AY2) (Tons/ha
     1(kg/ha):''$)')
      READ *,AY2

      WRITE (5,'('' AVERAGE PRICE OF PRODUCE (Rs/Tons) or (Rs/kg) (A
     1  :''$)')
      READ *,AP2

      HNR2=(AR2*AY2*AP2)
      WRITE (5,'('' ADDITIONAL RETURN (BENEFITS) FROM DRAINAGE PROJE
     1(HNR2) (Rs):''$)')
      WRITE(5,*)HNR2

      HNR=HNR1+HNR2
      WRITE (5,'('' NET ADDITIONAL RETURN (BENEFITS) FR  DRAI     PRO
     1CT(HNR) (Rs):''$)')
      WRITE(5,*)HNR

      BC=(HNR/TAC)
      WRITE (5,'('' BENEFIT COST RATIO (BC)                     :''$)')
      WRITE(5,*)BC

      WRITE (5,'('' DO YOU WANT TO STOP PROGRAMME (IF YES TYPE 1):''$)')
      READ(5,*)NCHA
      IF(NCHA.EQ.1) GO TO 90

90    dummy2=setvideomode( $DEFAULTMODE)
      STOP
      END
```

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