Principles of Irrigation and Drainage

prepared

for

Rural Engineers

Land Capability Planners

and Soil Surveyors

of the

Rural Physical Planning Units

Principles of Irrigation and Drainage

prepared

for

Rural Engineers

Land Capability Planners

and Soil Surveyors

of the

Rural Physical Planning Units

March 1981
Rural Physical Planning Unit
Western Region
Ministry of Agriculture

PREFACE

In the preparation of physical development plans for rural (agricultural) areas the assessment of drainage requirements and irrigation potentials is an important aspect of the engineering component. In each Rural Physical Planning Unit the Rural Engineer. is primarily responsible for the proper inputs in drainage and irrigation. The Land Capability Planner, and to a lesser extent the Soil Surveyor, should assist the Rural Engineer in gathering relevant data. In order to strengthen these person ability in these subjects, a training course has been organized and sponsored by the Netherlands Bilateral Assistance Project attached to the Rural Physical Planning Unit in Montego Bay (JAM/76/04) from 9 - 13 March 1981 at the Smithfield Training Centre, Hanover.

The document in hand has been prepared as course material for the participating Rural Engineers, Land Capability Planners and Soil Surveyors of the four Rural Physical Planning Units. They can use these notes as reference materials during their professional work. The new knowledge will help the staff of the Planning Units to make well-founded decisions in the formulation of development proposals for the rural areas.

I RAINFALL

1. Introduction

A basic feature in any irrigation and drainage study, is rainfall. As rainfall is extremely variable in time and space, the rainfall data covering long periods and recorded at various stations in and near the study area will have to be studied.

In Jamaica such data are generally available from the Meteorological Service, Kingston. For most stations long series of yearly and monthly data are available. For some stations figures on daily and even hourly rainfall can be provided.

The amount of rain that falls on the ground in a certain period of time is expressed as the depth P (in mm/inch) to which it would cover a horizontal plain on the ground.

The rainfall depth in a certain area may be considered a statistical variable, its value depending on :

1. the area under study
2. the season of the year
3. the length of the observation period

In any case in which for a given area an irrigation and/or drainage system has to be designed the season and the lenght of the observation period chosen depend on the type of problem related to the objective of the project.

2. The Area under Study

For the study of rainfall of an area, one can only use rainfall data from stations, representing the rainfall at those specific points. These data have to be converted to area rainfall. For this, several methods exist, one of which can be used depending on the situation.

- to arrive at the rainfall falling on the area, one takes the arithmetic mean of rainfall depths as recorded at stations in or near the study area. This can only be done if the area is homogeneous in terms of geography and topography and all stations are supposed to be representative for the area.

- the weighted mean of rainfall depths at all stations relevant to the area can be used also. The weight attributed to the data from a certain measuring station is determined by the portion of the study area which is under the influence of this measuring station. The subdivision of the study area amongst the rainfall measuring stations is done by means of polygons. This is the so-called Thiessen method.

lines are drawn between adjacent stations on a map. The perpendicular bisectors of these lines form a pattern of polygons, each round a station. The area which each station is taken to represent is the area of its polygon, and this area is used as a factor for weighting the station precipitation.

the sum of the products of each station area and precipitation is divided by the total basin area to get the average precipitation. around the edge of the basin, where parts of polygons extend beyond the basin boundary, only the protion of polygon which is inside the drainage area is used. In this matter stations near but outside the drainage basin may well have polygon areas which extended into the drainage basin, and their data are included.

The method is used with non-uniform station spacing, it gives weight to station data in proportion to the space between stations. The procedure is mechanical and and, once the station weights are assigned, can be carried out readily by machine methods. While its objectivity is an advantage, the method rigidly excludes consideration of information other than station spacing and precipitation amounts.

the principle of the weighted mean of the rainfall from the different stations can be used but now the weight of these stations is determined by the portions of the area which are under their influence, after the drawing of isopluvial lines, lines connecting points of equal rainfall.

3. The Season

In some cases it is sufficient to restrict the study of the rainfall of an area to a specific season. For instance when a drainage problem concerns drainage for crop protection, it is the growing season for which the rainfall data have to be studied. If an irrigation system has to be designed in most cases only rainfall data from the dry season are relevant. Considerations like this should be borne in mind when starting a rainfall study for irrigation and drainage projects.

4. The length of th e Observation Period

In a rainfall study one is interested in the amount of rain which can fall within a certain time span. In a general study on water availability for crop growing, or of water excess, monthly rainfall may be needed. For irrigation purposes the rainfall observation period depends more on the irrigation interval i.e. the time between 2 irrigations, which is determined by the water-holding capacity of the soil, and by crop response to drought. Irrigation intervals can be in the order of some weeks. In these cases we are interested to know how much rain can fall in such a period. For erosion control structures and the drainage of small steep watersheds or of urban areas where storage capacities are small, information on hourly rainfall can be needed.

I.5 Frequency Analysis

Drainage structures and systems are designed and implemented to safely discharge water from or through certain areas. Their capacity is determined by a certain amount of rain that can fall on the area to be drained.

The chance that a certain amount of rainfall will occur at which the capacity of the drainage system/structure will fully be utilised is the so-called design frequency.

The higher the rainfall, on which the capacity of the structure/system is based, the less likely it will occur, so the less risk of failure of the structure. There is however, a certain point at which the cost of ensuring more safety outweights the benefit of a further reduction in the risk for failures. Therefore, the choice of a design frequency is an optimisation problem.

Example: To supply water to an irrigation system by means of a gravity system the water level in a river is raised by a weir. To determine the design frequency the following table is prepared.

Capacity (cfs)	Yearly Risk %	Additional Cost $	Depreciation $	Yearly Risk $	Total Cost $
1700	5	—	—	10000	10000
2000	2	30000	3000	4000	7000
2300	1	46000	4600	2000	6600
2700	.5	62000	6200	1000	7200
3100	.2	81000	8100	400	8500

The basic costs of the weir are $200,000 depreciation is 10% of the additional expenditure needed for the extra capacity.

From the table it appears that the total yearly costs are the lowest for a weir with a capacity of 2300 cfs. This structure has a capacity which will be too small only once in 100 years.

In case enough economic and hydrological data are available on economic calculation as described above can be made. In other cases, standard design frequencies are chosen.

For large scale flood protection works, an average failure of only once in 1000 or 10,000 years may be accepted. Infrastructural works as culverts and small bridges in rural areas are usually designed for discharges which occur once in 10 years.

The design frequency is 10 years. If possible failure has implications in an agricultural sense only i.e. loss of production - as may occur in irrigation and drainage projects - an average failure of once in 5 or 10 years is generally accepted.

I.6 Rainfall Analysis

In Section I.5 it was explained that for different types of drainage projects different rainfall design frequencies will be used.

To arrive at the amount of rainfall that occurs with a certain frequency a rainfall analysis has to be carried out.

Data available from stations relevant to the study area are compiled. If necessary, they are converted into area rainfall using one of the methods described in Section I.1.

Below, a statistical method is described with which different frequencies of rainfall can be calculated. Rainfall data are set out on log-normal paper after which the cumulative frequency can be derived. The following steps are required :

Step 1: obtain rainfall data for the selected station (s) for as many years as possible.

Step 2: arrange the monthly rainfall data or, daily or hourly rainfall data, depending on the type of problem in order of magnitude with the highest rainfall first.

Step 3: calculate for each rainfall the plotting position by using the Hazen-equation. $F_a = \frac{100\ (2n - 1)}{2y}$

in which :

F_a = the plotting position in percent
n = the rank number in order of decreasing rainfall (e.g. highest rainfall has rank number 1.)
y = number of records

Step 4: device the vertical scale of the log-normal probability paper in such a way that the highest and lowest rainfall values fit into it.

Step 5: plot the rainfall data against their calculated Fa positions.

Step 6: draw a straight line as precisely as possible through all the points.

Step 7: derive from this line the rainfall with the desired frequency.

II. DRAINAGE

1. Introduction

Drainage is the removal of excess water by natural or artificial means. In agriculture the objective of drainage is to prevent the occurrence of an excessive moist condition in the root zone, which either directly or indirectly has a harmfull effect on the growth of crops. A further objective of drainage is to prevent accumulation of salts in the root zone or to leach accumulated salts out of the soil profile.

There are two ways in which water is or can be removed from an area. One is by surface run-off the other through infiltration and subsequent percolation in the soil and underlying materials. Surface drainage is the dominant type of drainage in hilly areas. Sub-surface drainage is dominant in flat areas. Two important soil characteristics which determine the ability of the soil to transmit and transport water are : the infiltration rate of the soil and the hydraulic conductivity. Both characteristics can be measured in the field by simple methods i.e. the double ring infiltrometer method and the augerhole method. This will be explained during a field day.

In order to enable the calculation of dimensions for drainage structures such as drains, culverts, bridges and other structures, one needs to know the peak flows which have to be discharged by these structures. When (for surface drainage) no flow measurements are available, methods are used which enable the estimation of these peak flows.
The methods used in computing these peak discharges vary considerably with the topography of the area as explained above (Section II.1).

Surface drainage systems in sloping areas have to handle peak run off rates with a certain probability of occurrence. These peak run-off rates are mainly conditioned by the natural drainage pattern or system of the basin. Drainage systems in flat areas however are mainly designed to remove a certain volume of excess water within an economically determined period of time. Since the approach applied in both types of areas is basically different, they will be discussed separately. In all methods described below, peak discharges will be calculated with a certain chance of occurrence. The chance of occurrence chosen depends on the importance of the relevant structure or canal as explained in Section I.2, a return period of 10 years is regarded acceptable for road drainage structures. However, if structures tend to be large and expensive sometimes a lower chance of occurrence is used. To convert discharges calculated with a chance of occurrence of 10 years to discharges with other chances the conversion factors can be used :

TABLE II.1

CONVERSION FACTORS (F) FOR PEAK DISCHARGES AT DIFFERENT RETURN PERIODS (T)

T	F
5	0.83
10	1
15	1.1
25	1.2
50	1.3

II.2 Drainage of Sloping Areas

a. Areas smaller than 250 acres

For areas smaller than 250 acres, the so-called "rational formula" is used, to compute peak discharges originating in these areas. The principle behind the formula is as follows : with the same chance of occurrence, the mean peak rainfall intensity will decrease, as the time interval considered increases. The rainfall for example which can be expected to occur once in 10 years, during a 10 minutes period is 50 mm/10 min 300 mm/hr. The amount of rain that can be expected to fall once in 10 years in a period of 20 min might be 7.5 mm/20 min :225 mm/hr. When the rainfall duration exceeds the time of concentration (Tc) – the time of concentration is the time interval between the beginning of the rainfall and the moment when the whole area above the point of outlet contributes to the run-off – the mean rainfall intensity will be less than the mean intensity over a period equal to the time of concentration. If on the other hand the rainfall duration is less than the time of concentration the rainfall intensity to be considered will be higher, but only a part of the area will contribute to the run-off.

These two considerations lead to the principle of the rational formula, which says that the maximum rate of runoff has to be expected when the rainfall duration equals the time of concentration of the catchment.

$$Q_p = C * I * A'$$

Q_p = peak discharge m^3/hr

C_p = run-off coefficient

I = mean rainfall intensity over a period equal to the time of concentration m/hr

A = Catchment area m^2

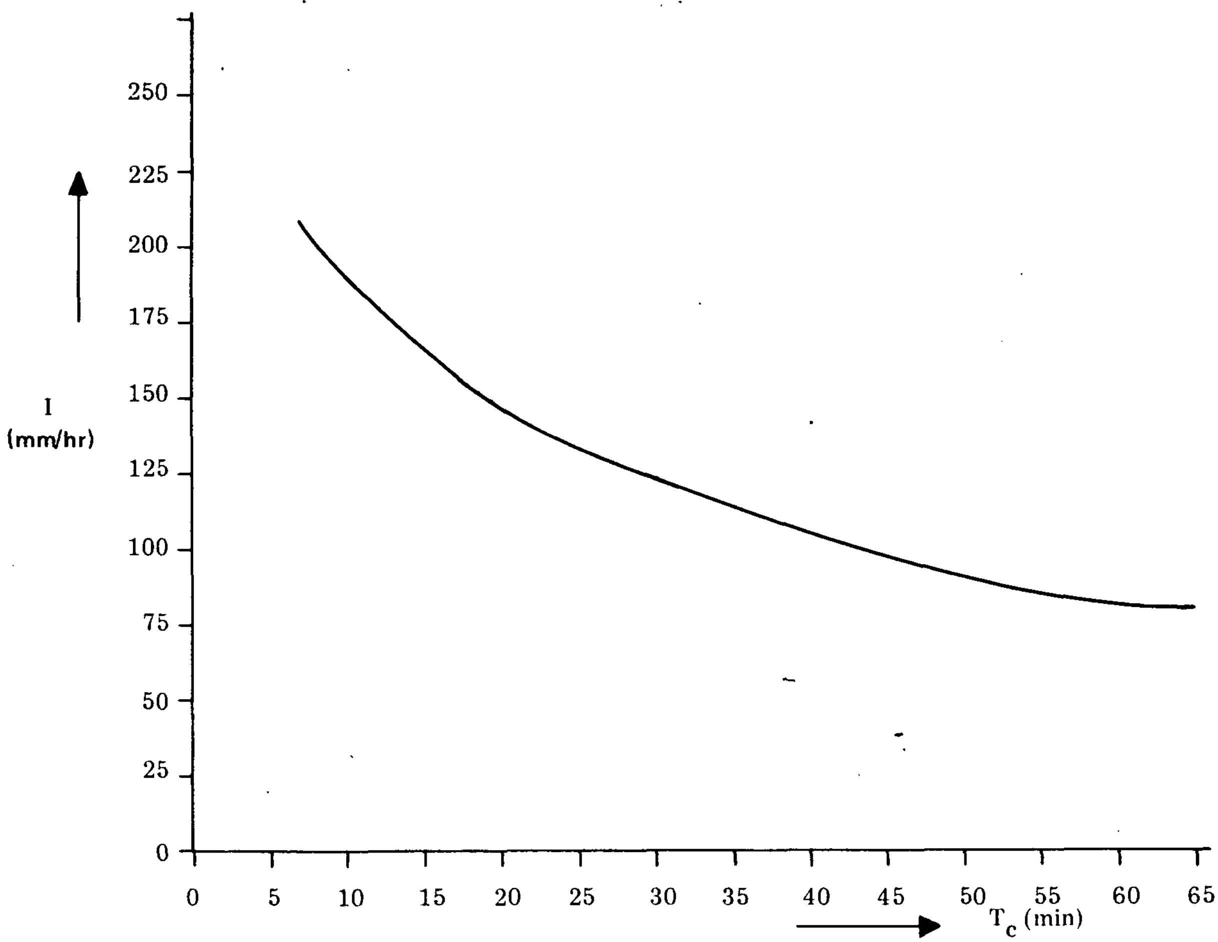


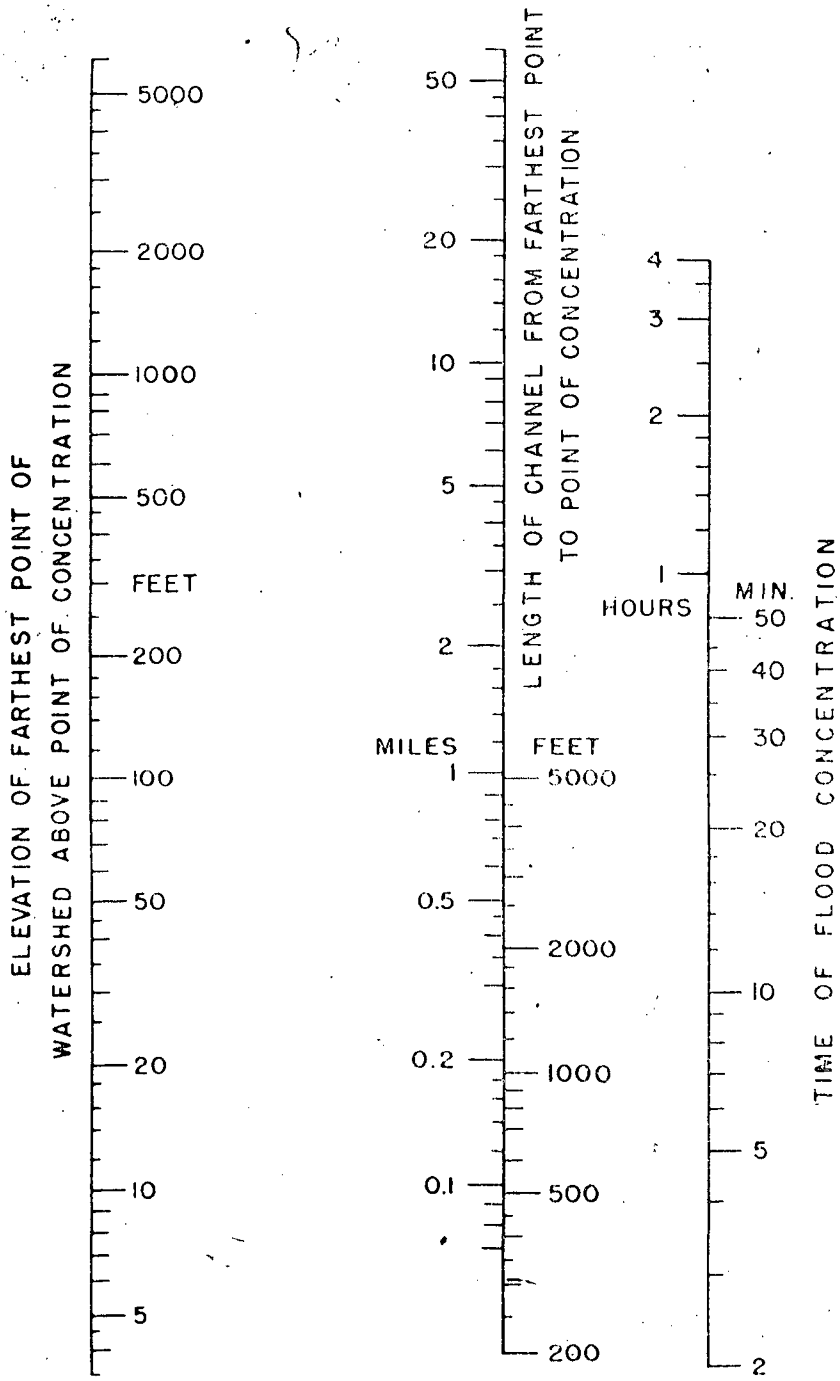
TABLE II.2

VALUES FOR THE RUNOFF COEFFICIENT C IN Q = C.I.A.
AS DETERMINED BY LAND USE AND SOIL TYPES

Slope	Sandy loam	Clay and Silt Loam	Tight Clay
Forest			
0 - 5%	0.10	0.30	0.40
5 - 10%	0.25	0.35	0.50
10 - 30%	0.30	0.50	0.60
Pasture			
0 - 5%	0.10	0.30	0.40
5 - 10%	0.15	0.35	0.55
10 - 30%	0.20	0.40	0.60
Arable Land			
0 - 5%	0.30	0.50	0.60
5 - 10%	0.40	0.60	0.70
10 - 30%	0.50	0.70	0.80

NOMOGRAM II. 4

TIME OF CONCENTRATION AS FUNCTION OF LENGTH OF WATERWAY AND DIFFERENCE IN ELEVATION



To determine the time of concentration a nomogram II.4 is attached, from which the time of concentration can be derived. This time of concentration depends on the length of the catchment and the difference in elevation. When the time of concentration is determined Graph II.3 gives us the rainfall intensity over this time of concentration with a chance of occurrence of 10% (once in 10 years). From Table II.2 the run-off coefficient is derived. When a catchment has sub-areas with different characteristics the weighted mean of the different c-values should be used. Now the peak discharge can be calculated.

b. <u>Areas Between 250 and 750 Acres</u>

For areas ranging between 250 and 750 acres the Cook Method is used. This is an empirical formula. The basis of the Cook Method is, that the peak discharge Q is calculated as a product of three factors :

$$Q_p = P \times R \times F$$

In which :

Q_p = peak discharge	(cfs)	
P = unadjusted peak run-off	(cfs)	Fig. II.6
R = rainfall factor		
F = frequency factor		Table II.2

The unadjusted peak run-off is arrived at, by assigning numerical values to four run-off producing characteristics: relief, soil infiltration (I), vegetal cover (VC) and surface storage. The total score of the area on these four characteristics $= \Sigma W$; together with the size of the area this ΣW value will give P, the unadjusted peak discharge. This is the peak discharge as it could occur once in 50 years in the U.S. To convert this peak discharge to a 10 year peak discharge the conversion factor F is introduced which depends on the main annual precipitation and (I + VC). P also has to be converted to Jamaican climatological conditions by means of R, which is based on rainfall levels and is estimated to be 1.35. for W sec Table II.5

c <u>Areas Larger Than 750 acres.</u>

For areas larger than 750 acres the so-called "CURVE NUMBER" method is used. This is a very complicated method and therefore will not be discussed in this chapter. A photocopy explaining the use of this method is attached. (see Annex I).

TABLE II. 5

RUNOFF—PRODUCING CHARACTERISTICS OF DRAINAGE BASINS WITH CORRESPONDING WEIGHTS W (the weights are shown in brackets).
(After SCHWAB et al . . . 1971)

	Designation of basin Characteristics	RUNOFF-PRODUCING CHARACTERISTICS			
		(100) Extreme	(75) High	(50) Normal	(25) Low
		(40)	(30)	(20)	(10)
Total score of area on these 4 features gives the value of W	Relief	Steep, rugged, terrain with average slopes generally above 30%	Hilly, with average slopes of 10 to 30%	Rolling, with average slopes of 5 to 10%	Relatively flat land, with average slopes of 0 to 5%
		(20)	(15)	(10)	(5)
	Soil Infiltration (I)	No effective soil cover; either rock or thin soil mantle of negligible infiltration capacity	Slow to take up water; clay or other soil of low infiltration capacity, such as heavy gumbo	Normal; deep loam with infiltration about equal to that of typical prairie soil	High; deep sand or other soil that takes up water readily and rapidly
		(20)	(15)	(10)	(5)
	Vegetal cover (VC)	No effective plant cover; bare except for very sparse cover	Poor to fair; clean-cultivated crops or poor natural cover; less than 10 per cent of drainage area under good cover	Fair to good; about 50 per cent of drainage area in good grassland; woodland, or equivalent cover; not more than 50 percent of area in clean-cultivated crops	Good to excellent; about 90 per cent of drainage area in good grassland, woodland, or equivalent cover
		(20)	(15)	(10)	(5)
	Surface storage	Negligible; surface depressions are few and shallow; drainage-ways steep and small; no ponds or marshes	Low; well-defined system of small drainage-ways; no ponds or marshes	Normal; considerable surface-depression storage; drainage system similar to that of typical prairie lands; lakes, ponds, and marshes less than 2 per cent of drainage area	High; surface-depression storage high; drainage system not sharply defined; large flood-plain storage or a large number of lakes, ponds or marshes

SURFACE DRAINAGE SYSTEMS FOR SLOPING AREAS

Surface drainage methods applied in sloping areas (slopes exceeding 2%) are closely related to problems of erosion control. The methods comprise the creation of suitable conditions to regulate or intercept the overland flow before it becomes hazardous as an erosion force. This usually means some form of terracing.

Drainage and erosion control are not the only reasons why sloping lands are terraced. Sometimes the objective is water conservation. If so, bench type terraces or step type terraces are constructed. (Fig. II 8.a). The original slope of the land is altered to form a number of vertical steps. Such terraces are given a level surface and the terrace channels have no slope. The rice sawahs in Asia are examples of step type terraces.

The terraces applied for drainage and erosion control are basically of two types : the cross-slope ditch system (Fig II 8.b) and the standard erosion control terrace (Fig II.8.c).

The cross-slope ditch system is a channel type graded terrace also called Nichols terrace and is used on lands with a slope up to 4%, where flat land system is effective on soils with poor internal drainage and where the overall slopes are rather long and regular but where many minor depressions occur.

The ditches should run approximately parallel to the contours of the land with a uniform or variable grade of between 0.1 and 1% (or a mean of 0.5%), depending on the topography. The use of a variable grade often permits a better alignment of the terrace and a better fit of the terrace to the field. The soil surface between the ditches must be smoothed and all farming operations should be done parallel to the ditches. Spoil from the ditches can be used to fill up minor depressions or can be spread out to form a low layer of not more than 7 cm on the downslope side of the ditch (Fig.II.8.b).
Cross-slope ditches can have either a traingular or a trapezoidal shape, with side slopes ranging from 1:4 - 1:10. Their cross-sectional area can vary from 0.4 - 0.7 m. Depths will be between 15 and 25 cm and the top width from 5 - 7m. The maximum length of a ditch draining to one side only is about 350 - 450 m.

The distance between the ditches depends on the slope, the rainfall intensity, the erodibility of the soil, and on the crops that will be grown. It varies between 30 m on lands with a 4% slope and 45 m on lands with 0.5% slope.

With the cross-slope ditch system, between 80 and 100% of the water contained in the ditch is below the original land surface, which reduces the harmful effects of a possible break in the downslope bank.

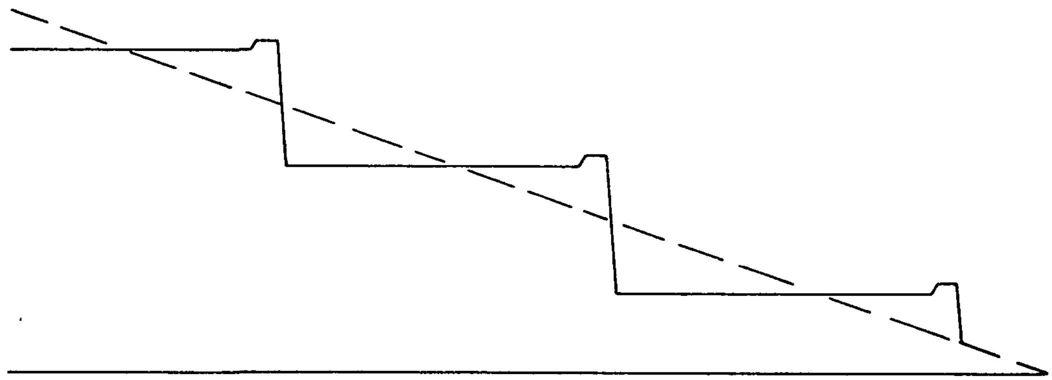


Fig. II 8a. Cross-section of Bench Terrace

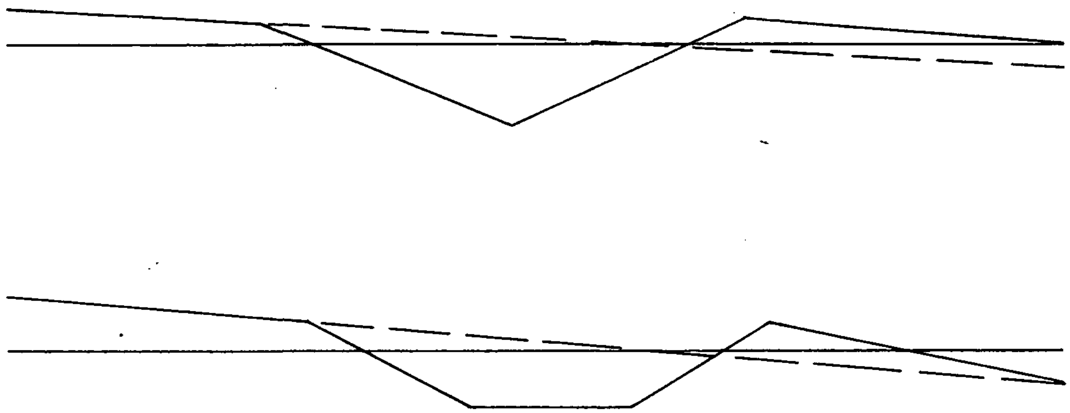


Fig. II 8b. Cross-sections of Cross-slope Ditches

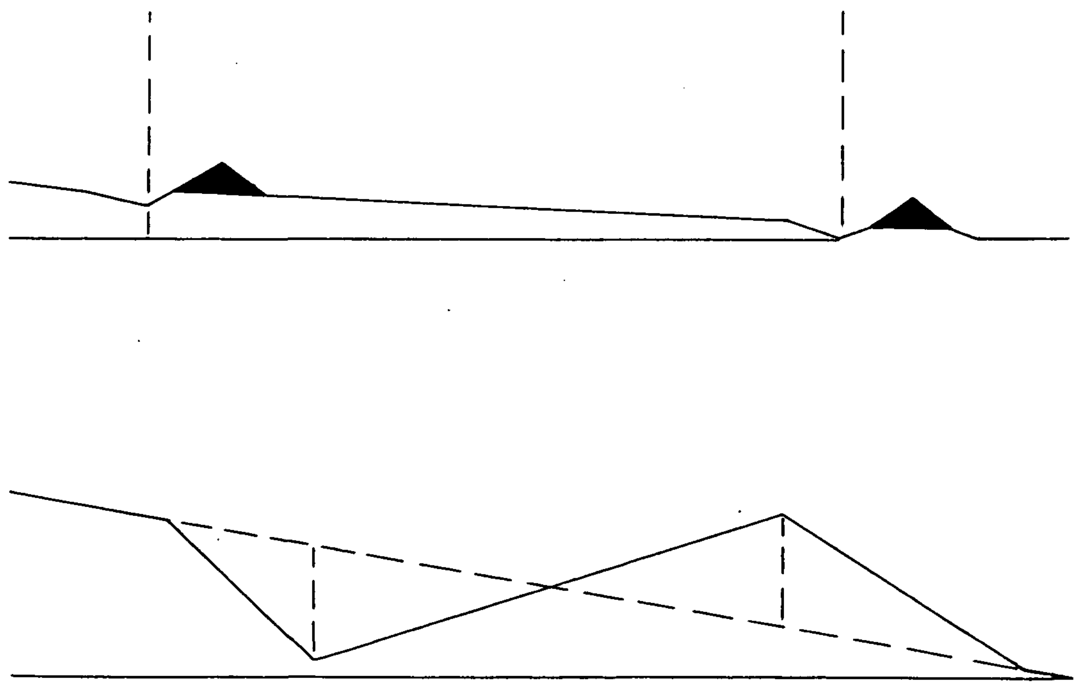


Fig. II. 8 c. Cross-section of Standard Erosion Control Terrace

The standard erosion control terrace is a ridge type graded terrace also called Mangum terrace and is used on lands that slope as much as 10% (Fig 8.c.).

The difference between the cross-slope ditch and the erosion control terrace is that with the latter the spoil from the channels is used to build up a relatively high ridge on the downslope side. In such channels only 50% of the water is contained below the original land surface. Greater storages would require greater amounts of earth moving and would increase the risk of the ridges rupturing.

Like the cross-slope ditches, the channels of the erosion control terraces should run approximately parallel to the contours of the land with a uniform or variable grade of between 0.1 and 0.6% (or a mean of 0.3%), depending on the topography. Natural impediments and sharp curves should be avoided. If there is a sudden break in the slope of the land, a channel should be located directly above it.

The distance between the channels is governed by the same factors as the cross-slope ditch: slope, rainfall intensity, soil erodibility, and the crops to be grown. The following empirical formula has been developed for use in the USA.

$$VI = a\,S + b$$

where

- V.I. = vertical interval between corresponding points on consecutive terraces (ft.)
- S = average slope of the land (%)
- a = empirical constant, which varies from 0.3 - 0.6
- b = empirical constant (b = 1 for erodible soil and poor cover and b = 2 for resistant soil and good cover).

The length of the terraces, and thus of the channels, will usually depend on the location of a suitable disposal ditch. Terraces should not be so short that they impede farming operations, not so long that the channels would require too great a cut. The maximum length of a terrace channel draining to one side only is about 350 or 450 m.

With the length and the location of the terraces known, the area between two channels can be calculated. Manning's flow formula can then be used to calculate the cross-sectional area of the channel.

$$V = K_m R^{2/3}\, s^{1/2}$$

where

v	=	flow velocity of the water at the outlet	(m/sec.)
K_m	=	roughness coefficient	($m^{1/3}$/sec)
R	=	hydraulic radius	(m)
s	=	slope of the channel (dimensionless)	

The flow velocity at the outlet should not exceed a certain critical value. A value often used is 0.60 m/sec, although on sandy soils, 0.45 m/sec is applicable and 0.30 m/sec on pure sands.

The depth of the channels will depend on the length of the terrace and the slope of the land. On lands that slope 2%, depths will vary from 25 cm for terraces 60 m long, to 35 cm for terraces 300 m long. If the land slopes 10%, channel depths will vary from 20 cm for 60 m terraces to 30 cm for 300 m terraces. Side slopes can range from 1:10 on land with a 2% slope to 1:4 on land with a 10% slope. Channels can be either triangular or trapezoidal and their cross-sectional area can vary between 0.35 and 0.90 m ^{2} A freeboard of about 10 cm should be maintained in the channels.

When the discharge is known and the side slopes and critical flow velocity have been chosen, the most suitable combination of water depth, bottom width, and channel gradient can be found. The location of the top terrace is very important. If the top terrace fails, it often causes the failure of the lower terraces. The watershed area above the top terrace should not exceed 1 - 1½ ha.

In sloping areas, where the field drains run approximately parallel to the contours, the water must be disposed of by a drainage channel which runs downslope. The slope is usually so steep that such channels will have to be lined or fitted with overflows or drop structures to prevent scouring.

In certain circumstances, vegetated waterways can be used to advantage. The vegetational cover reduces the flow velocity of the water while at the same time allowing a comparatively high velocity. Permanent, dense, sod-forming grasses are the most suitable vegetation for such channels but the choice, of course, will depend on climate, soil, and available species.

Allowable velocities in erosion resistant soil covered by dense grass vegetation are 2 m/sec for slopes of 0 - 5% and 1.75 m/sec for slopes of 5 - 10%. In easily erodible soils, the allowable velocities in densely grassed channels are 1.50 m/sec with slopes of 0 - 5% and 1.25 m/sec with slopes of 5 - 10%. Vegetation other than grasses can be used on slopes of up to 5% and the allowable velecities are then 1 m/sec on erosion resistant soil and 0.50 m/sec on easily erodible soil.

In the design of vegetated waterways, the roughness coefficient is taken as n = 0.04, a value corresponding with that for freshly cut grasses. Where the maximum runoff occurs in periods when the vegetation has a higher retarding capacity than freshly cut grass, one should add some 10 - 15 cm to the calculated design depth to ensure that no overtopping occurs.

The waterway can be parabolic, triangular, or trapezoidal. Side slopes should not be steeper than 1:4 to allow the passage of farm machinery. Minimum bottom width is 2.5 ,. When the discharge is known and the side slopes and allowable flow velocity have been chosen, the most suitable combination of bottom width, water depth, and grade can be calculated.

Other points to consider are that :

- a vegetated waterway should not be continuously wet, so as to prevent the vegetation cover from deteriorating. If groundwater is flowing into the waterway. it should be intercepted by a tile drain. Surface water can be carried off by a small concrete or asphalt tricke channel constructed at the bottom of the waterway.
- the fertility of the soil in the vegetated waterways should be maintained (manuring).
- seeding mixtures should include quick-growing annuals and hardy perennials : sometimes sodding may be necessary.
- the vegetation should properly be maintained and the waterway should not be passed with farm machinery when it is still wet.
- special attention should be paid to the terrace outlets; the vegetation cover may be extended over a small distance into the terrace channel.

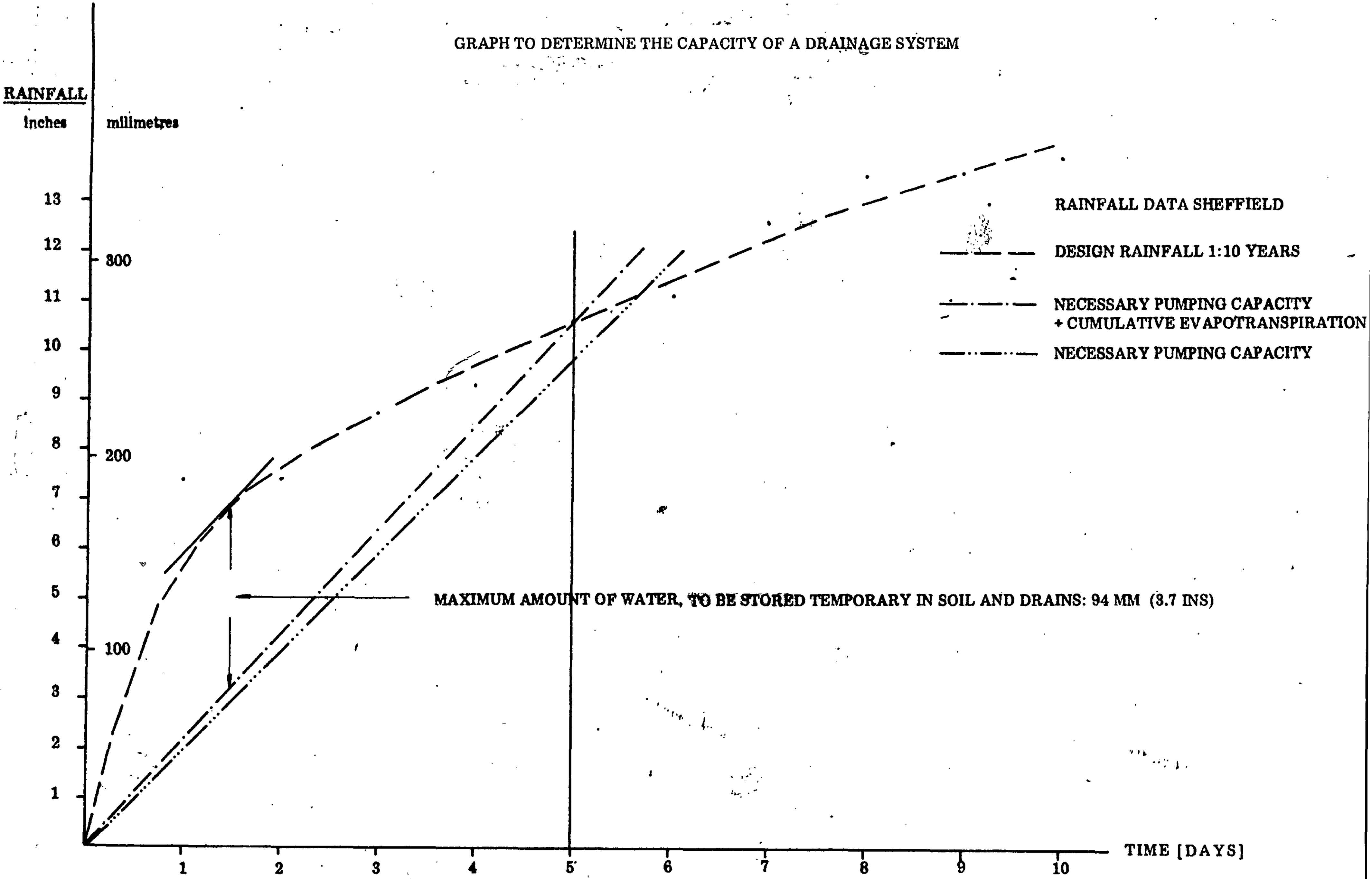
II.3 Drainage of Flat Areas

a. Computing Design Discharges

Flat areas, as meant here, are generally small agricultural watersheds with average land slopes of less than 1%. Under these conditions the question is not so much: What will be the peak run-off with a certain chance of occurrence, but: what should be the maximum period allowed for removal of a certain volume of excess surface water occurring with a certain probability. In countries were substantial research has been done, many empirical relations and formulas have been developed. This however is not the case in Jamaica. Therefore a simplified hydrological procedure is followed. First of all it is decided ' at risk of failure of the drainage system is accepted. If it is reasonable that only once in 10 years the capacity of the system is allowed to be insufficient, than the amounts of rain that can fall in 1, 2, 3, 4 etc. up to 10 consecutive days are plotted in a graph against the time. After this it is decided within how many days the drainage system should be able to discharge the amount of rain falling within that period. This decision is based on agronomic considerations. An example of this procedure is presented in Figure II.10 In this case it is assumed that after 5 days of rainfall the drainage system should have removed the rain which has fallen in the area. From the graph it can be calculated how much water (mm/day) should be removed by the drainage system. In In this procedure an allowance is made for the evapotranspiration which takes place in this period. From figure II.10it becomes clear that the drainage system should be able to remove 50 mm/day. In the figure also the amount of water is indicated which has to be stored in drains and soils temporary, in case the drainage system will be based on this 50 mm/day.

FIG. II. 10

GRAPH TO DETERMINE THE CAPACITY OF A DRAINAGE SYSTEM



b. Drainage Systems for Flat Areas

The surface drainage systems applied in flat areas (maximum slope 2%) differ from those in sloping areas. In flat areas the lack of sufficient slope is a limitation while in steep areas the main limitation is the risk of erosion.

The most commonly used system is that of parallel field drains. Depending on hydraulic properties of the soil and on rainfall their dimensions can vary. They can be shallow thus carrying run-off or deep and carry the sub-surface flow. Another system used is the random system in which low spots requiring drainage are connected to a main drain by field drains. In case parallel field drains are used and drainage mainly consists of sub-surface drainage, the required drain spacing can be calculated according to the Hooghoudt theory. To determine this distance first the drainage depth has to be established. This drainage depth is the distance between the groundwater level midway between the drains and the surface. This depth should be chosen in accordance with the demands of the crops. Examples of desired drainage depth for some general kinds of land use are listed in Table II.9. When the drainage depth is chosen the Hooghoudt Formula is used to calculate the distance between parallel drains.

$$L^2 = \frac{8\,k.d.h. + 4\,k.d.h.}{q}$$

In which formula :

L	=	distance between drains	(m)
K	=	hydraulic conductivity	(m/day)
h	=	difference between water level halfway between the ditches and water level in the ditches.	(m)
q	=	drainage criterion	(m/day)
d	=	depth of 'equivalent layer'	(m)

To establish the value of d nomogram II.11A has to be used, which gives d as a function of L, U (wet cross-sectional area of ditch) and D (depth between water level in ditch and an impervious layer) When this is done L can be calculated. Also use can be made of general nomograms as II. 11B,C

II.4 Drainage of Saline Soils

Many factors contribute to the development of saline soil conditions. Salinity is caused by evapotranspiration of water by plants and soils and insufficient leaching of salts remaining in the rootzone after evapotranspiration. Salt concentrations in soil vary widely both vertically and horizontally depending on such conditions as variations in texture and hydraulic conductivity. The extent of salinization is governed by the rate of evapotranspiration of saline water and the counteraction of leaching water from precipitation flooding and irrigation. For soils which are irrigated with irrigation water in which salt is present a certain amount of water extra to the amount needed to satisfy evapotranspiration should percolate through the soil to remove salt from it. This process of removing salts from a soil is called leaching. When this leaching would not exist the salt from the irrigation water would remain and accumulate in the soil and render it unsuitable for agriulcture.

The same applies to soils in low lying coastal areas where intrusion from seawater through pervious substrata is likely, as is the case in many coastal areas in Jamaica. Once soils under such conditions are drained a permanent downward water flow through the soil profile should be established. The amount of water which should percolate with the aim to remove excess salts is the leaching requirement :

For planning purposes, the leaching requirement may be determined from the equation :

$$LR = \frac{EC_{iw} \times 100}{EC_{dw}}$$

LR =	leaching requirement in % of total applied irrigation water.	
EC_{iw}	electrical conductivity irrigation water	mmho/cm
EC_{dw}	electrical conductivity drainage water	"

In Table II.12 acceptable salinity levels for different crops are listed. Levels of salinity are expressed as the electrical conductivity as measured in the saturated extract. When the leaching . . . * amount of water to percolate through the soil and reach the drains. Calculations based on certain models also can be made to estimate the time needed to desalinise soils. They are not explained here, but reference is made to the Meylersfield report, as prepared by the Planning Unit West.

* requirement is known it can be calculated what the drain spacing should be in order to facilitate this . . . . . .

NOMOGRAPH II - 11A
FOR THE DETERMINATION OF THE EQUIVALENT DEPTH (d)

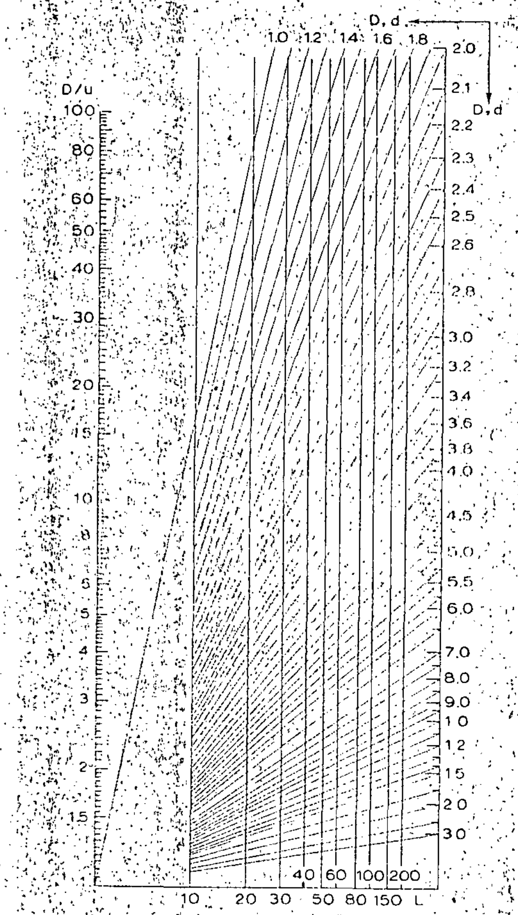
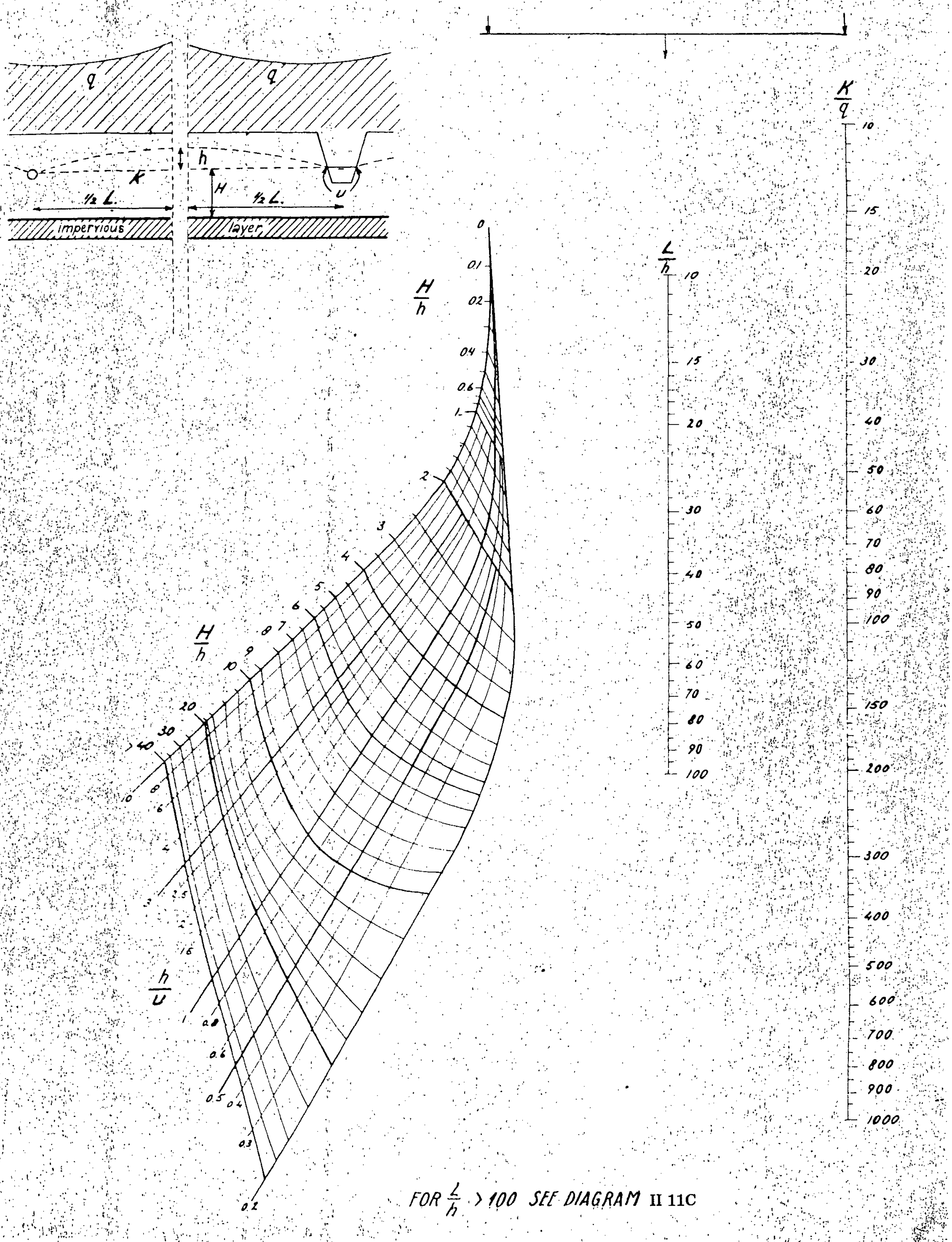


TABLE II. 9
DESIRABLE GROUNDWATER DEPTH (M)

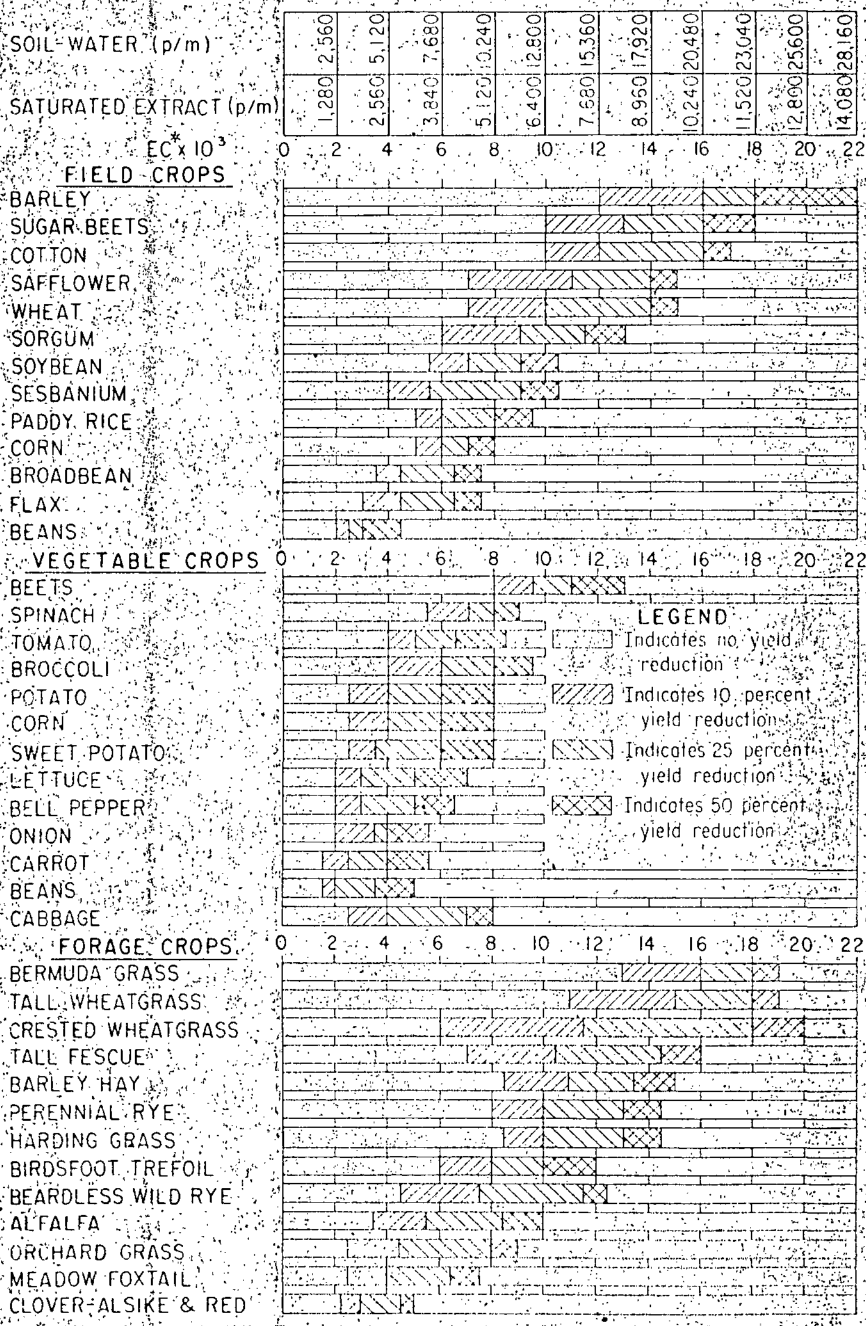
Grass	0.30 - 0.40
Vegetables	0.50 - 0.70
Corn	0.70 - 0.80
Orchards	0.50 - 0.70
Bananas	0.70 - 1.00
Sugar Cane	0.70 - 1.00

NOMOGRAM II - 11B
DETERMINATION OF DRAIN SPACING



FOR $\frac{L}{h}$ > 100 SEE DIAGRAM II 11C

Table II. 12—*Salt tolerance for field, vegetable, and forage crops.*



EC* = Electrical conductivity in millimhos per centimeter at 25° C.

III. Irrigation

1. Objectives

Irrigation can be defined as the provisions, measures and activities, of a temporary as well as a permanent nature, aiming at the supply of water, in some cases together with other matters, to the soil, respectively to the plant in order to promote or maintain the growth of crops.

This is the main objective. However irrigation can have additional objectives such as :

- the supply and distribution of water for the improvement of other environmental conditions, such as soil or plant temperature, the salt content of the soil or prevention of night frost.
- the conveyance by means of water, of nutritious or protective elements such as fertilizer, riversilt.
- saturation of the soil for puddling (used in paddy fields).

2. Disadvantages

Irrigation may have under certain circumstances, unfavourable effects on the physical, chemical or biological properties of the soil, on the quality and the level of groundwater, or on the environment of man and plant. These effects are most significant in areas where an insufficient water control is excercised so that the supply of water is in excess of the quantities utilized by the plants, evaporated and drained. By means of good water management and through the selection of suitable irrigation methods the unfavourable consequences of irrigation can usually be avoided or reduced. Some unfavourable side effects are :

1 Deterioration of soils

Due to the application of large quantities of water,in unstable soils a loss of structure and a dispersion of fine particles in the upper layers may occur.

2. Erosion

Irrigation on fairly to steeply sloping lands can cause erosion, particularly when excessive water is applied or if the ground surface is not properly prepared. Especially when long furrows are used the flow in the furrow will be relatively large and will have a high stream velocity at the upper end. Soil material will then be removed to the lower end of the furrow.

3. High Groundwater Table and Salinity.

Irrigation often introduces drainage problems when the existing drainage system of the area, either natural or artificial is not adjusted to the discharge of additional quantities caused by excess irrigation. Furthermore, irrigation supplies usually carry salts in solution, which after evaporation of the water, remain in the soil or are transmitted to the groundwater. These salts if accumulated over a certain period of time may reach a concentration harmful to plants. Salinisation can also be caused by a groundwater table, that reaches close to the surface, in which situation a continuous transport of salts to the rootzone will take place by capillary action.

4. Plant Diseases and Insect Problems

The change in the plant environment causing a higher humidity both in the soil, and usually temporarily, in the surrounding air may cause new diseases and insect problems to occur.

3. Irrigation Capacity and Water Requirement

For the design and the operation of an irrigation system the water quantities must be known, that are required for a period of one year or for the growing season as well as for shorter periods such as a calendar month, a decade or week, and a day.

Water requirements for a crop are to a large extent governed by the evapotranspiration, the sum of the transpiration of the plants and the evaporation from the soil surface and the leaves. Another term used is : consumptive use. The potential evapotranspiration Ep of a crop is defined as the evapotranspiration under conditions of optimum availability of water.

The actual evapotranspiration Ea is the evapotranspiration occurring in reality for a given crop and soil, and under the moisture conditions existing at the relevant moment. The actual evaporation; can be related to a so-called energy-indicator. Examples of energy indicators are: Pan evaporation; product of daylight duration and mean day temperature (Blaney-Criddle Method). or the evaporation of a thin layer of water on the leaves of the crop (Penman Method).

The actual evapotranspiration is:

$$E_a = C_1 \times C_2 \times C_3 \times E$$

where:

- C_1 = the crop coefficient, depending on the crop and the energy indicator applied.
- C_2 = the phase coefficient, depending on the phase of growth, with maximum value equal to unity.
- C_3 = the moisture coefficient, depending on the moisture content of the rootzone, with maximum value equal to unity.
- E = energy indicator.

In Jamaica some meteorological stations are measuring open pan evaporation (Class A-pan). Another method used in Jamaica is the Blaney Criddle Method.

For the calculation of an irrigation systems' capacity it is safe to assume C_2 and C_3 both to be unity. Therefore only C_1 needs to be known to convert the energy indicator E into a potential optimal (beacuse C_2 and C_3 are unity) evapotranspiration $Epo = C_1.E$.

Table III. 1 gives C_1 values for different crops and energy indicators.

TABLE III.1

C_1 VALUES FOR DIFFERENT CROPS

Energy Indicator	Penman	Blaney-Criddle	Class A pan
Rice	1.1	1.2	1.0
Grass	1.0	1.1	0.9
Alfalfa	1.2	1.3	1.1
Cotton	1.0	1.1	0.95
Vegetables	0.7	0.8	0.7
Corn	0.9	1.0	0.9
Treecrops	1.1	1.2	1.0
Cane	1.3	1.4	1.2
Wheat	0.8	0.9	0.75

The application depth is the amount of water which is supplied to the crop at every irrigation gift. It is determined by:

1. the depth of the rootzone for the specific crop and its relevant growth phase.

2. the retention capacity of the soil between field capacity and wilting point*.

3. the degree to which the soil profile is allowed to dry up.

* *Field Capacity: Is that soil moisture percentage that is held by the soil against gravity forces.*
Wilting point: that soil moisture percentage at which plants start wilting.

Therefore the application depth of irrigation water as expressed as the depth in mm of the layer of water applied to the field can be established as:

$$W_n = \frac{F_c - W_p}{100} \times \frac{U}{100} \times D$$

Where	Fc	=	field capacity	(vol. %)
	Wp	=	wilting point	(vol. %)
	U	=	degree of depletion of available moisture (%)	
	D	=	depth of rootzone	(mm)
	Wn	=	net application gift	(mm)

In Table III.2 for different crops their rooting depths are listed.

Table III.2
Rooting Depths for Different Crops (cm)

Alfalfa	180	Cotton	150	lettuce	30	Orchard	150
Beans	120	Grain	150	Melons	100	Pasture	60
Citrus	120	Sorghum	150	Onions	30	Potatoes	180
Tobacco	100	Vegetables	70	Rice	60	Sudan Grass	180
Coffee	150	Lemons	100	Oranges	125	Sugar Cane	180

It is safe to take the allowable degree of depletion as 50%. In this way optimum plant growth is assured. The irrigation interval, which is the time between two irrigation gifts than can be calculated by dividing the net application by the potential optimal evapotranspiration

$$n = \frac{W_n}{Epo} = \frac{W_n}{C_1 \times E}$$

Where :	n	=	irrigation interval in days	
	Wn	=	net application depth	(mm)
	Epo	=	potential optimum evapotranspiration	(mm/day)

It should be noted that in many irrigation schemes allowances should be made for special purposes i.e.

- Salinity Control. As explained in Section II.4 sometimes an additional amount of irrigation water is needed to supress a possible salinisation of the area.

- Percolation Percolation is the downward movement of water through the rootzone to the subsoil. A phenomenon common to rice fields.. Based on field tests this percolation should be ascertained and incorporated in the system design.

- Land Preparation. In rice cultivation the soil is often prepared by puddling. This is carried out best at a moisture content between field capacity and saturation. This requires additional water.

The amount of water which should be available and for which the system should be designed, is influenced by the efficiency of the system, because during the conveyance of the water from source to rootzone a certain percentage is lost. The technical efficiency is defined as the ratio between the portion that becomes available for beneficial utilization and the supplied quantity. In this way we can distinguish :

- the field application efficiency: e_a
- the farm ditches efficiency: e_b
- the canal or conveyance efficiency: e_c

In Table III.3 $e_a \times e_b$ values are listed for different soil types and irrigation methods. The overall irrigation efficiency now is :

$$e_p = e_a \times e_b \times e_c$$

The canal - or conveyance efficiency is generally in the order of 90%
The volume of required irrigation water for a given area, with different crops is given by the following equation :

$$V_i = \sum^{ni} \left(10\ Epo.\ A_i \frac{100 + a}{100} \right) \frac{1}{e_p}$$

Where :	V_i	=	irrigation supply	m^3
	n_i	=	number of crops	
	E_{po}	=	optimum potential evapotranspiration for crop n	mm
	A_i	=	area of crop n	
	a	=	additional irrigation percentage for special purpose	%
	e_p	=	project efficiency	%

Table III-3.

Average farm-irrigation efficiencies in per cent
for various surface irrigation methods
(well engineered and well managed irrigation systems)

Soil conditions	Border	Furrows, corrugations	Flooding from contour ditches	Basins
1. Sandy soils				
a. well-graded	60	40-50	45	70
b. insufficient grade	40-50	35	30	-
c. rolling or steep		20-35	20	-
2. Medium textures, deep				
a. well graded	70-75	65	55	70
b. insufficient grade	50-60	55	45	
c. rolling or steep	-	35	35	
3. Medium textur, shallow				
a. well graded	65	50	45	60
b. insufficient grade	40-50	35	35	-
c. rolling or steep	-	30	30	-
4. Heavy soils				
a. well graded	60	65	50	60
b. insufficient grade	40-50	55	45	-
c. rolling or steep	-	35-45	30	-

Farm irrigation efficiency – the percentage of irrigation water delivered at the farm headgate that is stored in the soil and available for consumptive use by the crops.

ref. J.Keller. Journal Irr.Dr.Div. 91, IR 2, June 1965, 62-73. A. S. C. E.

II.4 Water Resources

1. Water Quantity

The two main resources from which irrigation water can be obtained are surface water, such as a river of spring, and groundwater.

a. Surface Water:

Only in a few cases springs feed directly into the irrigation system and than only for limited areas in valleys or near foothills. Most of the springs contribute to riverflow. The major supply of irrigation water is derived from rivers. If the diversion from the river and transportation to the fields is taking place by gravity such a system is indicated as gravity irrigation. If at one or more places the water is lifted by means of pumps the system concerned is one of lift irrigation. Intake works (or head works) can be designed in several ways. The most simple solution is an open intake in the river bank with no control over river level. A better solution is to have a gate at the intake. The best solution is to have a diversion dam across the river which results in a guaranteed water supply to the irrigation system. To asses the reliability of the water supply, flow data should be compiled and analysed in a similar way as rainfall data, When no data are available as for small streams, flow measurements can be carried out in extreme dry periods to get an impression of the minimum flow on which can be counted. A simple field method is the float method: a floating object is placed in the water course and its travelling speed is measure-ed. Multiplied with the wet cross-sectional area and a correction factor of 0.7 gives an estimate of the discharge. A better method is the use of a current meter, which gives an accurate estimate of the stream velocity. Measurements preferably should be taken at 0.2 and 0.8 times the total water depth and the average of these two values taken as the mean velocity in the cross-section. Multiplied by the wet cross-sectional area this gives the discharge.

b. Groundwater

Groundwater is found nearly all over the world, but can be utilized in an economic way in relatively small areas only; wherever it is confined in impermeable formations, it will not flow towards boreholes or galleries. The best opportunities exist in geological structures wherein the groundwater is moving, although often at a very limited velocity. Sand and gravel deposits usually yield reasonable high outputs, whereas in clay and silt the permeability restricts the flow towards the well to the extent that only a small continuous flow will result. Sometimes soft porous sandstone can be exploited if sufficient cracks provide for a certain degree of permeability. The groundwater exploration takes place by test drilling and pumping tests, but, furthermore, by applying various geophysical methods, such as electric resistance measurements and seismic recording. These latter methods will in first instance give qualitative indications, which together with the results of drilling and pumping tests can be interpreted.

In planning the extraction of groundwater on a large scale a thorough study must be carried out regarding the question whether the extraction will cause a sufficient inflow into the area. Without an inflow at equilibrium with the yield, the aquifer will become exhausted within a shorter or longer period In various areas of the Western United States this exhaustion takes place. A second important consequence of the pumping of groundwater may be a decrease of the river run-off, due to the lowering of the piezemetric head, At present, therefore, it is generally accepted that the utilization of surface and groundwater resources must be studied as an entity. In an integrated planning of surface and subsoil resources the conclusion can be reached that a seasonal surplus of surface flow, e.g. during the rainy season, can best be stored in a subsurface reservoir. At a later time this stock will be withdrawn by pumping, thus the capital cost of a reservoir dam, if topographically feasible, can be saved, but in-stead hereof the operational pumping cost must be included in the estimates.

2. Water quality

Before any final decision can be taken with respect to the execution of an irrigation plan, clear evidence must be available that the water resources envisaged to be utilized will not have any harmful effects on the crops and on the people who will have to handle the water.
The quality of the irrigation water will be determined by a number of characteristic analyses, the most important ones hereof are the following :

i. concentration of dissolved solids gives a first preliminary judgement as to the water suitability. The total dissolved solids (T.D.S.) are sometimes expressed in parts per million (p.p.m. = $mg.l^{-1}$), but more common, due to a simpler determination, the concentration is measured by the electrical conductivity (EC) in micromhos. per cm at 25°C.

For many rivers it is found that :

$$\text{T. D. S. (p.p.m.)} = 0.65 \text{ EC } (\mu\text{mhos.cm}^{-1})$$

The U.S. Salinity Laboratory at Riverside (Cal.) distinguishes the following T. D. S. -classes:

C_1	$EC < 250\ \mu mhos.cm^{-1}$	low salinity	
C_2	$250 < EC < 750$	"	medium "
C_3	$750 < EC < 2250$	"	high "
C_4	$2250 < EC$	"	very high "

In case more or less saline irrigation water is used, an additional quantity is required on top of the plant requirement in order to maintain a salt-equilibrium in the soil moisture. This additional quantity can be supplied by rainfall, but in arid climates it usually consists of an extra depth of irrigation.
The additional quantity for the clasees C_1 and C_2 is limited but depends on the salt sensitiveness of the crop and the salinity level of the soil moisture related to it.

The quantity required for leaching with C_3 -water may be substantial and, therefore, increases the drainage requirements, whereas water of C_4-class must be avoided as far as possible. If no better quality is available and C_4-water is used, special drainage measures must be taken and the choice of crops will be restricted to salt tolerant crops.

ii. sodium adsorption-ratio is the second important test, which may never be passed over. The decisive factor in this respect is the possible effect that the Na^+ ion can have on the soil structure of clays, by which this structure may be destroyed and the soil becomes nearly impermeable in wet condition. This process depends on the degree in which the sodium will be exchangeable as defined by the sodium adsorption ratio (S.A.R.):

$$S.A.R. = \frac{Na^+}{\sqrt{\frac{Ca^{++} + Mg^{++}}{2}}} \quad \text{(conc. of Na, Mg and Ca meq./1)}$$

The S.A.R. -value can be determined with the aid of the nomogram of Fig. III.4 when the concentration of Na, Mg and Ca are given in $meq.l^{-1}$. This nomogram, furthermore, shows a scale of the exchangeable sodium percentage (E.S.P) of the soil which will be at equilibrium with the irrigation water. The E.S.P. is determined empirically by the Riverside laboratory.

Also for the S.A.R. four classes are introduced

S_1			SAR	<	3-10	low sodium hazard	
S_2	3 -10	<	SAR	<	7-18	medium	" "
S_3	7-18	<	SAR	<	11-26	high	" "
S_4	11-26	<	SAR			very high	" "

The differences in the class limits are determined by the T.D.S. value, as the adverse effects of the sodium appear already at a lower S.A.R. value when the total salt concentration is high than in case of a small total concentration. The suitability of the water is therefore considered on the combined classification of T.D.S. and S.A.R. This suitability is further depending on the texture of the soil. Clay soils are more vulnerable than sandy soils, therefore class S_2 may be acceptable on light soils whereas it may be dangerous for clays. S_3 and S_4 water can only be utilized in combination with special treatment of the soil and with good drainage (Fig. III.5)

iii. bicarbonate concentration can affect the final S.A.R. -value as HCO_3^- can react with Ca^{++} and precipitate as $CaCO_3$. Thus the sodium concentration is relatively increased and the S.A.R. will be larger than originally determined. Therefore in cases that a high bicarbonate concentration is found, special attention should be given to the resulting sodium hazard.

III.6 Irrigation Methods

Various methods of applying water to the rootzone of crops are used. The methods may be grouped into four broad classifications :

- surface irrigation
- subsurface irrigation
- trickle irrigation
- sprinkle irrigation (See Fig. III.6)

Surface irrigation is most widely used for irrigating crops and can be used on most irrigable soils and for nearly all crops. Sprinkler and trickle irrigation can be employed for most soil and topographic conditions and for those areas where surface irrigation may be inefficient. Sometimes an irrigation method is determined by a certain limiting condition which precludes other methods leaving no alternative (e.g. surface irrigation for rice). The economic factor is often the governing one in the choice of a specific method.

SURFACE IRRIGATION

Surface irrigation is a method of irrigation in which water is applied over the soil surface.

a. Flood water spreading

A method of surface irrigation practised in areas through which rivers run which are dry for the greater part of the year, except during the rainly season when a torrential flow with heavily silted water is coming down. This water is spread out over the land adjoining the rivers, sometimes, cheap type of headworks are constructed diverting spate water into canals leading to embanked fields. Crops are then grown on the moisture left behind in the soil. Normally, one such spreading has to suffice for the whole growing period of the crops.

b. Flood irrigation

A method of surface irrigation in which during flood time river waters are let into natural depressions (basins) adjoining the rivers by means of a canal network, submerging the land to a considerable depth. The water is retained in the basins for a certain period. When the level of water has been subsided sufficiently, the water, in so far it has not evaporated or been absorbed by the soil, is discharged back into the river, and crops are grown receiving no other irrigation. After the harvest the land lies fallow until the next season.

c. Level irrigation (sometimes referred to as check irrigation).

The level irrigation methods are based on the rapid application of irrigation water to a level or nearly level area enclosed by dikes or plant beds: basins (block checks) or ponding-up furrows (furrow checks).

IRRIGATION METHODS

- SPRINKLER IRRIGATION
  - OSCILLATING NOZZLE LINES
  - PERFORATED PIPES
  - ROTATION SPRINKLERS
  - FIXED HEAD SPRINKLERS
- SURFACE IRRIGATION
  - FLOOD WATER SPREADING
  - FLOOD IRRIGATION
  - LEVEL IRRIGATION
  - FLOW IRRIGATION
- TRICKLE IRRIGATION
  - DRIP DELIVERY
  - TRENCH DELIVERY
  - OOZY DELIVERY
- SUBSURFACE IRRIGATION
  - SUBSURFACE IRRIGATION BY WATER-TABLE CONTROL
  - SUBSURFACE IRRIGATION BY POROUS TUBES

Fig III-6

respectively. The areas are filled with water to the desired depth and the water is retained in that area until infiltrated (non-rice crops) or for long periods (paddy rice).

Many different kinds of crops can be irrigated by the level irrigation method. Apart from irrigated rice, basins are used to irrigate close growing crops like cereals, ponding-up furrows are used to irrigate row crops like cotton, ground-nuts, potatoes, etc. Ponding-up furrows are used especially in case crops are sensitive to wet soil conditions around the stem of the plants or in case the soil crusts badly when flooded.

The level irrigation method is used on many different kinds of soil. The method is best suited to soils having a moderate to low infiltration rate and a moderate to high available moisture holding capacity. Although an efficient system for water application by using the level irrigation method can be designed for soils having a high infiltration rate and a low available moisture holding capacity, the basins and ponding-up furrows will be rather small. This necessitates the construction of a dense system of delivery and drainage ditches which system will interfere with cultural practices.

Concerning the topography, flat areas with slopes less than $2^{o}/oo$ are best suited to this method of irrigation and give the best field layouts. On sloping lands, flow irrigation methods will be used preferably, although contour checks can be constructed by terracing the land.

d Flow irrigation

The basic principle of flow irrigation is that the irrigation water is delivered into the field and flows over the land whilst infiltrating into the soil. Methods of flow irrigation are commonly used on sloping land with slopes ranging from 2 to $40^{o}/oo$ and in some cases on even steeper slopes.

Using flow irrigation methods, deep percolation losses and surface runoff losses will be unavoidable.*

Wild flooding is an uncontrolled flow irrigation method. The water is supplied to the land from openings in field ditches, which run approximately along the contours. The distance between the field ditches and the spacing of the openings depends on the land slope, the nature of the soil and the crop, and on the stream size. Since the water is flowing without any levees to guide it or otherwise to restrict its movement over land which is not levelled, destruction of the land by erosion may take place. Wild flooding gives an uneven spreading of the water over the land and, hence, a very non-uniform application; efficiencies are, in general, very low. The method of wild flooding is practiced for the irrigation of close growing crops (small grains and pastures) in areas where irrigation water is abundant and inexpensive and where equipment for land-levelling is not available.

* *In order to arrive at an efficient use of the water that length of run should be selected at which the total losses are minimal. At this length (the optimal length of run) the application efficiency will be maximal.*

Contour ditch irrigation differs in so far from wild flooding, that more attention is paid to the supply of water to the land and to the movement of the water over the land. Some land preparation is carried out by filling-up depressions and cutting-off knolls. Water is brought into the field from supply ditches running along the contours of the land. Intermediate ditches take care of the redistribution of the water in lateral direction. The contour ditch irrigation method is used too for the irrigation of close growing crops. Application efficiencies are generally low.

In using the borderstrip method of irrigation, the area to be irrigated is divided into strips by constructing low dikes: levees or border checks. These levees restrict the lateral movement of the water, causing it to flow to the end of the field. In reality, the borderstrips are wide, shallow channels in which the water flows from the head ditch to the end of the borderstrip in an elongating thin sheet, moistening the soil as it goes.

This method of flow irrigation is suitable for irrigation of all close-growing or drilled crops, except rice grown in ponded water. Border strip irrigation can be used on most soils. It is best suited to soils that have a moderately low to moderately high infiltration rate. Usually, it is not used for coarse sandy soils that have a very high infiltration rate because of the limitations in design. Nor is it well suited to soils having a very low infiltration rate since to provide adequate infiltration time the irrigation stream has to be applied for a long period, which is causing excessive surface runoff losses, or the stream has to be so small that complete coverage of the borderstrip is not assured. The borderstrip irrigation method is commonly used when slopes in the direction of irrigation parallel to the levees range from 2 to 10 $^{o}/_{oo}$, to as much as 40 $^{o}/_{oo}$ for pasture lands. If the natural slope perpendicular to the contourlines is too steep, bench borders (borderstrips across the contour lines on a controlled grade) can be constructed. The topography must be relatively smooth or the soils deep enough for adequate levelling. In some areas land levelling costs may be high enough to exclude the use of the borderstrip irrigation method. Table III.7 gives recommended dimensions for borders on different soil types.

Irrigation by the furrow methods is accomplished by running water in small, paralled ditches (furrow) that carry the water as it moves down the slope of the field. The water infiltrates into the bottom and the sides of the furrows to provide the desired wetting of the rootzone soil. In contrast with borderstrip irrigation , furrow irrigation does not wet the entire soil surface, thus lessening the puddling of heavy soils. Furrows are particularly well adapted to irrigate crops which are subject to injury from water covering the stems ofthe plants. Row crops, such as vegetables, cotton, potatoes, maize, etc. planted on ridges, are generally irrigated by furrows. The furrow irrigation method can be used on all soils except coarse sands that have very high infiltration rates and provides a very poor lateral distribution of water between the furrows. The method must be used with extreme care on soils that have high concentrations of soluble salts, because excessive amounts of salts may accumulate in the ridges between the furrows. This is also a hazard when irrigation water is used containing salts.

Table III-7

Soil Type	Per cent Slope	Unit flow per meter width of border	Average depth of water applied	Strip Check Width	Strip Check Length
Dimensions for strip checks (borders), deep rooted crops					
	m per 100 m	liters per sec	mm	metres	metres
Sand - Infiltration rate of 2.5 +cm per hour	.2 - .4	10 - 15	100	12 - 30	60 - 90
	.4 - .6	8 - 10	100	9 - 12	60 - 90
	.6 - 1.0	5 - 8	100	6 - 9	75
Loamy sand - Infiltration rate of 1.8 to 2.5 cm per hour	.2 - .4	7 - 10	125	12 - 30	75 -150
	.4 - .6	5 - 8	125	9 - 12	75 -150
	.6 - 1.0	3 - 6	125	6 - 9	75
Sandy loam - Infiltration rate of 1.2 to 1.8 cm per hour	.2 - .4	5 - 7	150	12 - 30	90 -250
	.4 - .6	4 - 6	160	6 - 12	90 -180
	.6 - 1.0	2 - 4	160	6	90
Clay loam - Infiltration rate of 0.6 to 0.8 cm per hour	.2 - .4	3 - 4	175	12 - 30	180 -300
	.4 - .6	2 - 3	175	6 - 12	90 -180
	.6 - 1.0	1 - 2	175	6	90
Clay - Infiltration rate of .25 to 0.6 cm per hour	.2 - .3	2 - 4	200	12 - 30	350 +
Same, Shallow rooted crops					
Clay loam - 0.6 meter deep over permeable subsoil	0.15-0.6	6 - 8	50-100	5 - 18	90 - 180
	0.6 -1.5	4 - 6	50-100	5 - 6	90 - 180
	1.5-4.0	2 - 4	50-100	5 - 6	90
Clay - 0.6 meter deep over permeable subsoil	0.15-0.6	3 - 4	100-150	5 - 18	180 - 300
	0.6 -1.5	2 - 3	100-150	5 - 6	180 - 300
	1.5 -4.0	1 - 2	100-150	5 - 6	180
Loam- 0.15 to 0.45 meter deep over hardpan	1.0-4.0	1 - 4	25- 75	5 - 6	90 - 300

Furrow irrigation is adaptable to a great variation in land slope. The method is best suited to sites where the furrow slope does not exceed 20 ^{o}/oo, provided erosion from rainfall is not a hazard. Contour furrows make it possible to irrigate successfully lands having slopes up to 40 ^{o}/oo or even more when deep furrows are used without causing erosion. Under this condition water flowing in furrows directly down the slope would do serious damage. Water can be applied most efficiently if the furrows have a uniform slope.
Different furrow shapes may be used to achieve special results. The most common furrow shape is the V-shape. Such furrows, 15 to 20 cm. deep and 25 - 30 cm wide, will normally carry a flow of about 3 l sec. $^{-1}$ when used on slopes not exceeding 3 ^{o}/oo. Shallow furrows are often used to wet the soil near the surface of the ridges for [illegible] the germination of the seeds. For deep rooted crops deep furrows can be used. Broad-based furrows are sometimes used to increase the infiltration rate of the furrows on heavy soils. Maximum and recommended lengths of furrows are listed in Tables III.8 and III.9.

The spacing of the furrows will depend upon the wetting pattern that is obtained by the lateral movement of water in the soil, the crop to be irrigated and the type of tillage equipment employed. However, the main objective in selecting furrow spacing is to make sure that the lateral movement of the water between adjacent rows will wet the entire effective rootzone of the crop. The lateral movement of water in the soil is realized by the capillary force of the soil. In general the finer the texture, the higher the capillary force, the further the lateral movement of water, the wider the furrow spacing. Profile restrictions like a hard/ to spread out the water sideways. Table III.10 gives values concerning furrow spacings for common soil types, which can be used in design. Field observations concerning the lateral movement ofthe water by digging a trench or by making soil borings perpendicular to the furrows should be carried out to see whether the selected furrow spacing is adequate.
The length of the furrows depends on the factors mentioned earlier. The length of a furrow may be as short as about 50 m. for shallow rooted crops cultivated on soils having a high infiltration rate or as much as 400m. or even more for deep rooted crops grown on soils with low infiltration rates. Table III.9 gives relationships between the basic variables in furrow irrigation, which can be used as guides for designing. The values given are only indicative/ for instance, the maximum allowable non-erosive furrow stream depends not only on the slope, but also on the degree of cohesion of the soil particles, the degree of consolidation of the furrow, the furrow shape, etc. Field trials as described before should be carried out to determine the optimum length of the furrow under the local conditions.

<u>The corrugation irrigation method</u> can be seen as a variation of the furrow irrigation//close growing crops such as small grains and pastures on steep slopes. The corrugations, usually about 10 cm deep, form the major water channels, but often some flooding between the corrugations takes place. The spacing between the corrugations depend on the lateral movement of the water in the soil. The corrugations should run in the direction of the steepest slope because they are easily blocked. Existence of cross-slopes could result in serious erosion. On pasture land corrugations may be used on slopes of 10%

pan or a compact subsoil will tend to slow down the downward movement and. . .

// method. In this method small furrows or corrugations are used for irrigating...

Table III-8

Maximum lengths of cultivated furrows in metres

Furrow Slope per cents	Clays				Loams				Sands			
	Average depth of water applied - cm											
	7.5	15	22.5	30	5	10	15	20	5	7.5	10	12.5
0.5	300	400	400	400	120	270	400	400	60	90	150	190
.1	340	440	470	500	180	340	440	470	90	120	190	220
.2	370	470	530	620	220	370	470	530	120	190	250	300
.3	400	500	620	800	280	400	500	600	150	220	280	400
.5	400	500	560	750	280	370	470	530	120	190	250	300
1.0	280	400	500	600	250	300	370	470	90	150	220	250
1.5	250	340	430	500	220	280	340	400	80	120	190	220
2.0	220	270	340	400	180	250	300	340	60	90	150	190

Length and spacing of corrugations in metres

Slope per cent	Heavy-textured clay soils		Medium-textured loam soils		Light textured sandy soils	
	Length	Spacing	Length	Spacing	Length	Spacing
Deep-rooted crops or shallow soils						
2	180	.75	130	.75	70	.60
4	120	.65	90	.75	45	.55
6	90	.55	75	.65	40	.50
8	85	.55	60	.55	30	.45
10	75	.50	50	.50		
Shallow-rooted crops or deep soils						
2	120	.60	90	.60	45	.45
4	85	.55	60	.55	30	.45
6	70	.55	50	.50		
8	60	.50	45	.45		
10	55	.45	40	.45		

Table III-9

SUGGESTED LENGTHS OF CULTIVATED FURROWS

FOR DIFFERENT SOILS, SLOPES AND DEPTHS OF APPLICATION

SOIL TEXTURE :		COARSE			MEDIUM				FINE		
FURROW SLOPE	MAX. ALLOWABLE NON EROSIVE FURROW STREAM	DEPTH OF APPLICATION (in mm.)									
0/00	1/sec	30	50	100	30	50	100	150	50	100	150
		SUGGESTED FURROW LENGTH (in m.)									
2.5	3.0	75	100	140	125	160	210	290	230	300	400
5.0	2.0	70	90	125	115	145	190	260	210	270	360
7.5	1.5	60	70	100	90	120	160	215	175	230	300
10	1.0	50	60	85	75	100	135	180	145	195	260
15	0.7	–	50	70	60	85	115	150	120	165	220
20	0.5	–	–	60	50	70	95	125	100	140	190

Remark: in case of erosion hazard from rainfall, the use of slopes steeper than 5 0/00 (fine textured soils) to 7.5 0/00 (coarse textured soils) is not recommended.

Table III-10

RECOMMENDED FURROW SPACING FOR SOME SOIL TYPES

SOIL TYPE	PROFILE	FURROW SPACING
coarse sands	uniform profile	0.30 m.
coarse sands	compact subsoil	0.45 m.
fine sands to sandy loams	uniform profile	0.60 m.
fine sands to sandy loams	more compact subsoil	0.75 m.
medium sandy-silt loams	uniform profile	0.90 m.
medium sandy-silt loams	more compact subsoil	1.00 m.
silty clay loam	uniform profile	1.20 m.
very heavy clay	uniform profile	0.90 m.

without causing significant erosion. The corrugation irrigation method is particularly good for soils that have low infiltration rates or that disperse when flooded, resulting in a hard surface crust upon drying. Corrugations can temporarily be used on borderstrips for a germination in order to avoid seedbed erosion,recommended lengths are given in Table III.8.

SUBSURFACE IRRIGATION

Subsurface irrigation is a method of irrigation in which water is applied be-low the soil surface. Also referred to as "subirrigation" or "Subsoil irrigation."

Subsurface irrigation by watertable control

A method of subsurface irrigation in which a (artificial) watertable by means of open ditches, drain pipes or mole chains is maintained at a pre determined depth, depending on the rooting characteristics of the crop grown. Moisture reaches the rootzone through upward capillary movement.

b. Subsurface irrigation by porous tubes

A method of subsurface irrigation in which the rootzone is wetted by perforated or porous tubes installed in the rootzone, A great disadvantage of this method is that the pores of the tubes can become choked. Apart from the fact that in such a case the tube has to be replaced, choking can easily be detected: wilting plants may be the first indication.

TRICKLE IRRIGATION

Trickle irrigation is a method of irrigation in which the wetting of the soil is restricted to the rootzone of the crop as well invertical as in horizontal direction. In general tricke irrigation is accomplished by tubes placed on the soil surface at close proximity to the croprows, so that the water is supplied only to that volume of soil in which the root intensity is largest. Water is conveyed in the tubes under low pressure, commonly in the range of 0.2 - 1.5 atm.

a. Drip Delivery

A type of trickle irrigation in which on the tubes nozzles or capillary pipes are fastened or perforated elements form a part of the tube. In the nozzle perforated elements or capillary pipes the water moves through a narrow slit or along an elongated path, which results in a reduction of pressure causing the water to drip out at a slow rate, commonly 2 - 4 $l.h^{-1}$, sometimes 10 $l.h.^{-1}$. The water infiltrates around the orifice into the soil. A disadvantage of this type of trickle irrigation is that the orifices become easily choked.

b. Trench Delivery

A type of trickle irrigation in which nozzles are placed on the tube.

The diameter of the nozzles on one tube may vary between 1.6 mm at the head and 2.1 mm at the end of the tube in order to deliver and equal discharge. The nozzles discharge the water at a rate of 36 to 72.l/hr depending on the kind of soil. Each nozzle supplies the water into a shallow trench, normally 5 m. long, from which the water infiltrates into the soil.The tubes are receiving water alternatively during several hours. The nozzles are not easily choked. Best suited to irrigate orchards.

c. Oozy Delivery

A type of trickle irrigation in which a porous (plastic) hose or a porous baked earthen pitcher is used. The water oozes slowly through the porous walls and infiltrates into the soil. The porous hose is laid out on the soil surface along the crop rows; the pitcher is buried to its neck in the soil and filled with clean water, the crops (vegetables) are grown around it.

SPRINKLER IRRIGATION

Sprinkler irrigation is a method of irrigation in which water is applied through the air. Also called "spray irrigation" and sometimes referred to as "overhead irrigation."

Types of sprinklers

- oscillating nozzle lime
  pipe provided with a single row of small nozzles and supported at 0.30 m. to 2 m. above the ground; the pipe can be rotated by means of an automatic device (hydro-driven) over an angle of 180° or less so that a rectangular strip of land is irrigated; most often used in nurseries.

pressure range	:	1.0 - 3.0 atm.
diameter nozzle	:	often about 1 mm.
nozzle capacity	:	0.03 - 0.10 m^3/hr.
spacing nozzles	:	0.6 - 1.5 m
width of coverage	:	8 - 20 m

- perforated pipe
  light portable tube laying on the ground with a great number of small perforations over the top side, irrigating a rectangular strip of land; sensitive to wind and to clogging of the perforations; used in some orchards and in truck crop nurseries.

pressure range	:	0.5 - 2.5 atm.
precipitation rate	:	15 - 25 mm/hr.
width of coverage	:	6 - 15 m

- fast rotating sprinkler (reaction or whirling sprinkler)
  sprinkler with one or two nozzles: the nozzle(s) is (are) so oriented that the reaction from the jet(s) in the nozzle pipe causes a fast rotation; suitable for irrigation in horti- and arboriculture.

pressure range	:	1.0 - 2.5 atm.
diameter nozzle	:	1.5 - 6 mm
sprinkler capacity	:	0.2 - 1.0 m^3/hr
diameter of coverage	:	6 - 20 m

- slow rotating sprinkler
  sprinkler consisting of one or two inclined nozzles mounted on a body which is rotated around a vertical axis by the action of a hammer blade, activated by the escaping water jet; some high pressure giant sprinklers are rotated by a water-activated gear drive; most agricultural sprinklers are of this type ; three categories can be distinguished:

  a) Small size intermediate pressure sprinkler

pressure range	:	2.5 - 4.0 atm.
diameter nozzle	:	3 - 6 mm
sprinkler capacity	:	1 - 3 m^3/hr
diameter of coverage	:	25 - 35 m

  b) Medium size intermediate pressure sprinkler

pressure range	:	3.0 - 4.5 m.
diameter nozzle	:	6 - 12 mm
sprinkler capacity	:	3 - 10 m^3/hr
diameter of coverage	:	35 - 50 m

  c) Large size high pressure sprinkler (giant sprinkler, sprinkler canon, raingun)

pressure range	:	5 - 9 atm.
diameter nozzle	:	15 - 45 mm
sprinkler capacity	:	20 - 250 m^3/hr
diameter of coverage	:	75 - 175 m

- fixed head sprinkler
  stationary sprinkler; various types; used for the irrigation of gardens and lawns (for example: pop-up fixed head sprinklers in sports fields).

Types of sprinkler systems

The basic elements of a sprinkler system are :

- supply network (main items: pump and distribution network with hydrants)
- sprinkler lines or sprinkler units

Sprinkler systems can be classified according to the way the basic elements of the system are installed :

- permanent system;system in which the supply network and the sprinkler lines are permanently installed, giving a complete coverage of the area to be irrigated; the distribution network is buried. Permanent systems are required for frost protection: they are not recommended for field crops unless sprinkler lines equiped with rising (telescopic) sprinklers a are installed at a depth of at least 0.40m below soil surface. Most permanent systems are found in orchards and vineyards.
- semi-mobile system; system in which the supply network is in a fixed position, while the sprinkler lines/sprinkler units are mobile. Most common sprinkler system in agriculture.
- mobile system; system in which both supply network and sprinkler lines/ sprinkler units are mobile. Useful for incidental irrigation in areas where extreme dry meteorological conditions requiring irrigation are occurring exceptionally.

pressure range	:	7 - 9 atm.
capacity	:	20 - 60 m^3/hr
irrigated area per position	:	1.5 - 2.5 ha.

Performance of sprinkler installation

- sprinkler capacity

$Q = 3600.c.\ A.\ \sqrt{2gH}$ m^3/hr

Q = sprinkler capacity	m^3/hr
c = discharge coefficient ($\pm$ 0.95)	
A = cross-sectional area nozzle opening(s)	m^2
H = pressure head in the sprinkler	m
g = acceleration due to gravity	m/sec^2

- required capacity sprinkler installation

$$Q_{max}\ (\text{area } A) = 10.\ \frac{W \times A}{t}\ m^3/hr$$

Q_{max} (area A)	= required capacity sprinkler installation area A	m^3/hr
W	= average gross irrigation requirement during peak irrigation period	mm/day
A	= acreage of area A	ha
t	= effective sprinkling hours per day	hrs/day

- required number of sprinklers

$$n = \frac{Q_{max}\ (\text{area A})}{Q}$$

- sprinkler spacing

  square arrangement
  rectangular arrangement (in case one wind direction prevails)
  triangular arrangement (best distribution pattern, but difficult in rearranging)

- precipitation rate

$$= 1000 \cdot \frac{Q}{a \cdot b} \quad \text{mm/hr}$$

i	= precipitation rate sprinkler installation	mm/hr
a	= sprinkler spacing on sprinkler line	m.
b	= spacing between sprinkler lines	m.

III.7 Pumps

Pumps essentially consist of two parts: a rotating part called a runner or impeller and a stationary part called a casing or housing. By applying power to the shaft of the runner, water can be displaced, as with an Archimedean screw, or can be forced into a rotary motion and led away under pressure, as with flow under pressure. The rotating pumps can further be divided according to whether the flow through the impeller is esentailly in a radial or an axial direction. The three types of flow pump that may be distinguished are: the radial flow or centrifugal pump the mixed flow pump, and the axial flow or impeller pump. Each type of water-lifting device has particular characteristics which make it the most suitable one under certain operating conditions.

1. Archimedean screws consist of a shaft to which one or more helically round blades are attached, placed in an accurately fitting casing. They are mainly used to lift water over limited elevations and in cases in which up-stream and downstream water levels do not change considerably.

2. Axial flow or impellar pump. In axial flow pumps, water flows almost axially towards the propellor type runner but is discharged with a tangential component. Guide vanes behind the impellor remove the swirl given to the water. These pumps are suited to lift large amounts of water over a limited elevation.

3. Centrifugal pump
A diesel or electromotor rotates an impellor fitted with vanes immersed in water and enclosed in a casing. Water enters the rotating impellor at the centre and discharges from the impellor into the casing with a combined radial and tangential flow. This type of pump is suited to lift water at a great head.

4. Mixed flow pumps
This pump discharges water at a moderate head because its shape is slightly different from a centrifugal pump. It is suited to lift small as well as large amounts of water at moderate head.
For all types of pumps a cross-section and a graphic presentation is given in Figs. III., II and III.12.

To choose a pump one should try to achieve the highest efficiency of a pump as is indicated in the pump characteristics.
An important limit factor to the performance of a pump is the Net Positive Suction Head NPSH.

$$NPSH = H_b - H_{st} - {}_zH_{2w} - H_d$$

In which:

H_b	=	atmospheric pressure	(m)
H_{st}	=	maximum static suction lift	(m)
${}_zH_{2w}$	=	headloss in suction pipe	(m)
H_d	=	vapour pressure	(m)

H_{st} represents the difference in height between the pump and the water level in the sump. By incrasing Q, NPSH also increases and the allowable H_{st} rapidly decreases. All types of pumps and theirperformance ranges are graphically represented in Figures III.11 and III.12. The power, required to run a pump is given by the following equation :

$$N = \frac{Q \cdot H}{273 \eta}$$

In which formula :

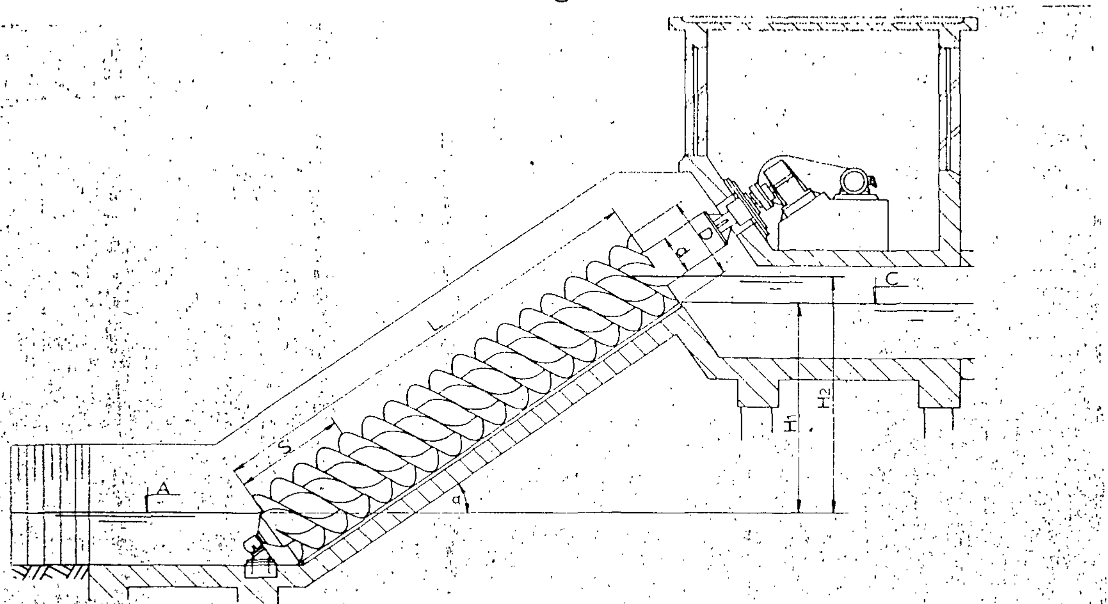
Q	=	discharge	(m^3/hr)
η	=	efficiency	(%)
H	=	head	(m)
N	=	power	(HP)

III.7 Pipelines

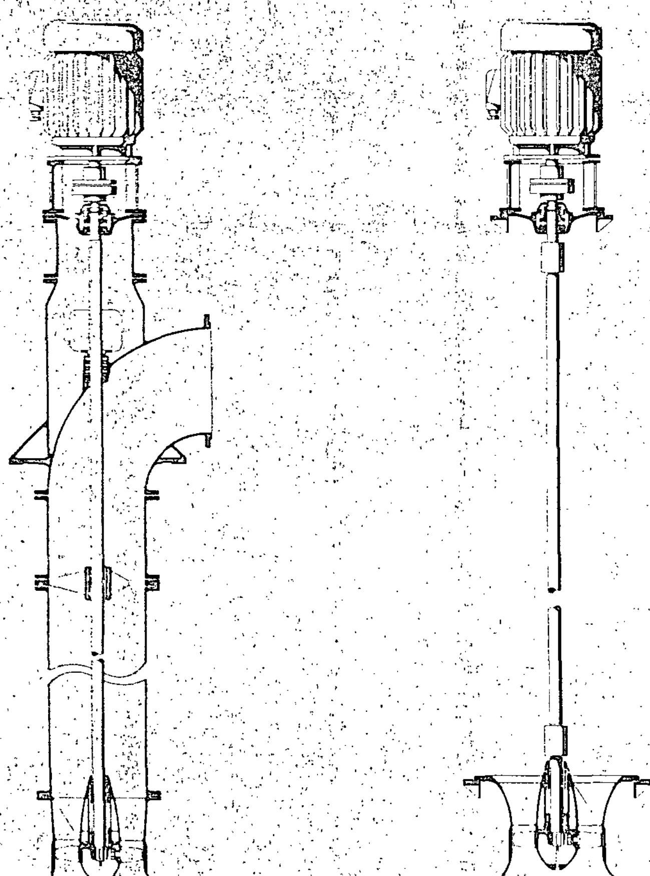
In irrigation systems water is transported through pipelines from the sources where the pressure is applied to the field. Friction losses between the water and the inside of the pipe cause head losses. These head losses can be calculated with :

$$h = \lambda \frac{L}{D} \frac{\gamma}{2g} v^2$$

Fig III-11

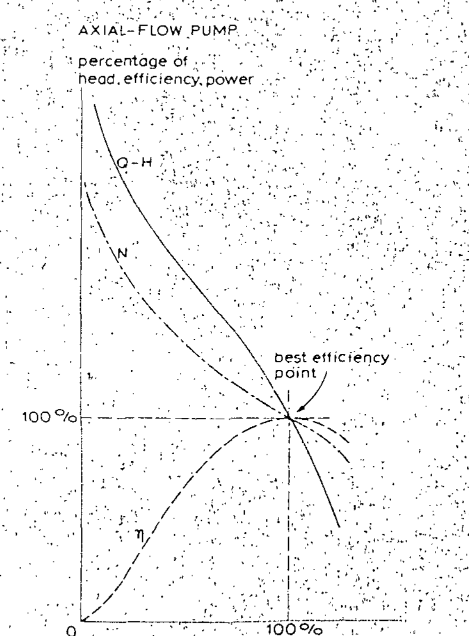


Archimedean screw (open type)



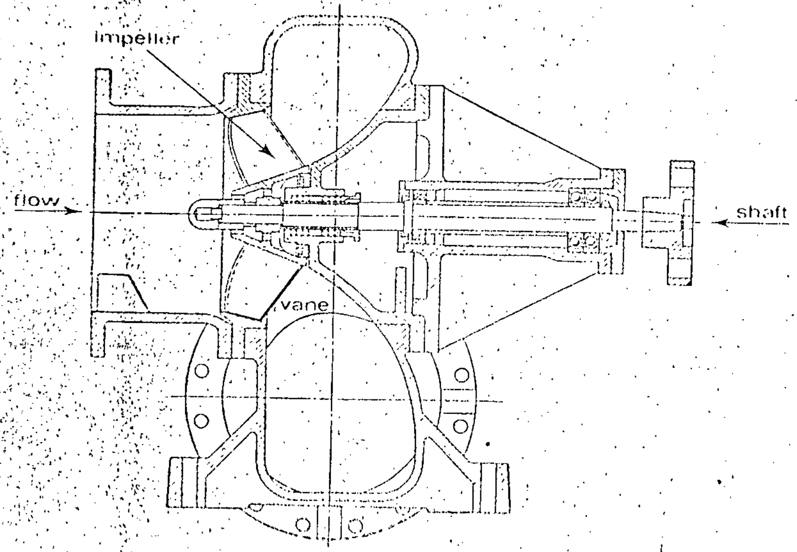
Closed and open axial-flow pump.

207



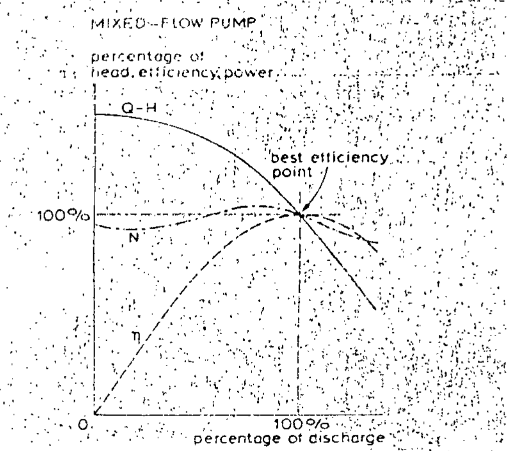
Characteristics of an axial-flow pump.

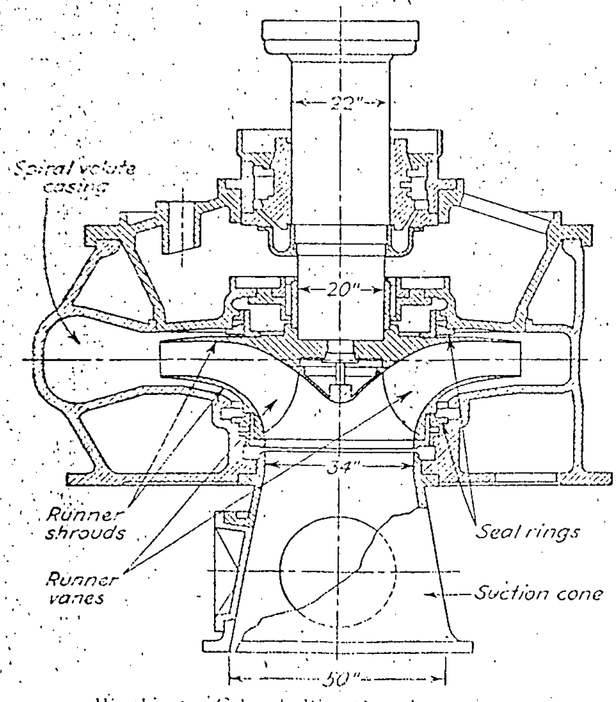
Fig III-12



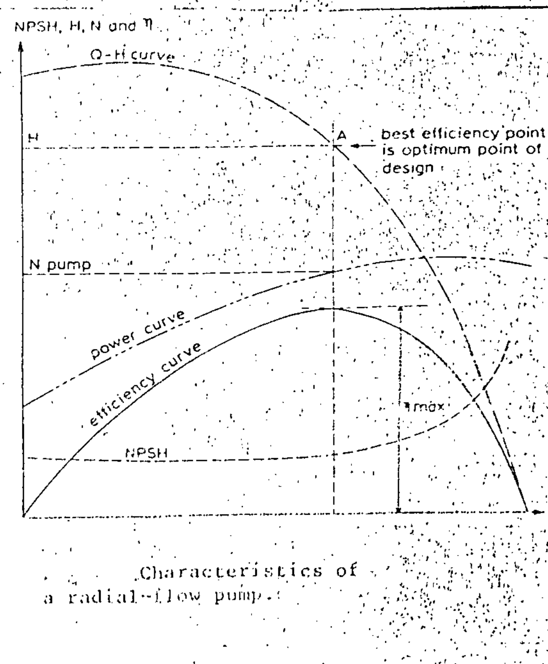
Worthington mixed flow pump

Mixed-flow pump.





Worthington Colorado River Aqueduct pump



Characteristics of a radial-flow pump.

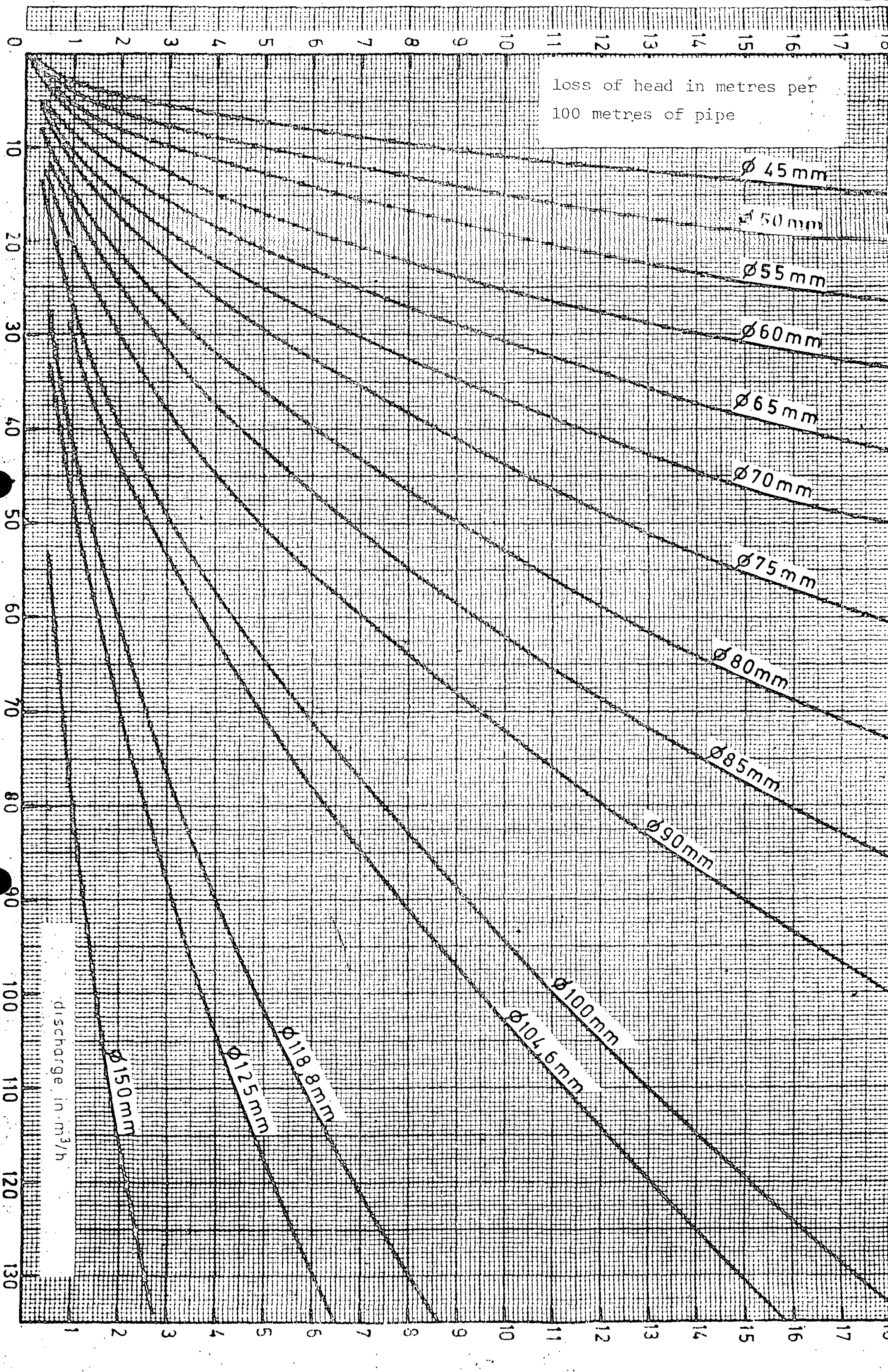


Fig III-13 Head losses in plastic and asbestos-cement pipes, roughness 0.02 mm

Fig III-14 Head losses in plastic and asbestos-cement pipes, roughness 0.02 mm

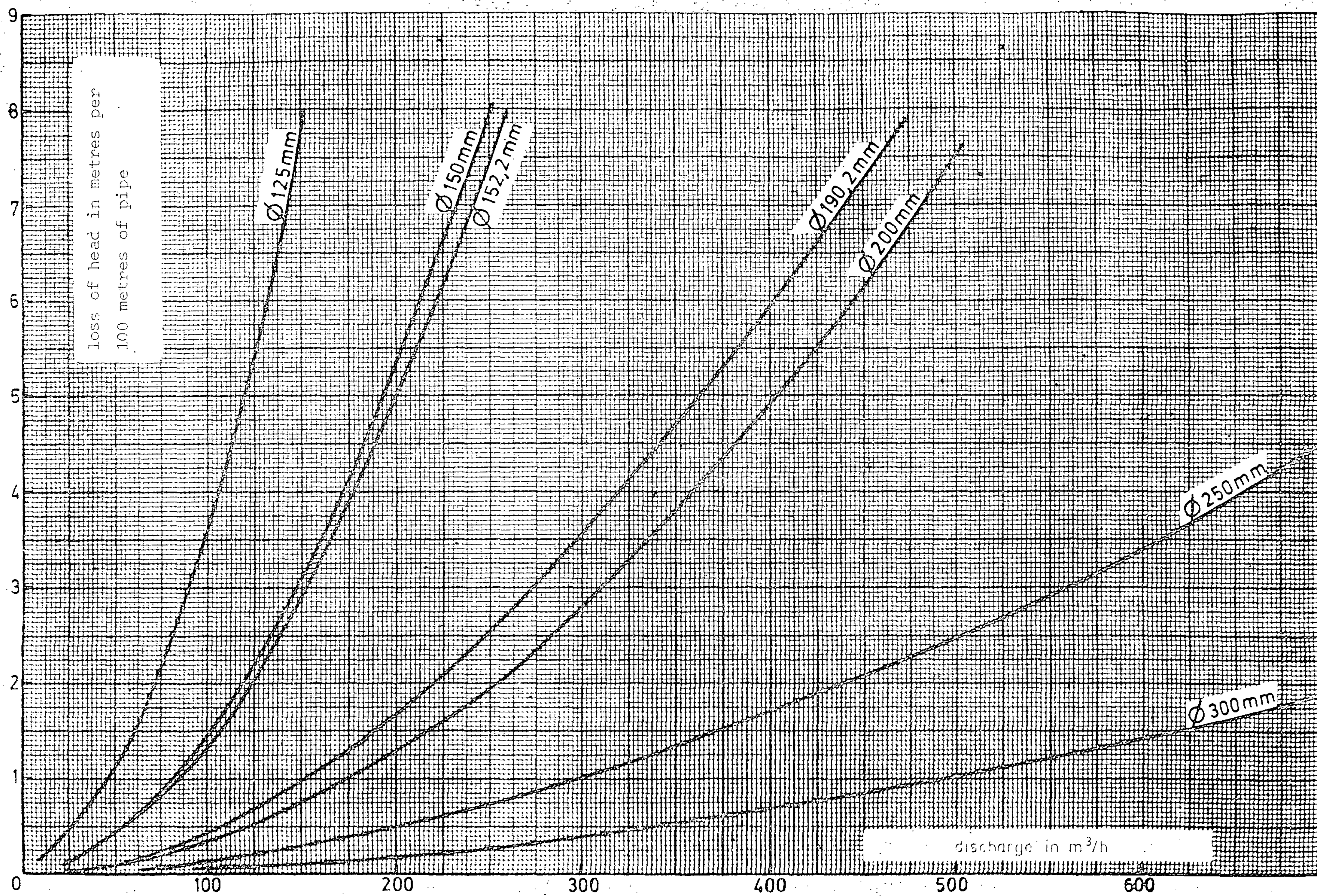
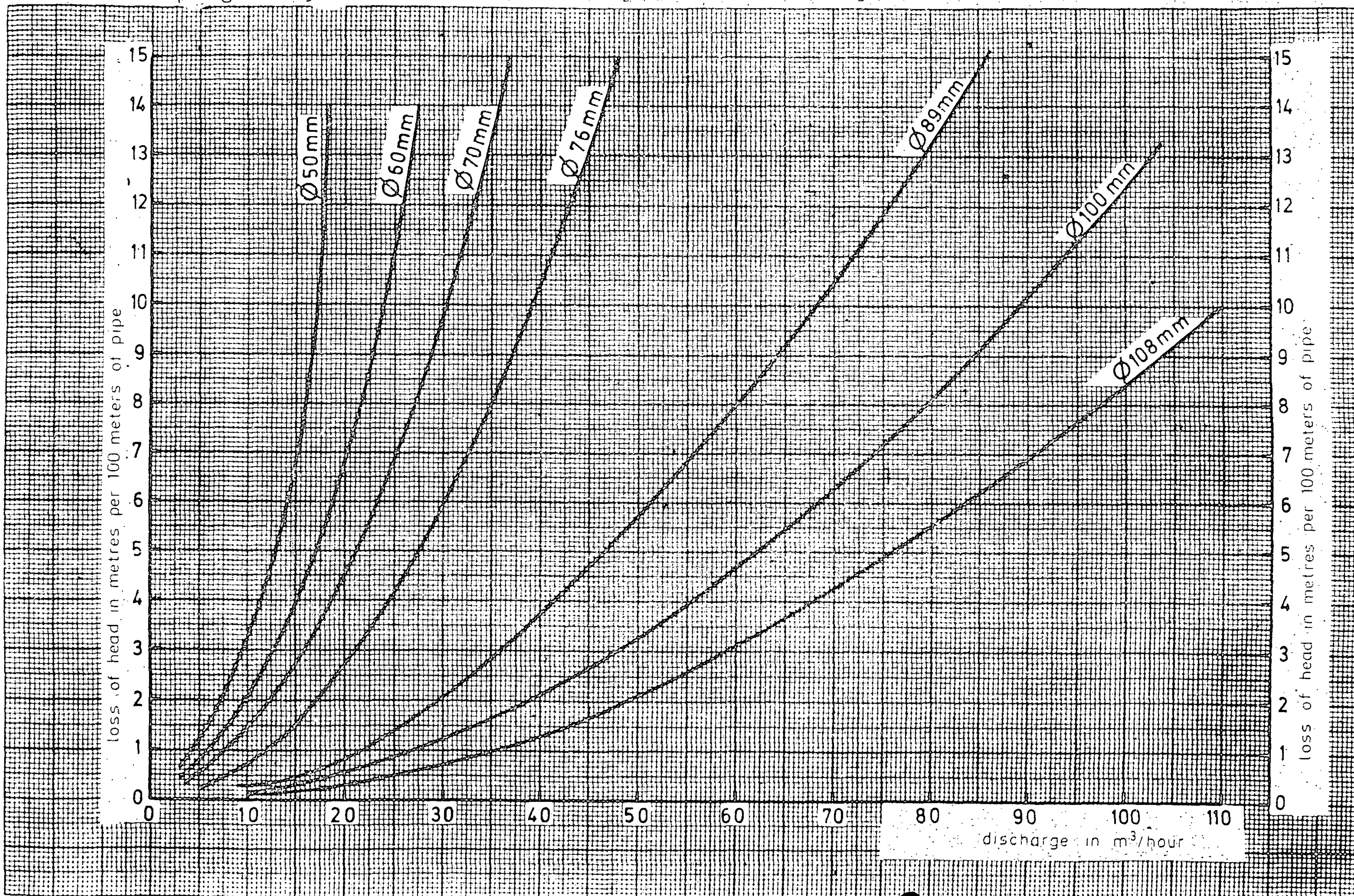


Fig III-15 Head losses in quick coupling pipes of aluminium or galvanized sheet steel



IV HYDRAULIC DIMENSIONS OF STRUCTURES

1. Canals

Both in irrigation and drainage projects canals form a major part of the system. To calculate their dimensions several formulae have been developed. Although in theory distinction should be made between laminar and turbulent flow of the water in the canal, usually one of several empirical formulae, which apply to turbulent flow, is used :

1. Manning's Formula :

$$Q = K_m * A * R^{2/3} * S^{1/2}$$

Q =	flow	(m^3/s)
K =	Mannings coefficient	
A =	wet cross-sectional area	(m^2)
R =	hydraulic radius	(m)
S =	bedslope	(m/m)

2. Chezy's Formula:

$$Q = A * C * R^{1/2} * S^{1/2}$$

Q =	flow	(m^3/s)
C =	Chezy coefficient	
A =	wet cross-section	(m^2)
R =	hydraulic radius	(m)
S =	bedslope	(m/m)

The Mannings and Chezy coefficients are for a given canal, constants, their value depending on the canals rugosity (roughness) and shape.

The relevant values of K_m and C can be derived from Table IV.1.

TABLE IV. 1

Rugosity coefficients for channels with other than coarse bed material

Type of channel and Description	Manning's Coefficient $n = \frac{1}{Km}$	Chezy's Coefficient C			
		R_h = 1m	R_h = 2,5 m	R_h = 5 m	R_h = 10
A. Excavated or dredged.					
a. Earth, straight and uniform					
1. Clean, recently completed	0016 - 0020	63 - 50	72 - 58	81 - 65	91 - 73
2. Clean, after weathering	0018 - 0025	55 - 40	64 - 46	72 - 52	81 - 59
3. With short grass, few weeds	0022 - 0033	45 - 30	53 - 35	59 - 40	67 - 44
b. Rock cuts					
1. Smooth and uniuniform	0025 - 0040	40 - 25	46 - 29	52 - 33	59 - 37
2. Jagged and irregular	0035 - 0050	29 - 20	33 - 23	37 - 26	42 - 29
B. Natural streams.					
B. 1 Minor streams					
(top width at flood stage less than 30 m or 100 ft.)					
a. Streams on plains					
Clean, straight, full stage, no rifts or deep pools	0025 - 0033	40 - 30	46 - 35	52 - 40	59 - 44
B. 2 Flood plains					
a. Pasture, no brush					
1. Short grass	0025 - 0035	40 - 29	46 - 33	52 - 37	59 - 42
2. High grass	0030 - 0050	33 - 20	39 - 23	44 - 26	49 - 29
b. Cultivated areas					
1. No crop	0020 - 0040	50 - 25	58 - 29	65 - 33	73 - 37
2. Mature row crops	0025 - 0045	40 - 22	46 - 26	52 - 29	59 - 33
3. Mature field crops	0030 - 0050	33 - 20	39 - 23	44 - 26	49 - 29

c. Brush					
1. Scattered brush, heavy weeds	0035 - 0070	29 - 14	33 - 17	37 - 19	42 - 21
2. Light brush and trees (without foliage)	0035 - 0060	29 - 17	33 - 19	37 - 22	42 - 24
3. Light brush and trees (with foliage)	0040 - 0080	25 - 12	29 - 14	33 - 16	37 - 18
4. Medium to dense brush (without foliage)	0045 - 0110	22 - 9	26 - 105	29 - 12	33 - 13
5. Medium to dense brush (with foliage)	0070 - 0160	14 - 6.5	17 - 75	19 - 8	21 - 9
d. Trees					
1. Cleared land with tree stumps, no sprouts	0030 - 0050	33 - 20	39 - 23	44 - 26	49 - 29
2. Same as above, but with heavy growth of sprouts	0050 - 0080	20 - 12	23 - 14	26 - 16	29 - 18
3. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0080 - 0120	12 - 85	14 - 95	16 - 11	18 - 12
4. Same as above, but with flood stage reaching branches	0100 - 0160	10 - 65	12 - 75	13 - 8	15 - 9
5. Dense willows, summer straight	0110 - 0200	9 - 5	105 - 6	12 - 65	13 - 7.5

An important factor in designing canals is the stream velocity. Depending on the material in which the canal is excavated or constructed a certain velocity should not be exceeded otherwise erosion will occur. From Table IV.2 these limiting values can be obtained.

TABLE IV. 2

MAXIMUM PERMISSIBLE VELOCITY (M/SEC)
IN CANALS MADE IN DIFFERENT MATERIAL

MATERIAL	MAXIMUM PERMISSIBLE VELOCITY M/SEC	
	CLEAR WATER	WATER TRANSPORTING COLLOIDAL SILTS
Firm sand, colloidal	0.45	0.70
Sandy loam, non-colloidal	0.55	0.70
Silt loam, non colloidal	0.60	0.90
Alluvial silts, non-colloidal	0.60	1.05
Ordinary firm loam	0.70	1.05
Volcanic ash	0.70	1.05
Stiff clay, very colloidal	1.15	1.50
Alluvial silts, colloidal	1.15	1.50
Shales and hard pans	1.85	1.85
Fine gravel	0.70	1.50
Graded loam to cobbles	1.20	1.50
Coarse gravel, non-colloidal	1.20	1.85
Cobbles	1.50	1.60

A second design factor is the side slope stability. In Table IV. 3 recommended side slopes are listed as to be used in different materials.

TABLE IV.3

RECOMMENDED CANAL SIDESLOPES FOR
DIFFERENT MATERIALS

MATERIAL	SIDE SLOPE (b : a)
Rock	Nearly vertical
Muck and peat soils	4:1
Stiff clay or earth with concrete lining	2:1 - 1:1
Earth with stone lining	1:1
Earth for large channels	1:1
Firm clay	¾ : 1
Earth for small channels	¾ : 1
Loose sandy earth	½ : 1
Sandy loam or porous clay	1/3 : 1

IV.2 Bridges

In the following an example is given for the calculation of the span and height of a bridge. At first one of the methods described in section II.2 is used to estimate the peak discharge which can be expected to pass the future bridge with a certain chance of occurrence. It should be realised that discharges arrived at by using one of the methods from Section II.2. have a chance of occurrence of 1 out of 10 years. The basis for the calculation of the span of the bridge is the Manning formula.:

$$Q = K_m * R^{2/3} * S^{1/2} * A$$

Q =	peak discharge	(m^3/sec.)
K_m =	Mannings coefficient	
R =	hydraulic radius	(m)
S =	bedslope	(m/m)
A =	wet cross-sectional area	(m^2)

Example : An area of 60 hectares consisting of arable land with a silt loam soil and an average slope of 4% is drained by a perennial river which will be crossed by a new bridge. The length of the river from its most remote point to the bridge site is 1100 m and the difference in elevation between this point and the bridge is 135 m. The average bedslope of the river at the bridge site is 0.015% Determine the dimensions of the bridge with a design frequency of 25 years.

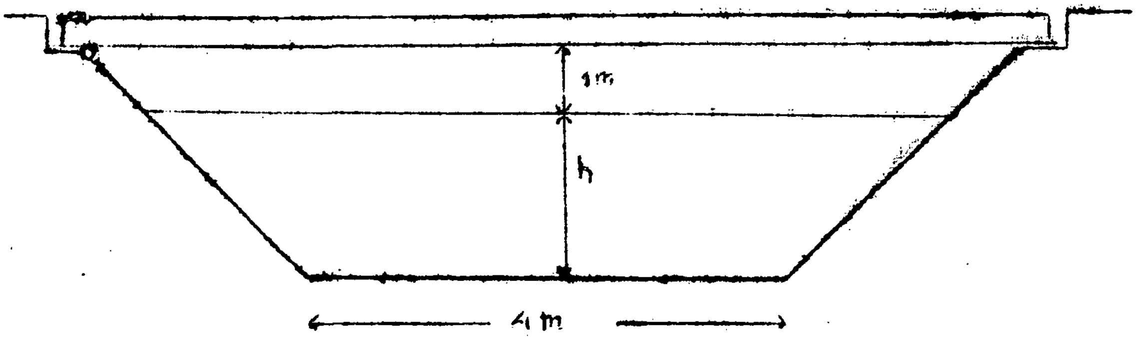
Using the rational method as explained in Section II.2 we estimate the peak discharge which could pass the structure once in 10 years.

$$Q = C * I * A.$$
$$= 0.5 * 0.210 \times 600{,}000$$
$$= 63{,}000\ m^3/hr = \quad 17.5\ m^3/sec.$$

To convert this discharge with a chance of occurrence of once in 10 years to one with a chance of occurrence of 25 years use the conversion factors from the table in Section II.1.

$$Q_{25} = 1.2 * Q_{10} \quad \underline{Q_{25} = 21.0\ m^3/sec.}$$

The cross-section of the riverbed at the bridge site is as follows :



Because in Mannings formula A as well as R (hydraulic radius) depend on h = water depth, no direct solution for h can be obtained so a trial and error procedure should be applied:

From Table IV. 1 take $K_m = \frac{1}{n} = 25$.

1. Take h = 1.00 m

$$A = \frac{4+6}{2} \times 1.0 = 5 m^2$$

$$B = 4 + 2 \quad 2 = 6.8 \text{ m (B = wet perimeter)}$$

$$R = \frac{A}{B} = \frac{5}{6.8} = 0.73$$

$$Q = 25 \times 5 \times 0.73^{2/3} \times 0.015^{1/2} = \text{[illegible]} \; m^3/\text{sec.}$$

The chosen water depth apparently is too small.

2. Now take h = 2.00 m

$$A = \frac{4+8}{2} \times 2.0 = 12 m^2$$

$$B = 4 + 4 \quad 2 = 9.66 m; \; R = \frac{12}{9.66} = 1.24$$

$$Q = 25 \times 12 \times 1.24^{2/3} \times 0.015^{1/2} = 42.51 \; m \; 3/\text{sec.}$$

The chosen water depth apparently is too great.

3. Now take h = 1.40 m

$$A = \frac{4+6.8}{2} \times 1.4 = 7.56 \; m^2$$

$$B = 4 + 2 \times 1.98 = 7.96 \text{ m} \quad R = 0.95 \text{ m}$$

$$Q = 25 \times 7.56 \times 0.95^{2/3} \times 0.015^{1/2} = 22.37 \; m^3/\text{sec}$$

So the water depth which can be expected once in 25 years is 1.40m. If we take a safety margin of 1 m into account the design height of the bridge is 1.00 + 1.40 = 2.40 m above the river bed. The span is then : 4 + (2 x 2.40) = 8.40 m

IV.3 Fordings

Under certain conditions it can be decided to cross a river by means of a fording. Factors which influence this decision are amongst others the traffic density on the road, the ratio between low flows and peak flows in the river or stream, the costs of the structure, etc. If the fording is not raised from the river bed the flow over the fording can be calculated using the Manning Formula explained above.

$$Q = K_m * A * R^{2/3} * S^{1/2}$$

If however, the fording is raised, in many cases the flow pattern prevailing at the fording will be similar to that above a weir. Then waterdepth and/or width of the fording are calculated with the formula :

$$Q = 1.7 * b * H^{3/2}$$

Q =	peak discharge	$m^3/sec.$
b =	width of fording	(m)
H =	water depth above fording	(m)

If a certain water depth should not be exceeded, than for a given (or calculated) flow automatically the width of the fording can be calculated. It should be realized that the width should be kept within a practical range so as to avoid excessive earth moving to adapt the cross-section to the fording.

IV.4 Culverts

Two cases can be discerned in flow through culverts. One situation in which the down stream water level controls the outflow, the other in which only the upstream water level determines the outflow. The latter case is rather complicated and in Jamaica's hilly topography not likely to occur. In cases where however it is clear that a channel section down stream of the culvert is the limiting factor (the bottleneck) in the water transport, then the following procedure should be followed :

1. calculate the peak flow
2. calculate the water depth in the down stream section using Mannings Formula. (H_2)
3. Calculate the water level upstream from the culvert using Q = 0.8 2g (H_1 - H_2) * A. H_1 = upstream water level

If there is no limiting factor downstream, the flow through the culvert is governed by the following equation :

$$Q = 0.8 \times A \times \sqrt{2gz}$$

Q =	peak discharge	(m^3/sec.)
A =	wet cross-sectional area of culvert	(m^2)
G =	9.81	(m/s^2)
Z =	head loss	(m)

When Q is given and a certain culvert diameter is assumed, the head loss can be calculated. This head loss equals the height to which water will rise above the top of the culvert. A check has to be made to see if this level is within safety ranges.

The maximum permissible velocity in the culvert should not exceed 3m/s.

ACCO

CATALOGUE NO.

29427

ACCO JAMAICA LTD.
PRODUCT OF JAMAICA