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Scientific Contribution
No. : INCOH/SAR-4/95

SURFACE DRAINAGE ASPECTS OF AGRICULTURAL AREAS

G. P. Malhotra

INDIAN NATIONAL COMMITTEE ON HYDROLOGY
(Committee Constituted by Ministry of Water Resources, Govt. of India)

INCOH SECRETARIAT
NATIONAL INSTITUTE OF HYDROLOGY
ROORKEE - 247 667, INDIA
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PREAMBLE

It has been estimated that the total world population will increase from 4.5 billion in 1980 to about 6.5 billion by the year 2000, with the most rapid growth in the developing countries. By that time, the countries within the humid tropics and the other warm humid regions will represent almost one-third of the total world population. This proportion will continue to rise in the twenty-first century. The developing and under-developed countries thus quite clearly are the regions facing potentially serious water problems. Hence, it is urgent to question as to whether the fields of hydrology and water resources management have the appropriate methods in place to meet the rising demands that will be made on the water resources. Hence it becomes very important and expeditious to review and update the state-of-art in different facets of hydrology and component processes. This call for compiling and reporting present day technology in assessment of water resources and determining the quality of these water resources.

The water introduced into the soil from various sources (e.g. rainfall, irrigation, inflow of ground water from others areas etc.) gets disposed off through natural drainage process and through use by crops to meet their physiological needs. When the inflow of water in the soil exceeds the natural drainage and crop use, the water table starts to rise. Considering such conditions, a simple but comprehensive definition of adequate drainage could be the removal of excess water and salt from the soil at a rate which will permit normal plant growth. The prime objective of a drainage system should be to achieve optimum integration of soil, crop and irrigation. The present state of art report covers mainly the drainage systems, factors influencing drainage, design consideration and other practical aspects.

The Indian National Committee on Hydrology is the apex body on hydrology constituted by the Government of India with the responsibility of coordinating the various activities concerning hydrology in the country. The committee is also effectively participating in the activities of Unesco and is the National Committee for International Hydrology Programme (IHP) of Unesco. In pursuance of its objective of preparing and periodically updating the state-of-art in hydrology in the world in general and India in particular, the committee invites experts in the country to prepare these reports on important areas of hydrology.

The Indian National Committee on Hydrology with the assistance of its Panel on Surface Water has identified this important topic for preparation of this state-of-art report and the report has been prepared by Dr.G.P.Malhotra, Former Engineer in Chief, Haryana Irrigation Department. The guidance, assistance and review provided by the Surface Water Panel are worth mentioning. The report has been compiled and finalised by Dr.K.K.S.Bhatia, Member-Secretary, Indian National Committee on Hydrology.

It is hoped that this state-of-art report would serve as a useful reference material to practicing engineers, researchers, field engineers, planners and implementation authorities, who are involved in correct estimation and optimal utilization of the water resources of the country.

(S.M.Seth)
Executive Member, INCOH
& Director, NIH

Roorkee,
April 10, 1995.

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INTRODUCTION

In post-independent India, planned efforts witnessed a great spurt in the development of irrigated areas both from surface and groundwater sources. From 22.6 million hectares (Mha) in 1951-52, the potential irrigable area increased to 67.9 Mha in 1984-85. However, because of improper and inefficient use of irrigation waters, sizable areas are losing productivity on account of waterlogging and salt related problems. Improvement of drainage in irrigated areas is, therefore, of prime importance to derive optimum agricultural benefits from irrigation facilities. A well planned drainage network keeps the rise of watertable under check which results in better plant growth as exhibited in Fig. 1.

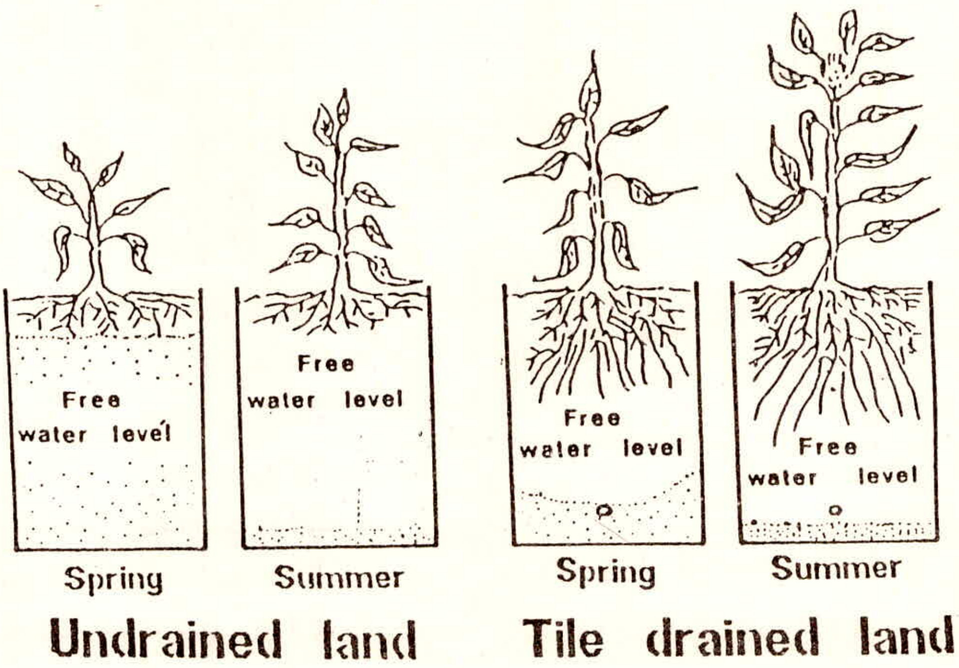


Fig. 1 Root development of crops grown on drained and undrained land
(Source - Schwab et. al., 1981)

WATER LOGGING

The National Commission on Agriculture (1976) defines an area as waterlogged when the watertable rises to such a level that the soil pores in the root zone of a crop get saturated resulting in the restriction of normal circulation of air, decline in the level of oxygen and increase in the level of carbon dioxide. In agricultural areas, such conditions generally cause severe damage or complete loss of crop.

The critical depth to watertable varies with the crop. Different crops can tolerate varying degrees of oxygen stress. Majority of the pulse and oilseed crops which are deep rooted and require fairly good circulation of air in the ' root zone, suffer when watertable rises within one meter depth (Fig. 2).

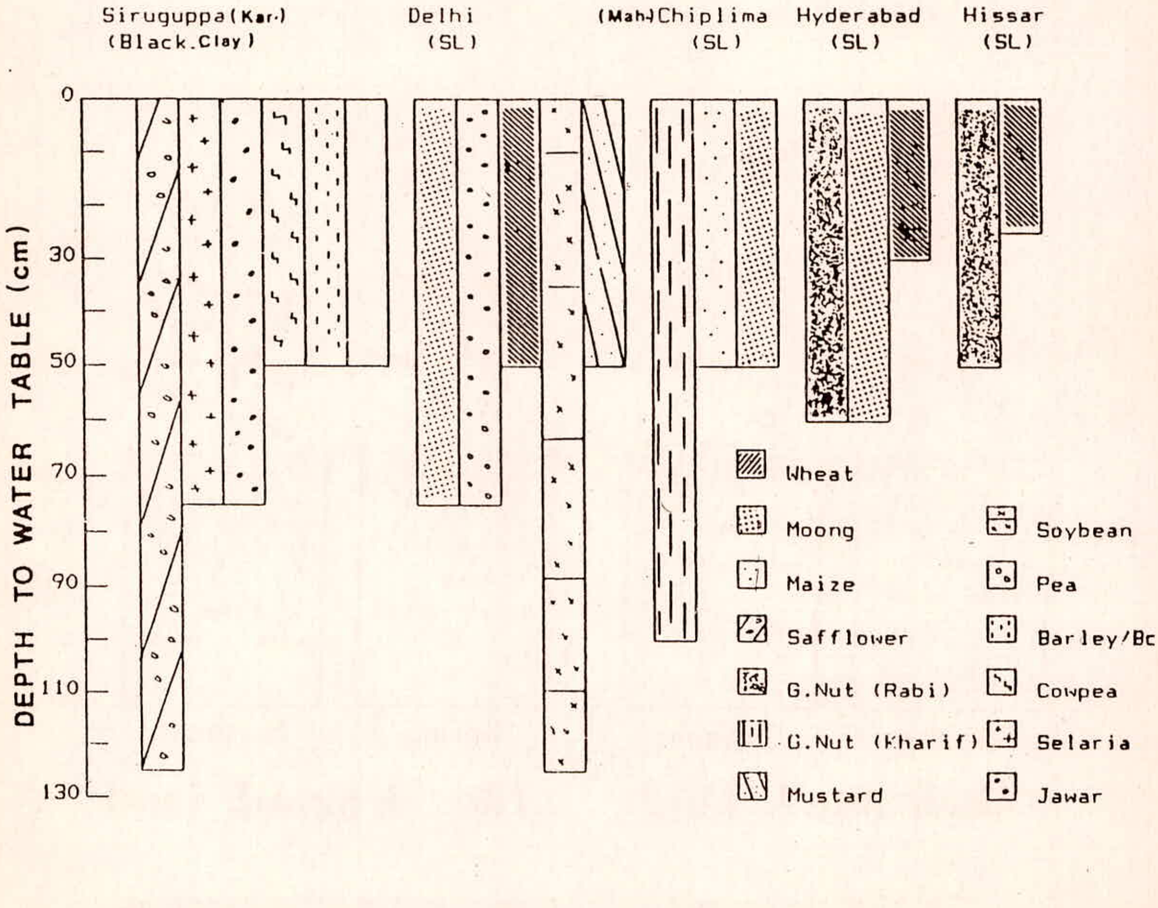


Fig. 2 Critical water table depths for crops

The soil texture and the quality of groundwater are other factors which determine the critical depth.

Table. 1 shows the reduction in agricultural yield of various crops due to different watertable depths. This table indicates the importance of lowering the watertable. This can be achieved through drainage. Hence drainage provides a means to ensure sustained production from irrigated agriculture.

Table 1
Percentage Reduction in Yield Resulting from Watertable at Various Depths

S. No.	Depth to Waterable(m)	% Reduction in crop Yields						
		Mango	Cotton	Oil Seed	Sugar Cane	Wheat	Rabi Fodder	Kharif Fodder
1	< 0.3	100	94	85	85	77	74	71
2	0.30 - 0.45	100	71	66	66	49	45	27
3	0.45 - 0.60	100	55	54	54	35	30	0
4	0.60 - 0.75	100	46	42	42	24	19	0
5	0.75 - 0.90	91	37	32	32	15	11	0
6	0.90 - 1.00	76	29	22	28	9	5	0
7	1.00 - 1.20	61	22	13	13	4	2	0
8	1.20 - 1.50	38	15	5	5	1	0	0
9	1.50 - 1.80	7	6	1	1	0	0	0
10	1.80 - 2.10	0	3	0	0	0	0	0
11	> 2.10	0	0	0	0	0	0	0

The extent of estimated waterlogged areas in India is shown in Table 2.

Table-2
Estimated Extent of Waterlogged areas in India

S.No.	State	Area (ha.)
1.	Punjab & Haryana	1,427,900
2.	Uttar Pradesh	686,800
3.	Gujarat	484,400
4.	West Bangal	309,500
5.	Maharashtra	111,500
6.	Jammu & Kashmir	10,000
7.	Andhra Pradesh	4,200
8.	Delhi	1,300
	Total	3,035,600

DRAINAGE

The water introduced into the soils from various sources (e.g. rainfall, irrigation; inflow of groundwater from other areas, etc) gets disposed off through natural drainage process and through use by crops to meet their physiological needs. When the inflow of water in the soils, exceeds the natural drainage and crop use, the watertable starts to rise. Considering such conditions, a simple but comprehensive definition of adequate drainage could be the removal of excess water and salt from the soil at a rate which will permit normal plant growth. The prime objective of the design and construction of a drainage system should be to achieve optimum integration of soils, crops and irrigation.

Well planned drainage systems lead to the following general benefits:

a) Good drainage leads to better soil aeration which permits more extensive root development. Reduced soil aeration increases the severity of soil borne root diseases.

b) Reduced soil moisture resulting from good drainage, permits better operation of tilling, planting and harvesting equipment. It also facilitates all manual operations.

c) Under good drainage conditions, better soil structure can be developed and maintained. Drainage reduces the chances of destroying soil tilth due to compaction which occurs under wet conditions.

d) With the removal of free water by a drainage system, soils warm up quicker, resulting in better seed germination and increased rate of plant growth.

e) Higher watertable reduces the supply of nitrogen which causes denitrification of soils. Drainage of soils increases the supply of nitrogen.

f) The damage to plants due to winds is reduced in well-drained agricultural fields. In fields with good drainage, the problem of weeds is minimized.

h) Well-drained grazing lands are less liable to damage by compaction. In wet lands, damage to vegetation and soils is extensive and is caused by animal traffic. Well drained grazing lands can support larger herds of livestock.

i) Livestock diseases which are caused under wet condition are reduced by good drainage. Common diseases are foot rot and liver fluke.

j) Drainage is essential for the control of salinity-alkalinity in arid and semi-arid regions.

DRAINAGE SYSTEMS

Well designed and constructed drainage systems fill the gap between the naturally available drainage and the established need. This supplementary drainage may be provided either by resectioning the natural streams or by constructing new drainage channels. The drainage planner in an irrigated area must take into account all aspects of land and water resources as well as future agricultural development.

(a) Surface drainage including land grading.
(b) Subsurface drainage
(c) Tubewell drainage
(d) Bio drainage
(e) Preventive measures, such as lining of irrigation channels, and better on-farm water management.

Factors which influence the selection of a drainage system are:

(i) Topography
(ii) Nature of Soils
(iii) Cropping pattern
(iv) Hydrological and climatological factors.

Surface Drainage of The Land

Surface alrainage is the removel of excess water from the land surface. This excess water may be due to heavy rainfall, application of irrigation waters, losses from irrigation channels and storages, or seepage from groundwater at higher elevations in the adjoining areas. Flat or level lands with shallow top soil over impermeable strata frequently require surface drainage. Open drains are required for removing large volumes of water including storm water.

Surface drainage systems broadly comprise of the following components:

(a) *On-farm field drainage system* - This system includes graded ditches which collect excess water from fields. These ditches are called field drains.
(b) *Intermediate or collector drains* - These drains link the field drains to the sub-main or main drains:
(c) *Main drains* - Main or sub-main drains are either natural or excavated drainage channels which collect water either from intermediate drains or directly from field drains.
(d) *Seepage drains* - These drains run along the irrigation channels and intercept surface or subsurface seepage flow. These drains prevent the waterlogging of areas adjacent to the irrigation channels. The flow intercepted by these drains is either discharged in main/intermediate drains or pumped back into the irrigation channels.
(e) *Land Grading* - This is the simplest type of surface drainage. Lands with natural ridges and depressions lead to pondage of surface waters and interruption of both irrigation

and surface drainage systems, provision of continuous gentle slopes by grading and smoothening results in regulated water flow and efficient drainage system.

Generally, the open drains in a surface drainage system have the following disadvantages:

(i) Cultivable and fertile land is used up in the construction of a surface drainage system. Since the drains are mostly in cutting, spoil banks created along the drains permanently render considerable areas as unproductive.
(ii) Open drainage system causes increased soil erosion - Storm water enters the field drains in sheet flow which leads to the erosion of fertile top soil from the fields.
(iii) An open drain system requires frequent cleaning and general maintenance expenses are high. The innumerable structures at the link points of field and intermediate drains as well as intermediate and main drains require continual upkeep for the drainage system to operate efficiently.
(iv) During the non-running periods of the open drains, many obnoxious weeds take root in the channels which are not only very difficult to remove but they also get distributed in the adjoining cultivated fields causing considerable problems to the farmers.

Subsurface Drainage

Subsurface drainage comprises of a system of (i) buried pipes or (ii) pipeless moled drains. The subsurface drainage system is used to

- Intercept the lateral flow of groundwater emanating from a known source of seepage upslope and appearing in a cultivated area (to be protected) downslope.
- lower the watertable to keep it below the tolerable limit of the crops grown in the area to be protected.
- remove harmful chemicals from crop root zone.

Pipe Drains

Pipes for subsurface drainage may be made of baked clay tiles, concrete, PVC or any other material from which perforated conduits can be manufactured. The water in the soil enters these pipes laterally through butt joints, slots or other perforations provided for the purpose. The water in the pipes flows down to collector of main drains.

Mole Drains

Provision of mole or pipeless drains is a temporary method of drainage. The moles function properly-only for a few years after which they gradually crumble.

Mole drains are cylindrical channels made in the subsoil by means of a mole plough. These are not lined with tiles or any other stabilizing material. Their hydraulic functioning is similar of the pipe drains.

Tubewell Drainage

In certain circumstances, pumping of groundwater into the surface drains provides an effective means to lower the watertable, If the pumped water is of suitable quality, it may be discharged into irrigation channels to augment supplies. Such dual purpose Augmentation Tubewells have been extensively used in Haryana.

The tubewell drainage system consists of a number of wells spread over the area required to be drained. While locating a drainage tubewell following considerations should be kept in view.

(a) A drainage well requires that the pumped aquifer should be interconnected with the watertable. If the tubewell is drilled into a 'confined aquifer, it will have little utility as a drainage well.

(b) Among the adjacent drainage wells some interference is desirable unlike the irrigation wells where interference is often avoided.

(c) The drainage wells need not be on a high point in the area as in the case of irrigation tubewells where command is the primary consideration. However, if the drainage well is proposed to be used as a direct irrigation tubewell (DIT), it may be located on the highest possible point where other necessary conditions for drainage are met with.

Bio Drainage

Planting quick growing trees of the exotic variety is considered as a suitable method to improve marshy and waterlogged lands. Such trees draw surface and subsurface water at a fast rate and transpire it to the atmosphere. This system of drainage requires thorough investigations of the climatic and soil characteristics of the drained area as well as the suitability of the various plant species proposed to be grown

Preventive Measures

Lands which have not yet been affected by waterlogging and salinity, can be prevented from degradation by taking the following measures:

(i) Lining of irrigation water distribution network (DISNET)
(ii) On-Farm water management
(iii) Maintenance of surface drainage system.

Lining of Water distribution Network (DISNET)

Loss of precious irrigation water through seepage from irrigation canals constitutes a sizable loss. It has been estimated that in a totally unlined system, 71% of the water released at the head of the main canal is lost through seepage from different channels before it reaches the plants a cultivated field - only 29% being the net utilization. Against this in a wholly lined system, the net utilization increases to 61%, Since most of the losses take place through smaller channels, like, watercourses, the lining of such channels is most beneficial as shown in Table.3. It can be seen from this table that the ratio of the wetted perimeter to discharge is highest in a field channel (45 in an unlined watercourse against 0.7 in an unlined main canal). Since the seepage loss from a canal is a function of its wetted perimeter, the saving in losses by lining in smaller channels is highest per unit discharge.

Table - 3
Seepage Losses Through Various Irrigation Channels*

Channel category	Average Discharge (m/s)	Watted Perimeter (m)		Ratio Col. 3 Col. 2		Cost of Lining per meter
		Unlined	Lined	Unlined	Lined	
1	2	3		4		5
Fixed Channels x (Watercourses)	40×10^{-3}	1.80	1.14	45.0	28.5	x
Tertiary Canals (Minors)	0.6	3.65	3.17	6.1	5.3	1.4x
Secondary Canals	3.0	8.13	5.80	2.7	1.9	2.8x
Primary Canals (Main & Branch Canals)	42.5	31.47	16.82	0.7	0.4	16.9x

*Source : Malhotra, G.P. (1985)

It is obvious that the reduction in seepage by lining of channels reduces waterlogging and drainage problems. It has been estimated that the seepage loss through an unlined channel in average silt and loamy soils is about 2.3 m^3/s/mill.sq m of wetted perimeter. The value is as high as 4 to 6 in sandy loam or sandy soils and upto 10 in porous gravelly soils. Concrete or brick tile lining to 0.15 m^3/s/mill. sq. m of wetted perimeter.

On - farm Water Management

It has been estimated that about 50% of the water delivered to an agricultural field at the farmgate, goes to waste due to application losses. Saving in these losses will not only result in better use of irrigation waters but also minimize the drainage problems.

Broad on-farm management practices include land grading and shaping, better layout out of distribution network scientific scheduling of irrigation water supplies, better planning of cropping pattern and optimal water use. It has been estimated that by adopting efficient on-farm management practices, the water application efficiency can be increased to 70% or even higher.

Maintenance of Surface Drainage Systems

Although the surface drainage systems are many a time well designed and executed their poor maintenance defeats the very purpose for which they were built, namely, disposal of excess runoff from the cropped land and providing a check on the rising watertable. Poor maintenance is generally due to lack of financial resources and a general hesitance on the part of of the planners, particularly if the previous year had been a dry one and the resources spent on readying the open drains appeared to be infuctuous. This is obviously fallacious and no effort should be spared in the annual maintenance as in the event of average or wet rainy season, the saving in crops and agriculture yields is many times more than the annual maintenance budget of the drainage systems.

The maintenance of drains should include restoring bed grades, repairing side slopes, maintenance of works particularly the inlet points in the field and the link structures, and the control of vegetative growth in the drains. Typha and bulrush are two of the many water loving plants which grow abundantly in irrigation as well as drainage channels. Typha has a highly restrictive effect on the flow in the drains.

FACTORS INFLUENCING DRAINAGE IN AGRICULTURAL AREAS

The necessity for providing surface drainage in irrigated agricultural areas stems from the fact that in the aftermath of heavy run off periods, the top soil gets saturated. It is well known that the plant roots require both air and water, and that most of the plants can not withstand saturated top soil for prolonged periods. Water accummulations both on and below the surface, may also upset the salt balance in the soil which may have adverse effects on agricultural productivity. Given the capacity of a natural drainage, any excess input of runoff to an area has to be disposed off through artificial means so that normal plant growth is ensured. From the above phenomena, it is evident that topography, runoff, soils and cropping pattern in an area play the most vital role in delineating the drainage needs of the area. The runoff includes the water input into the area both by rainfall as well as irrigation from canals. A well thought of methodology for preparing a surface drainage project or a command area should therefore aim at the optimum integration of all the above mentioned factors.

Topography

The topographical features of an area will not only help in selecting a particular type of drainage system (surface, land grading or subsurface etc.) but will also help in the location of inlets and subunits as well as alignment of collector drains. Steep and hilly areas may require minimal artificial drainage and a single line interception at the toe of such slopes may be adequate. In broad and flat lands, on the other hand, an open drain grid system may have to be designed parallel to the irrigation canals or along wet waterways. In closed basins, construction of sumps and pumping may have to be resorted. The outlet facility will also need to be constructed or the irrigation canals may be put to drainage use during closure periods.

Where surface slopes are adequately steep, the excess precipitation and heavy applications of irrigation water flow rapidly outside the area thereby minimizing the need for artificial irrigation. However, irrigated agricultural' areas are generally developed in flat lands which are ancient depressions and seldom have any natural drainage outlet. Development of drainage systems in such areas include the construction of an outlet system.

Table 4 shows the influence of various topographic features on different drainage parameters.

Table 4
Influence of Topographic Factors on Drains*

Topographic factors		Implied drainage considerations
1. Steep, hilly	a)	No outlet problem; surface drainage adequate.
	b)	Single line interception in swale bottoms.

		c)	Look for seepage at toe of slope, or at outcrops, or along waterways.
2.	Rolling	a)	Probably no outlet problem surface drain face drainage adequate.
		b)	Single line or herringbone pattern of drain system.
		c)	Single line along wet waterways
3.	Benches	a)	Probably no outlet problem.
		b)	Grid system on bench and probably an interceptor line at toe of bench.
4.	Gently sloping	a)	May have outlet problem; surface drainage generally adequate.
		b)	Grid system or open drains on grid parallel to canal system.
		c)	Single line along wet waterways
5.	Flat lake bed or flood plain	a)	Probably needs outlet drain.
		b)	Grid system or open drains on grid parallel to canal system in direction of greatest slope.
		c)	Drainage pump occasionally needed.
6.	Closed basin	a)	Would need outlet facility.
		b)	Drainage well or sump with pump might solve drainage and outlet problems.

*Source : Schwab, 1981

Hydrological & Climatological Factors

From the drainage point of view the runoff will include the total inflow into an area emanating from precipitation, irrigation as well as seepage from various sources, Hydrological data analyses are carried out to compute flood volumes, frequency and the duration of floods. Design standards for storm frequencies and allowable period of crop submergence have been evolved with the consideration of all factors. As per present practices, the design frequency of strom for drainage varies from 5 to 25 years depending upto the nature and importance of the structure. The submergence period for crops (except paddy) is generally restricted from 48 to 72 hours as beyond this period significant reduction in crop yield takes place.

For planning a drainage system, the sources of all waters flowing into an irrigated area should first be determined. The water source often governs the type of drainage to be provided. Thus, if excess water is due to precipitation, the measure to be adopted is surface drainage; if canal seepage are predominant, the construction of interception drains is indicated; and if the source of water is due to hydrostatic pressures manifested in various forms, pumping wells may provide the most practicable solution.

Rainfall

Design standards for strom frequencies and allowable periods of crop submergence are variously adopted by different organizations. U.S.B.R. stipulates a 5-15 year storm frequency for surface drains. For relatively expensive structures on drains, like road and rail bridges and canal crossings, 25-year strom frequency is indicated. For less major crossings a 10-year storm and for farm structures a 5-year storm frequency is recommended.

Irrigation

Many drainage problems in irrigated areas are traceable to faulty irrigation practices, particularly the application of too much irrigation water. To determine the extent to which irrigation practices contribute to such problems, studies should be made of i) the effect on the watertable for each irrigation, ii) watertable fluctuations throughout the irrigation seasons, and iii) longterm changes in watertable elevation after irrigation was introduced in the area.

The main factors which have created waterlogging and high groundwater levels are:

(i) Supply and application of full irrigation supplies to the command area even though the commands are only partially developed.
(ii) Farmers have still to adjust to irrigated agriculture.
(iii) Drainage network only partly complete in the command are where irrigation is introduced.
(iv) Structures, such as, tubewells, dug wells etc. using groundwater in pre-irrigation period get disregarded by farmers because of cheaper rates of canal water. The irrigation projects are sometimes designed for supplies,both from canal and groundwater sources. Hence, the use of existing groundwater facilities and extremely slow pace of new groundwater development vitiates the project design assumptions.
(v) Virtual absence of trained on-farm extension workers.

Seepage

The amount of seepage generally depends on the following factors :

(i) Height of canal embankment and soil type.
(ii) Distance of nearest drain from the canal and difference in the water levels of canals and drains.
(iii) Location to barrier or hard pan below soils.
(iv) Hydraulic conductivity of soils through which seepage flow takes place.
(v) Even when a canal is in cutting, such as in rocky reaches pervious strata like murum are encountered in the bed of the channels causing seepage and sub-soil water movement. These pressures are relieved through previou beds stimulating artesion pressure built-up and are relieved through fissures in rocky strata or by tubewell pumping.

Table 5 has been developed to help assess water source factors and their influence on drain types

Table 5*
Assessment of Water Source Factors and their Influence on Drains

Watertable factors	Implied drainage considerations.
1. Water table fluctuates with irrigation cycle	a) Improved water management may preclude drain system. b) Pipe drain grid system will handle excess irrigation water.
2. Watertable fluctuates with rainfall	a) Better surface drainage is needed b) Tube drain system should be considered.
3. Artesian pressure from deep water bearing aquifers	a) Drainage relief wells or deep systems are neeed
4. Seepage from canal or reservoir	a) Lining of canal or reservoir, to prevent seepage may eliminate the drainage problem. b) Interceptor drain pipe or open drain near canal or reservoir.
5. Seepage from outcrops or along toe of bench	a) Interceptor drain pipe or open drain.
6. Seepage from looking artesian wells	a) Soal or cap well to prevent uncontrolled flow. (b) Isolate artesian flow and carry away in deep open drain.
7. Ponded water at lower ends of fields	a) Proper levelling will eliminate pond areas. b) Pump back drain systems. c) Proper tailwater waste ditches.
8. Ponded water in fields	a) Proper grading for even distribution. b) Surface field drains.
9. Drainage water of poor quality	a) Drainage waste water must be disposed of so as to eliminate contamination down-stream (irrigated areas only)
10. Drainage water of good quality.	a) Drainage waste water can be reused or mixed with fresh water for reuse down stream.

*Source: Schwab, 1981

Soil Characteristics

The most important soil characteristic from the drainage point of view is the hydraulic conductivity or the coefficient of permeability (K) as it is generally known. It is the facility with which water moves in a soil and is a measurable property. The general value of K in an area determines how fast the surface runoff will seep into the ground. Given a flood volume and the cropping pattern (for the permissible value of submergence), the value of K will determine the residual value of the inflow flood which should be catered for by the surface drainage. Similarly, the value of K and prevailing groundwater table will indicate the necessity or otherwise of a subsurface drainage system.

Another important soil characteristic is its texture. This term relates to the proportion of various sizes of particles in a soil sample. This is an important property both for subsurface and surface drainage as it has a general relationship with hydraulic conductivity and water retention. Generally, the coarse textured soils have higher K and lower water retention as compared to fine textured soils.

Available soils data in a command area to be developed for drainage should be carefully examined. Important soil properties such as, specific yield and capillary fringe should be obtained either from the available data or by conducting quick field/ laboratory tests.

The salinity and alkalinity of soils generally develops through conjunctive use of capillary groundwater and irrigation water containing salts. Such salts not only retard the process of withdrawal of water by plants but their excessive presence (like sodium) can also cause poor infiltration. In such cases, sodium is needed to be chemically replaced by calcium and drainage system has to be installed to facilitate leaching out the replaced sodium. Such cases should be carefully tackled.

The extent of highly erodible soils in a command area should be carefully mapped. An ideal drainage system should not only aim to remove the excess runoff but also evacuate a reasonable amount of silt generated by the erosion process which finds its way into the open drains. This will be necessary to keep the maintenance costs of drainage channel as low as possible. However, depending upon the extent of erodible areas, and the volume of silt eroded, it may be desirable to replace the silt by excavating it from the drains during the dry periods. It will also be pertinent to look for soil conservation measures and suggest improved management and soil conservation. However, the decision depends upon the severity of the problem in a given command area.

Table 6 gives the influence of various soil factors on the choice of drains.

Table 6*

Assessment of Soil Factors and their Influence on Drains

Soil factors	Implied drainage considerations
1. Deep (2m or more) permeable sands, sandy loams or clay loams	Open drains or tube drain suitably spaced.
2. Deep (2m or more) impermeable silty clays and clays.	Careful management of irrigation water plus mole drains suitably spaced; surface drains and/or tube drains.
3. Shallow (1m or less) permeable sands, sandy loams and clay loams underlain by impermeable soils.	Consider deep plowing to 120-cm depth and then installation of drains at 120 cm depth with irrigation water management; tube drains at 1m depth in humid areas.
4. Shallow (l m or less) clays or silty clays underlain by permeable soils.	Tube drains suitably spaced with periodic subsoiling of upper soil strata; surface drains in humid areas.
5. Soils that gradually change to less permeable strata with depth.	Tube or open drains will have greatest effect if placed as deep as possible.
6. Soils that gradually change to less permeable strata with depth.	Tube drains will have greates efffect if placed as shallow as possible below the root zone and surface drains.
7. Deep (3 to 4m thick) impermeable clays and silty clays underlain by water -bearing coarse sands or gravels.	Sump or drainage well; surface drains in humid areas.

*(Source: Schwab, 1981)

Crops

The requirement of irrigation water for different crops varies widely. The percolation to groundwater is also variable from different types of standing crops. Sugarcane agriculture has been responsible for waterlogging in many areas. The table development of farrmlng lowland rice in new command areas has also been noticed subjecting the land to high Irrigation lossess.

While selecting crops, distinction should be made between the areas where waterlogging is developing and where it has already developed. Proper selection of crop rotation can help reduce the ill effects of waterlogging.

Crop Susceptibility and Stage of Growth : There are wide differences in susceptibility to damage amongst various crops and amongst varieties of a crop. Stage of growth at which submergence occurs also influences the extent of damage. In general, crops are more tolerant at later stages of growth than in the beginnng. Though no exhaustive studies have been conducted on crop damage vis-a-vis soil submergence and stage of growth, data pertaining to many crops on specific loactions are available. The results of these studies should be a fairly good indicator of the performance of these crops at other locations under conditions similar to that of the experiments. The information, therefore, should be useful in calculating the design flow rates.

Rice: Rice, the most tolerant crop to submergence is grown all over India covering wide variations of soils, rainfall, altitude and climate. Inspite of having lowest water use efficiency, it is an important cereal crop in some semi-arid tracts. Submergence of this crop is expected only during monsoon season. Gupta and Pandey (1981) studied the drainnage requirements of rice (Variety IR-8) for a semi-arid region with an average annual rainfall or 700 mm, (Karnal, Haryana). The average annual monsoon season rainfall is around 570 mm. The field observations suggest that every year at least for a few days, submergence depths exceed 100 mm which is taken as the permissible optimum depth of submergence. However, yield reduction occurs only in a few years when total monsoon season rainfall exceeds the value calculated for 5-year return period. At the experimental site it works out to be 780 mm. Similar results have been reported from Hyderabad (Andhra Pradesh) which also lies in the semi-arid region (Dhandapani, 1982). In order to formulate a drainage policy, Gupta and Pandey (1983) suggested a depth day index, E $_{WD}$ which can be expressed in the following form:

$$E_{wD} = \sum_{i=1}^{m} \sum_{j=1}^{n} (D_{ij} - d_i) P_{ij} F_j, \text{ for all } D_{ij} > d_i \qquad \text{........(1)}$$

Where,

E_{wD} = depth day index, cm days;
D_{ij} = depth of the stored water at ith day interval, and jth crop growth stage, cm;
d_i = optimum depth of submergence assumed as 10 cm for semi-arid stations, cm;
P_{ij} = number of days for which D_{ij} depth is maintained In the leld, days.
F_j = crop susceptibility factor for different growth stages, dimensionless,
i,j, = dummy variables for days and crop growth stages respectively;
m = total number of days;
n = number of growth stages considered.

Information of crop susceptibility factors is not available and therefore is taken as unity for all stages. The analysis of the data for the Karnal Station revealed that there is no reduction in yield till the index reaches 150. The reduction in yield at an index of 250 is only 6.4 percent. This study clearly reveals that submergence depth above 10 cm occurring once or twice for a period of one week or so may not be harmful. The studies at other places reveal that rice is most tolerant at initial and maturity stages but least at the grain formation stage.

Wheat, Barley and Oats: Wheat is another important cereal crop in India. Barley and Oats are also grown at almost the same time and are, therefore, prone to similar levels of flooding. The submergence in these crops could be either due to excess rainfall or irrigation water. Analysis of data from Ludhiana (Punjab) indicates that submergence of wheat crop for 2 days reduces the yield by 10 per cent. The yield reduction increases with increasing duration and is 25 percent for 4 days and 50 percent for 5 days submergence, Fig.3. The effect of submergence of wheat on moderately reclaimed alkali soil is reported in Table 7 (Karnal, Haryana).

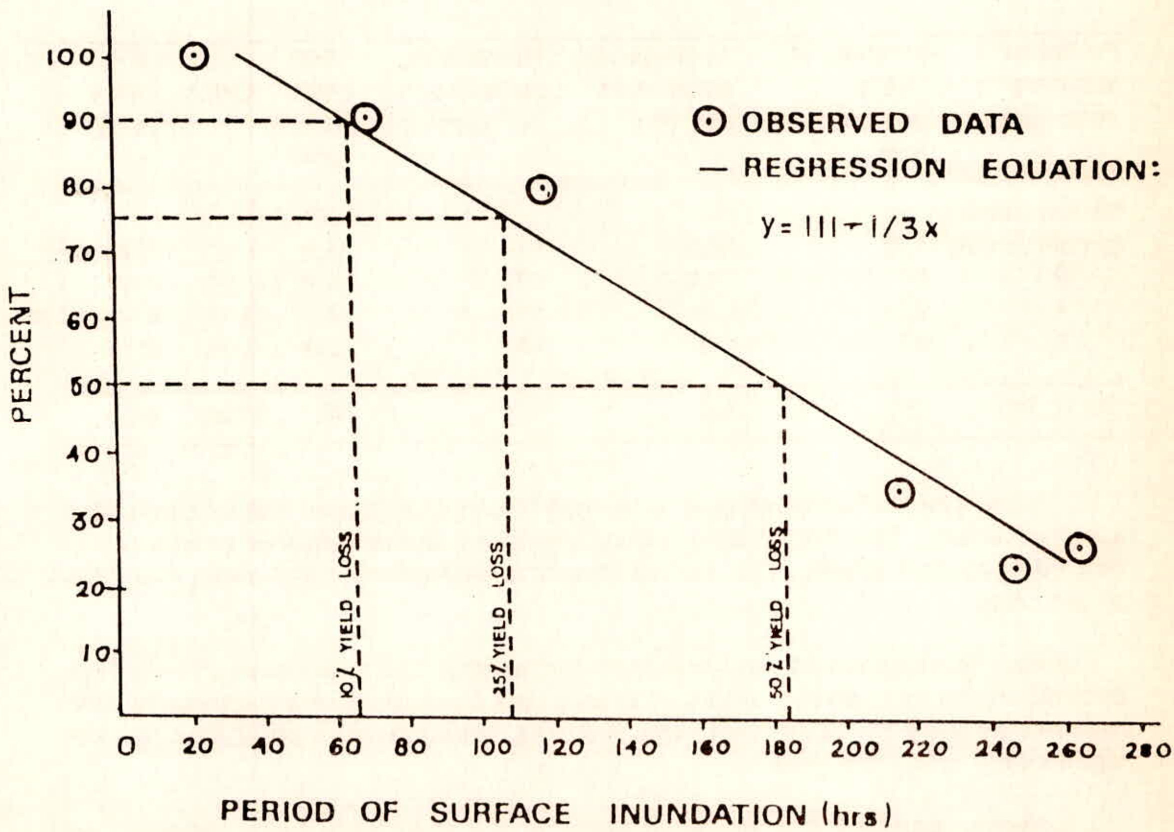


Fig. 3 Effect of Water inundation period of wheat yield
(Source Gupta and Pandey, 1979)

The data show that all the crop parameters are affected due to submergence. Wheat is rated more tolerant than barley and oats and therefore, expected damage is higher for these crops. It is reported that during flowering and initial grain formation stages, submergence could mean total loss of barley as well as of the oats crop.

Maize: Maize is comparatively more sensitive to submergence than other crops. More detailed studies have been conducted for this crop than any other single crop. The studies at Modhipura and Pusa (Bihar) indicate nearly 50 per cent loss of yield when submergence is 4 days in the initial growth stages. Submergence in initial stages is more harmful compared to later growth stages (Fig. 4). Maize is more sensitive to submergence for 2 days at 9-10 leaf stage (42 days after sowing) compared to 14 or 66 days after sowing. The yield reduction is around 16 percent. In evaluating runoff from an area planted with maize, 24 hours submergence should only be allowed.

Table 7
Effect of Short-term Water Submergence on Yield and Yield Components of Wheat.

Period of submerg-ence (days)	Number of tillers per metre row	Average len gth of earh-ead (m)	Number of spikelets per year	1000 grain weight (gm)	Yield Grain	Yield straw (t/ha)
No sub-mer-gence(Control)	133	12.5	17	35.0	4.41	6.78
2	97	11.0	17	34.8	3.65	5.34
4	82	9.8	15	34.8	3.13	4.19
6	67	9.5	13	32.3	2.35	2.74
CD (0.05)	15	1.0	1.7	NS	0.28	0.59

Cotton: The studies conducted at Navsari (Gujarat) indicated that cotton is also a sensitive crop. The loss of yield is quite significant if submergence occurs within first 50 days after sowing. The first 10 days of submergence could mean total loss of the crop.

Arhar: Tolerance of the crop increases with lapse of time after sowing. Three days flooding of the crop after 2 weeks of sowing was found to be most damaging and reduced the yield by 50 per cent. After 4 weeks, submergence upto 2 days will not significantly affect the yield.

Cowpea: Seedling and flowering stage of the crop have been identified as sensitive in Delhi. Submergence for one day reduced the yield by 12.5 percent.

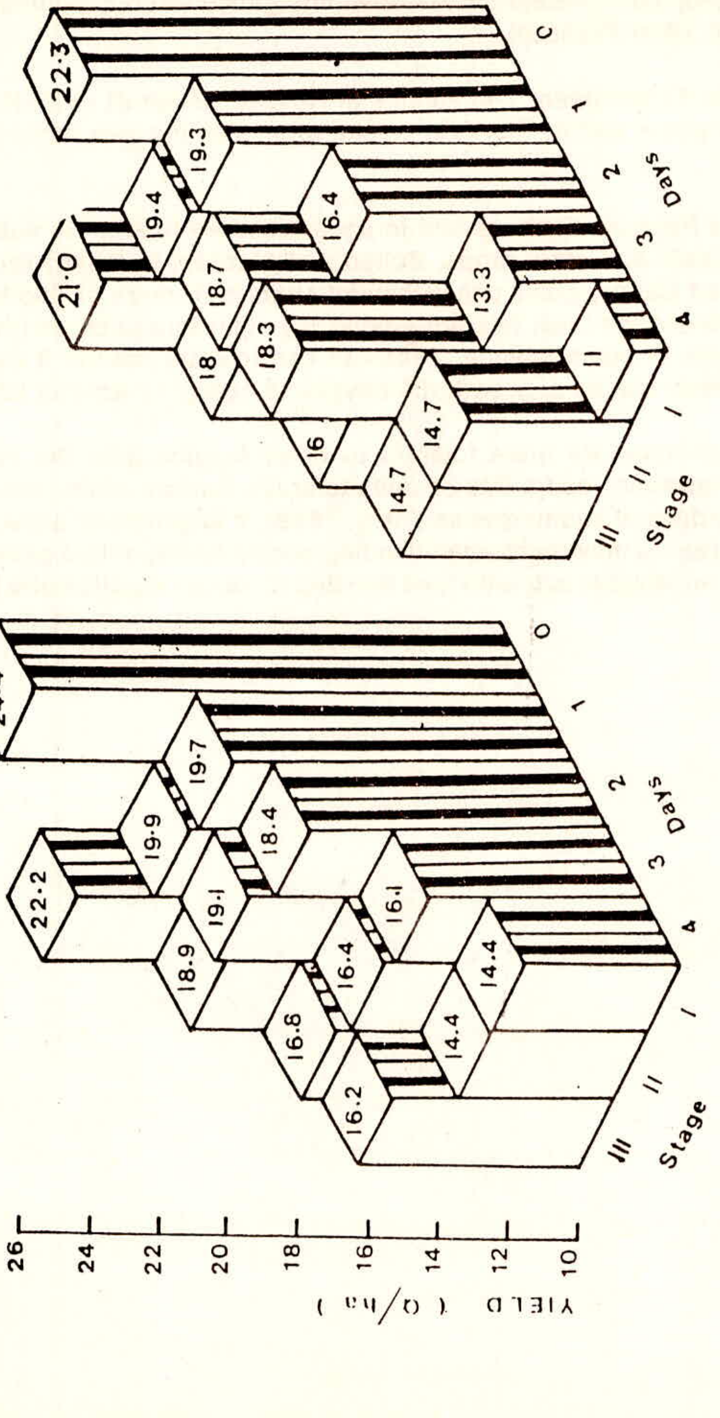


Fig. 4 Effect of stage of growth and duration of flooding on miaze yield

Groundnut: Pod development stage is more sensitive to submergence than flowering. This crop can tolerate 3 days of submergence without significant loss of yield (Pantnagar, Uttar Pradesh).

Soybean and Clusterbean: The studies at Navsari (Gujarat) revealed that one week of submergence during first four weeks after planting can reduce the yield significantly.

Grasses and Forages: Grasses and forages are more tolerant to submergence compared to cereals and other crops. Bolton and Meckenzie (1946) reported that Timothy and Reed Canary grass can withstand 49 days or more of flooding. Sweet clover and alfalfa are the least tolerant among the eight forage crops tried, with 9-12 and 10-14 days of submergence. Teosinite can tolerate around 9 days of root submergece in early stages of growth (30 days) and nearly 12 days at later stages.

Trees: Forest trees are more tolerant to water logging than the horticultural plants. Pear is, however, reported to be quite tolerant. Apricot, plum, and peach die only within a few days of submergence (Likry, 1938). It is generally understood that damage to fruit trees is maximum when flooding occurs during active growth stages. Exotic tree, like, eucalyptus can withstand flooding for larger duration and for greater depths.

DESIGN CONSIDERATIONS FOR OPEN DRAINS

A typical layout of a drainage network, from field drains to the outlet point is shown in Fig.5.

The design flow rates; channels discharge capacities and their dimensions; broad principles of location, spacing and alignment of drains; typical inlet and field structures; drainage outlets, broad construction practices, and cost estimates are briefly discussed in this section.

Design Flow Rate

Volume of Runoff

It is often desirable to predict the total volume of runoff which may originate from a catchment area. Combined with time of flooding allowed for a particular crop, it can be used to calculate the design flow rate. Three techniques are generally followed to estimate the volume of runoff.

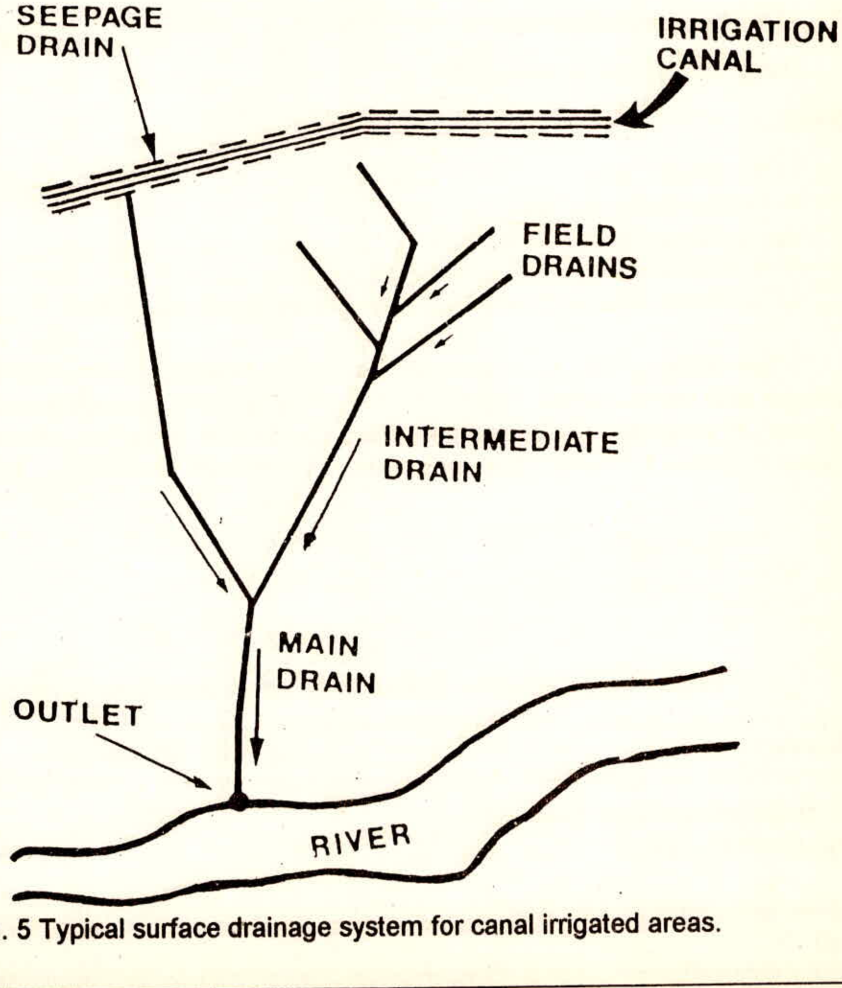


Fig. 5 Typical surface drainage system for canal irrigated areas.

(i) US Soil Conservation Service (USSCS) method (1972) as modified to conditions in India.
(ii) Use of drainage coefficients
(iii) Empirical formulae

Soil Conservation Service Method

This method was developed in the United States from many years of storm flow records of agricultural watersheds. The Ministry of Agriculture, Govt. of India utilized this technique for conditions in India. The method is commonly referred to as Curve Number Metnod or estimating runoff.

In this method, the rainfall is converted to runoff by the following mathematical relation,

$$Q = (P-Ia)^2 / (P-Ia+s) \quad \text{....(2)}$$

with the condition that

$P>Ia$; $S = Ia+G$, $G = p-Ia-Q$

Where,

Q = runoff, mm,
P = precipitation, mm,
Ia = Initial abstraction, mm,
S = Potential maximum retention, mm,
G = Precipitiation less initial abstraction and runoff, mm.

Initial abstraction, Ia, essentially consists of losses from interception, surface storage and water which infiltrates prior to runoff. It is usually incorporated as a fraction of potential maximum retention, S, Values of Ia for Indian conditions are shown in Table 8. As an example let us incorporate Ia = 0.35 in Eq. (2)

$$Q = \frac{(P-0.3S)^2}{P+0.7S} \quad \text{....(3)}$$

Table 8
Initial Abstractions Commonly used in Indian Conditions

Region	Initial Abstraction
All regions including black soil regions with AMC I	0.3S
Black Soil regions with AMC II and III	0.1S

Antecedent Moisture Condition (AMC): The watershed wetness prior to the runoff estimation is called Antecedent Moisture Condition (AMC). Three levels of AMC are used:

AMC-I Lowest runoff potential. The watershed soils are dry enough for satisfactory cultivation to take place.

AMC-II The average condition

AMC-III Highest runoff potential. The watershed is practically saturated from antecedent rains.

The AMC is estimated from the 5-day antecedent rainfall by the use of Table 9, which gives the rainfall limits by season categories.

The rainfall limits are plotted as boundary points for the AMC groups. No upper limit is intended for AMC-III.

The 5-day rainfall amount used is a simple total. For example if the AMC for a watershed is to be estimated for the data of July 20, which is in the growing season, and if the rain in mm for preceding five days was recorded as:

July 15	July 16	July 17	July 18	July 19	Total
3.0	15.0	0.0	9.0	20.0	47.0

From Table 9, the appropriate moisture group for 47 mm total rainfall and "growing season" reads out to be AMC II.

If S is known, Q can be calculated with the help of Eq. (3) for a given value of P. Curve numbers are evaluted from appropriated tables to calculate S. The value of S is given by the relation,

$$S = (25400/CN) - 254 \qquad ....(4)$$

Where,

CN = Curve number (weighted)

Once the value of Q is known in mm, the volum of runoff can be calculated simply by the relation,

$$\text{Volume of runoff} = 10^{-3} \times Q \times \text{Area in ha -m} \qquad ....(5)$$

Where,

Area is in ha and Q is in mm

The exact procedure for calculating the curve numbers and the volume of runoff is described in the following steps.

Table 9*

Antecedent Rainfall Conditions to Evaluate Antecedent Moisture Condition

General Description	5 days antecedent rainfall (mm) Dormant season	Growing season	Condition
Optimum soil condition from about plastic limit to wilting point	12	36	I
Average value for annual floods	12-28	36-53	II
Heavy rainfall or light rainfall and low temperatures within 5 days prior to the given storm	28	53	III

*(Source - Handbook of Hydrology, Min. of Agril., 1972).

Step I Determine the size of the drainage watershed and the extent of different types of soils and land use. Evaluate the area as percent of the total area under various hydrological soil groups.

Step II The rainfall data for the return period and duration considered safe for various crops in the protected region are estimated. In general 24-hour rainfall for 5 to 10 years return period is taken for design. In agriculture, 5-year return period values are more common. The point rainfall values reduction factors given in Table 10. The runoff potentials for various soil groups are given in Table 11.

Table 10

Areal Correction Factors for Rainfall

Drainage Area (ha)	Correction Factor
Upto 50	1.000
Upto 100	0.999
Upto 200	0.998
Upto 500	0.997
Upto 1000	0.996
Upto 2000	0.994
Upto 5000	0.936
Upto 10000	0.871

Table 11
Hydrologic Soil Groups for Determining Runoff Potential

Group	Runoff Potential	Characteristics
A	Low	Soils having high infiltration rates even when throughly wetted and consisting chiefly of deep,-well to excessive drained sands or gravel. Soils have a high rate of water transmission.
B	Moderately Low	Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textured soils. These soils have moderate rate of water transmission.
C	Moderately high	Soils having below average infiltration rate after presaturation. Comprise of shallow soils containing con siderable clay and colloids though less than those of group D.
D.	High	Soils having very slow infiltration rates when thoroughly wetted. It consists of clay soils with a high swelling potential, waterlogged soils, soils with a clay pan or clay layers at or near the surface and shallow soils cover nearly impervious material.

Step III In this step Curve Numbers (CN) for the area are read from Table 12. The land use and agricultural practices should be found out from actual conditions prevailing in the area. Whereas the conditions for agricultural lands are clear in Table 12, further information about orchards, forests and pastures could be obtained from Table 13.

The figures for curve numbers are for AMC II only. For obtaining corresponding numbers for other AMC's the conversion factors as given in Table 14 may be used.

Design Curve - To reduce calculation work, curves are available for directly evaluating runoff for a given storm. The four set of curves are Figs. 6 to 9 One of the sets which explains the hydrologic conditions of the area is used to calculate the runoff. Once the curve number of known, the runoff corresponding to this CN is evaluated from one or the other figure.

Table 12
Runoff Curve Numbers for Hyrologic Soil Cover Conditions

Land Use	Agricul-ture Practice	Hydrologic conditions	Antecedent Moisture Condition II Ia=0.3S A	B	C	Ia=0.1S D
			Curve Numbers			
A. Agriculture						
Culti -vated	Straight row contoured		76	86	90	93
		Poor	70	79	84	88
		Good	65	75	82	86
		Poor	66	74	80	82
Terraced	Contoured	Good	62	73	77	81
		Poor	67	75	81	83
	Bunded	Good	59	69	76	79
	Paddy*		95	95	95	95
B. Orchards, Forests & Pastues						
Orchards	- With understory cover		39	53	67	71
	- Without understory cover		41	55	69	73
Forest	- Dense		26	40	58	61
	- Open		28	44	60	64
	- Shrub		33	47	64	67
Pasture	- Poor		68	79	86	89
	Fair		49	69	79	84
	Good		39	61	74	80
C. Non-Agricultural						
Wasteland			71	80	85	85
Roads (earthern)			73	83	88	90
Hard Surface Areas			77	86	91	93
D. Supplementary for Sugarcane Crop						
Limited Cover, straight row			67	78	85	89
Partial cover, straight row			49	69	79	84
Complete cover, straight row			39	61	74	80
Limited cover, contoured			65	75	82	86
Partial cover, contoured			25	59	45	83
Complete cover, contoured			6	35	70	79

* 100 mm rainfall is assumed as storage. Remaining rainfall is used to calculate the runoff with CN=95 which is independent of the soil type.

Table 13
Hydrological Conditions for Pastures, Forest and Orchards

Vegetation condition	Hydrologic conditions
PASTURES	
Heavily grazed. Has no mulch or has plant cover on no less than 50 percent of the area.	Poor
Not heavily grazed. Has plant cover on 50-75 percent of the area	Fair
Lightly grazed. Has plant cover on more than 75 percent of the area	Good
FOREST AND ORCHARDS	
Heavily grazed regularly burned. Litter, small trees, and brush are destroyed.	Poor
Grazed but not burned. There may be some litter but woods are non protected.	Fair
Protected from grazing. Litter and shrub cover the soil	Good

Table 14
Corrected Curve Numbers for Actual Antecedent Moisture Condition of the Watershed

CN for Condition II	CN for Condition I	Ia=0.3S CN for Condition III	Ia=0.1S CN for Condition III
100	100	100	100
95	87	98	98
90	73	96	96
85	70	94	94
80	63	92	92
75	57	88	88
70	51	85	85
65	45	82	82
60	40	78	78
55	35	74	74
50	31	70	70
45	26	65	65
40	22	60	60

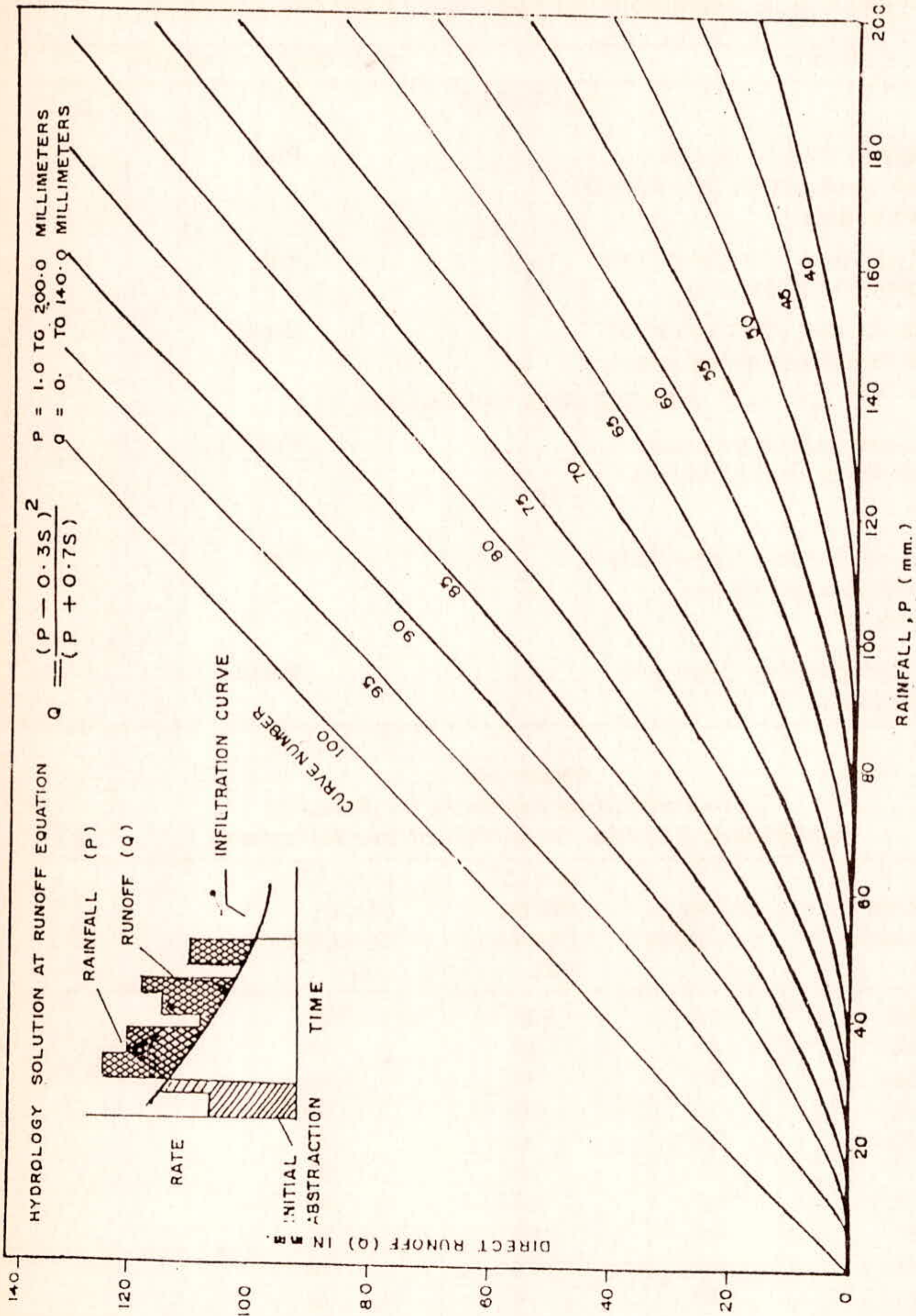


Fig. 6 Runoff curves for initial abstraction as 0.3S (0-200 mm)

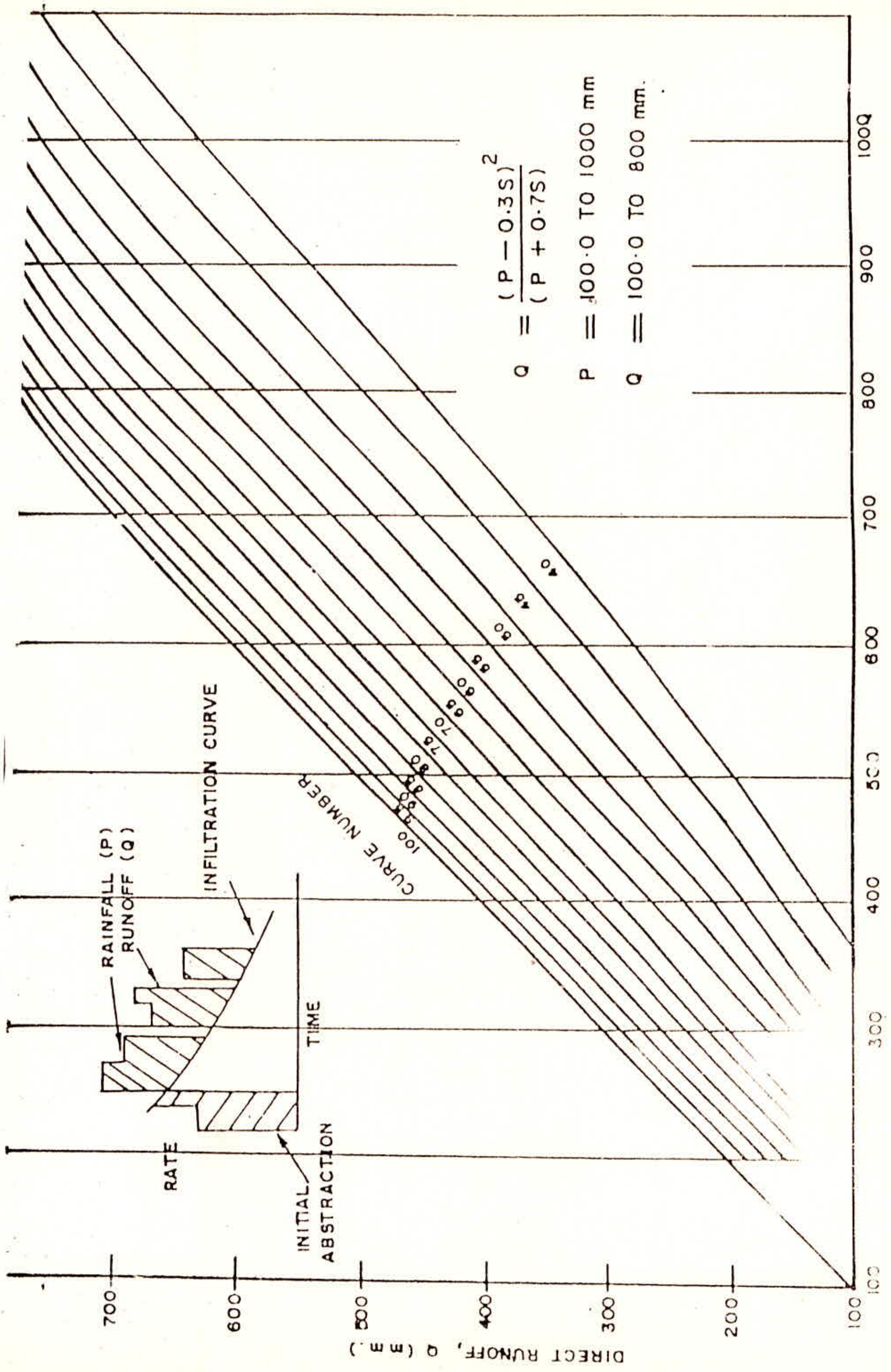


Fig. 7 Runoff curves for initial abstraction as 0.3S (100-1000 mm)

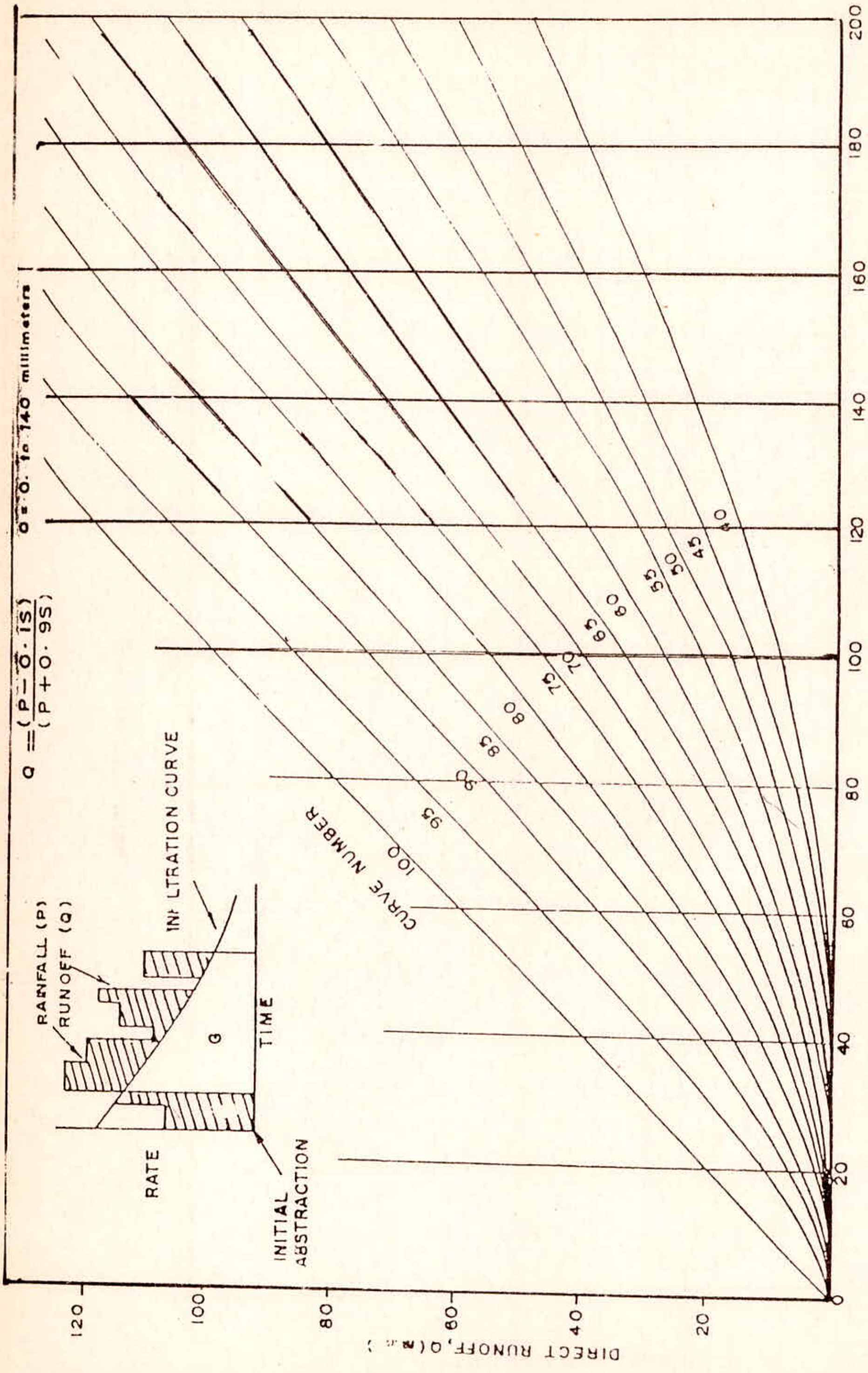


Fig. 8 Runoff curves for initial abstraction as 0.1S (0-200 mm)

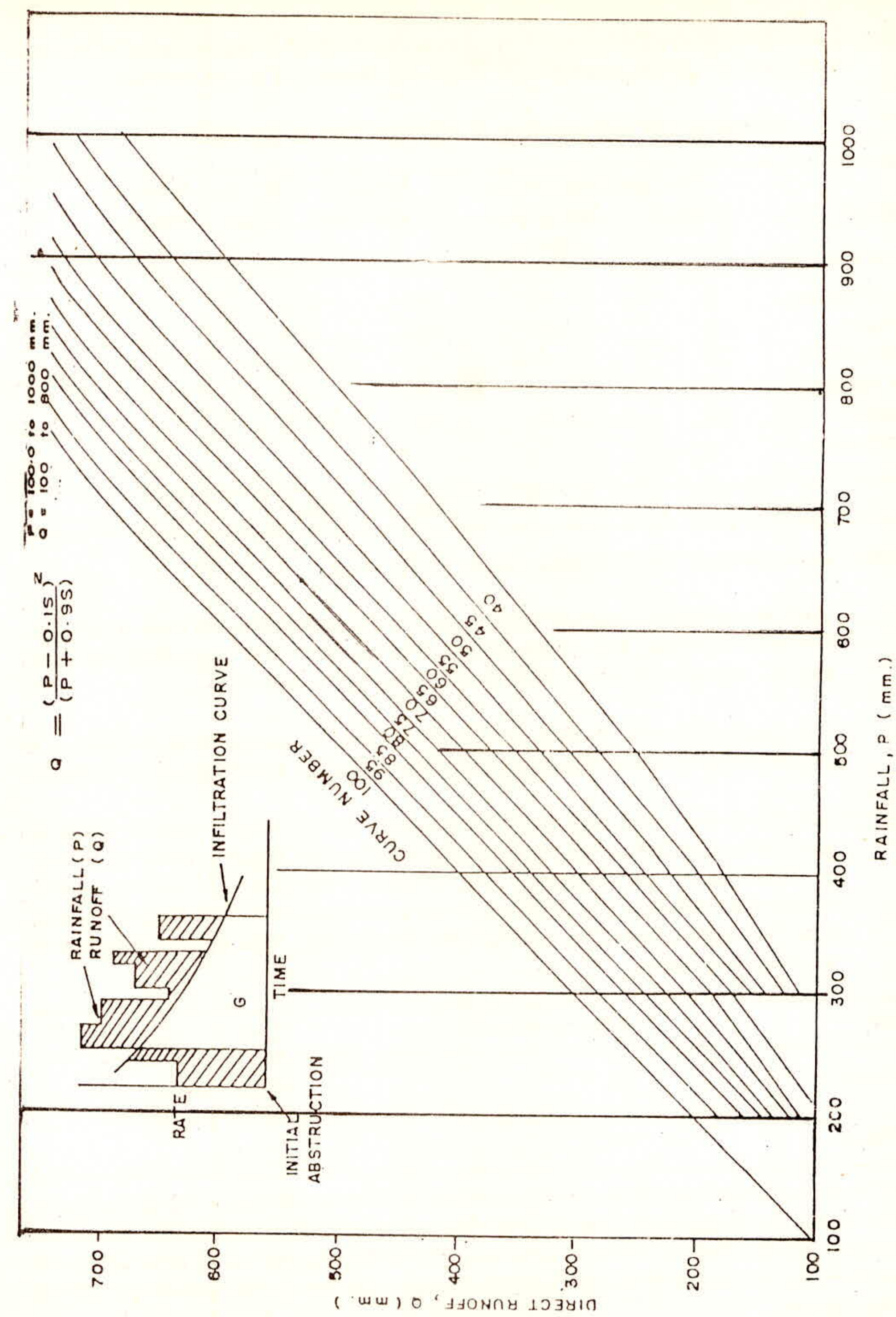


Fig. 9 Runoff curves for initial abstraction as 0.1S (100-1000 mm)

Step IV Calculate the weighted curve numbers for different soil groups and land use patterns. A typical example for such calculation is given below.

Example for Calculating Weighted Curve Number

Area description	Percent area	Hydrologic soil group area	Curve number	Curve time Number percent
Roads (Earthen	2	B	83	166
Wasteland	10	B	80	800
Pasture (poor)	20	B	79	1580
Forest (dense)	4	B	40	160
Cultivated (straight row)	64	C & D	92	5888
			Total	8594

Weighted curve number = 8594/100 = 85.94 = 86 (say)

Step V With the weighted curve number, S is calculated with the help of Eq.(4). Once S is known, the depth of runoff to be removed is worked out from Eq.(2) using Ia=0.1S or 0.3S depending upon the soil.

Step VI The depth of runoff is converted into volume of runoff using Eq.(5). The procedure are further illustrated by the use of an example which follows.

Example : Determine the estimated maximum runoff during Kharif season for a 5-year return period which may be expected in the Sogaria sub-catchment of 1600 ha in the Chambal CAD Project, Rajasthan. For this region Antecedent Moisture Condition III may be assumed. The following land use, soil conservation practices and Hydrologic Soil Group (HSG) are applicable to area.

Land Use	Area (percent)	HSG
Fallow Land	31	Kharif paddy
Paddy	24	Kharif paddy
Other crops	45	D

Solution: In this example we propose to solve the problem with two different angles. In the first case, we propose to find out the total volume of runoff expected from the area. It is needed to design the storage structure. In the second case drainage rate will be worked out for use in drainage system design. Following general assumptions have been made.

i) Ordinary crops are cultivated across the slope and fields are bunded.

ii) In the field with kharif paddy and wastelands, 100 mm of rainfall can be stored before the runoff will start (Handbook of Hydrology, Ministry of Agriculture, Govt. of India).

iii) Tolerance of crop to flooding has been taken as 40 hours for ordinary field crops and 72 hours for kharif paddy and wastelands such that 24 hour storm runoff is supposed to be drained out during these periods.

Total Volume of Runoff: For calculation of runoff Eq. (2) will be used For Hydrologic Soil group D and paddy, Ia = 0.Is. Therefore, in our calculations Ia will be taken as 0.IS.

Analysis of rainfall data revealed that for this catchment, 24-hour rainfall for a recurrence interval of 5 years is 125 mm. Therefore, the rainfall after carrying out correction for area, (Table 10) is 121.7 or approximately 120 mm.

Curve members for HSG kharif paddy is 95 and for ordinary crops (bunded, poor) is 83 (Table 12). After making correction for antecedent moisture condition (Table 9), the curve members for the two cases are 98 and 91 respectively. Therefore using Eq. (6).

S (Kharif paddy) = 25400/98 - 254 = 5.2
S (Ordinary crops) = 25400/91 - 254 = 25.1

Weighted runoff for the watershed is calculated as under:

Land use	Area %	Q (mm) Eq. (2.1)	Weighted runoff (Q x percent area)
Fallow land	31	15.37	476.47
Paddy	24	15.37	368.88
Other crops	45	96.80	4356.00
			5201.35

Therefore, weighted Q = 5201.35/10 = 52.0 mm
Therefore, volume of runoff from Eq. (5) $= 10^{-3} \times 52.0 \times 1600$
$= 83.20$ ha-m

Drainage Rate- A simple procedure described in CWC Handbook for Drainage of Irrigated areas mainly uses curves shown in Fig. 10. From these curves, the yalue of curve number (CN) for 1600 ha catchment area for each crop against its submergence tolerance are obtained. Discharges into the drain form the three parts of the catchment are computed as below:.

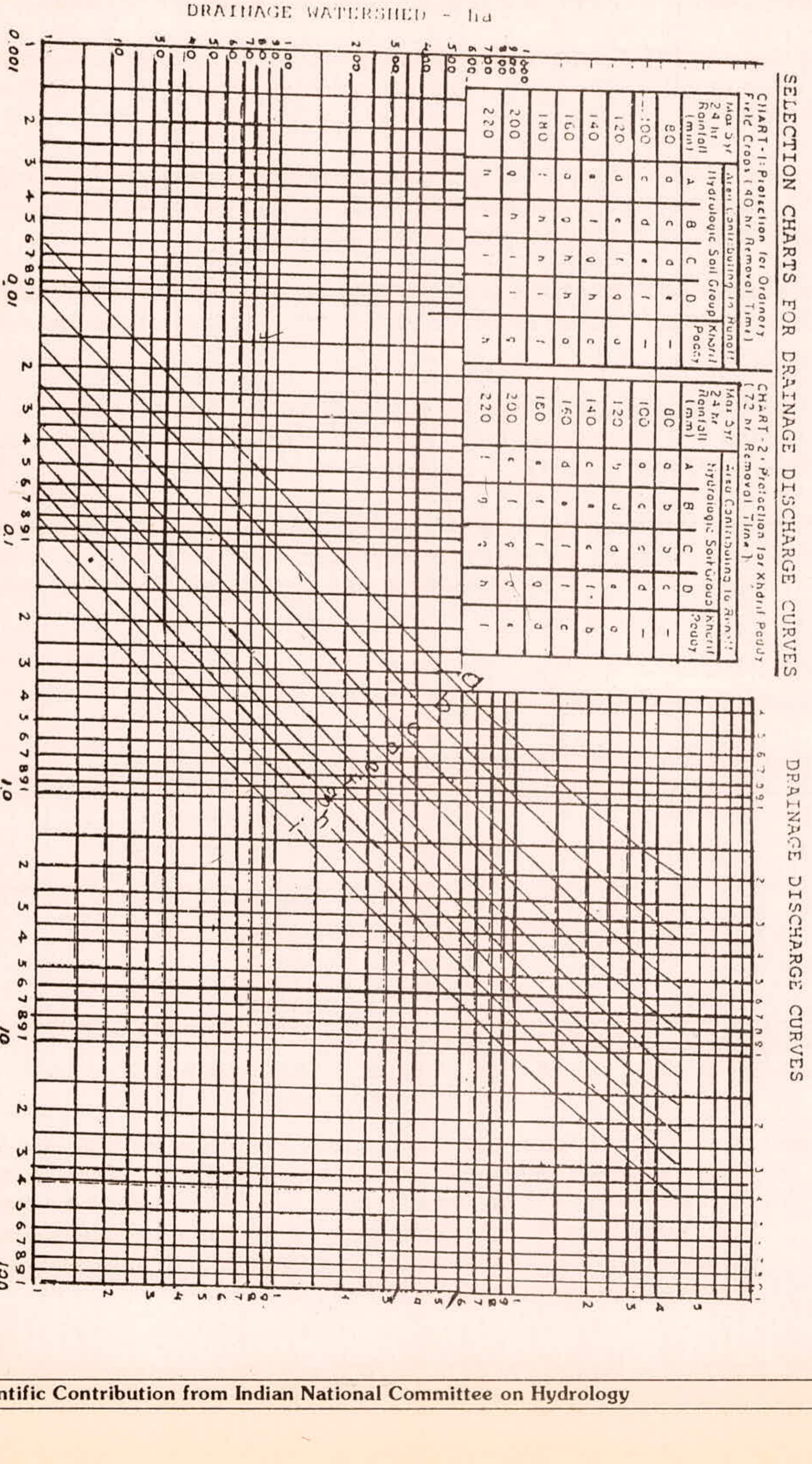


Fig. 10 Drainage area - discharge curves

Crop/Land	HSG	Curve No.	Curve Reading (cumecs)	Catchement Fraction	Discharge Col. (4x5) (Cumecs)
1	2	3	4	5	6
72 hours tolerance					
Fallow Land	Kharif Paddy	b	1.4	0.31	0.434
Paddy	Kharif Paddy	b	1.4	0.24	0.336
40 hours tolerance					
Other Crops	D	h	12.0	0.45	5.400
		Total for 1600 ha = = 6.17x1000/1600 1/s/ha = 3.85 1/s/ha.			6.170

Drainage Coefficients

Gupta et al (1971) worked out drainage coefficients for grain crops, vegetable crops and for rice separately. The value of Ia has been assumed to be 0.25. The drainage coefficients for different locations in India as suggested by Gupta et al are presented in Fig. 11 and Table 15. These value can be used for rough estimates of design discharge. if no other data are available.

Table 15
Estimated Surface Drainage Coefficients for Various Crops at Different Locations in India.

Location (Fig.11)	Drainage Coefficient (mm/day)		
	Grains	Vegetables	Rice
1	14	13	8
2	10	10	2
3	12	11	2
4	36	28	14
5	22	18	7
6	22	22	6
7	34	32	12

8	25	21	16
9	25	22	16
10	35	30	4
11	34	27	23
12	34	34	28
13	36	41	29
14	32	18	6
15	17	20	12
16	18	30	13
17	29	29	18
18	37	39	24
19	37	26	24
20	15	19	10
21	16	19	10
22	22	22	14
23	19	20	12

Empierical Formula

For calculating runoff, following empirical formula are generally used:

(a) Bostom Society Formula, Q = C A, where C is a factor to be determined on the basis of annual rainfall in a catchment, and A is area in sq miles. Q is runoff in cusecs.

(b) Rational Method, Q = CIA, Where Q is runoff in cusecs, C is runoff coefficient depending upon the characteristics of the drainage area, I is the uniform rate of rainfall intensity in inches/hour for a duration equal to the time of concentration and A is the drainage area in acres. Various values of C are used in different conditions. For a fuller treatment reference may be made to Ref. 12.

Channel Discharge Capacity, Velocity and Dimensions

Velocity

For open channels with uniform flow, Manning's formula is used for calculating the velocity in the channel. The formula is:

$V = R^{2/3} S^{1/2}/n$ (in metric units) ....(8)

$Q = A \times V$ ....(9)

Where,

V = average velocity of flow in m/sec

n = roughness coefficient

R = A/P, the cross sectional area divided by the wetted perimeter

S = hydraulic gradient, generally taken as bed slope in open channels, m/m

A = Cross sectional area of flow in sq m,
P = wetted perimeter, m
Q = discharge in Channel, $m^{3/s}$

Permissible Velocity

Permissible values of velocity to avoid scour may be adopted from Table 16.

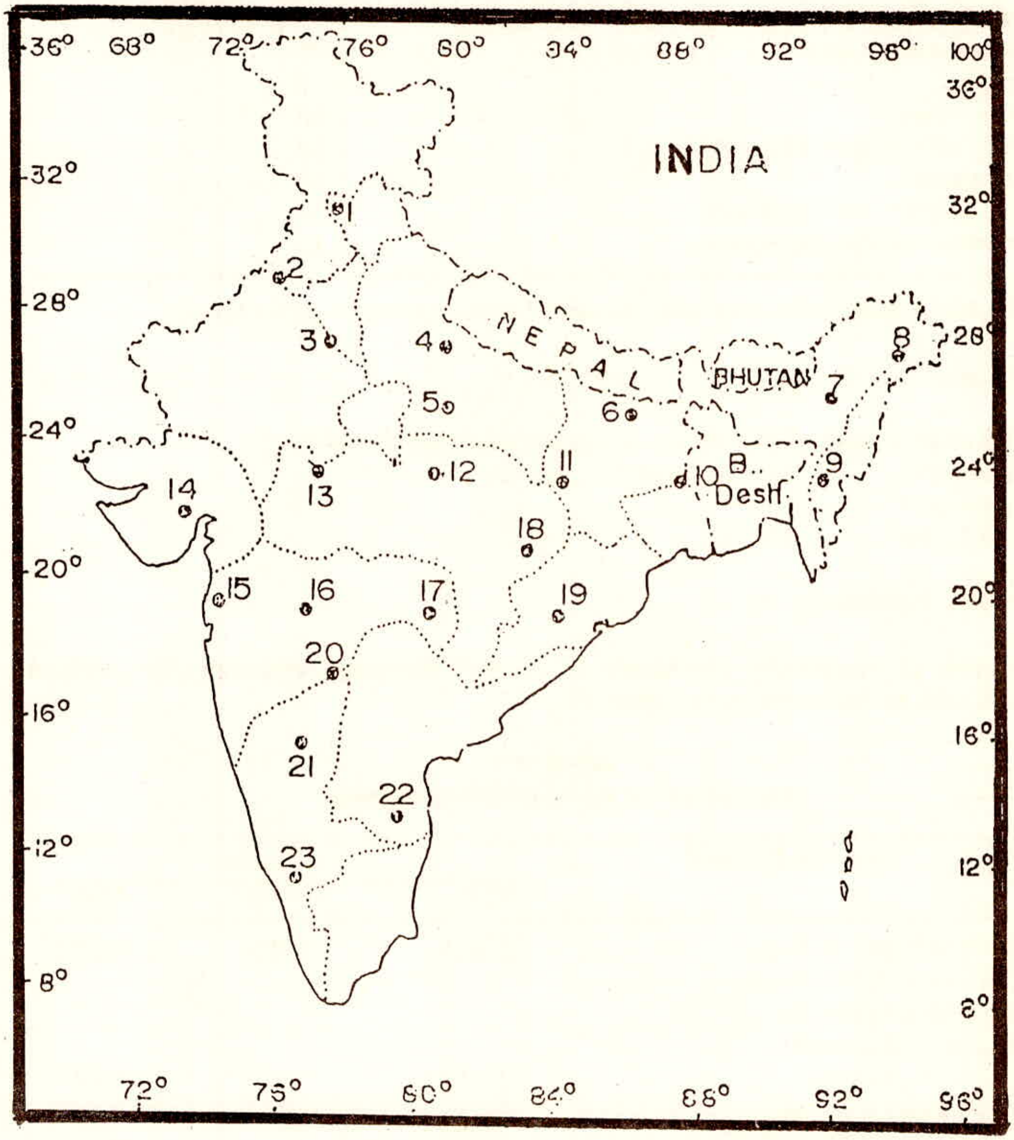


Fig. 11 Region for D.C. for use with Table 15

Table 16
Maximum Allowable Velocities in Channels for Different Soil Textures

Soil Texture	Maximum Allowable Velocity (m/sec)
Very light silty sand	0.30
Light loose sand	0.50
Coarse sand	0.75
Sandy and sandy loam	0.75
Silty loam	0.90
Firm clay loam	1.00
Stiff clay or stiff gravelly soil	1.50
Coarse gravel	1.50
Shale, hardpan, soft rock etc.	1.80
Hard cemented conglomerates	2.50

Slightly higher velocities are allowed if water contains colloidal silt.

Side Slopes

The side slopes of the drains are generally kept as below,

Firm soil 1.1 (horizontal : vertical)
Loam soil 1.5:1
Sandy soil 2.5:1

Roughness Coefficient "n"

Values of roughness coefficient 'n' in the Manning's equation for earthen channels can be selected from Table 17.

Table 17*
Values of 'n' for Earthen Channels

Sl. No.	Type of Channel	n values		
		Min.	Design	Max.
1.	Earth bottom, rubble sides drainage ditches, large,no vegetation	0.028	0.032	0.035
2.	(a) 0.8 m hydraulic radius	0.040		0.045
	(b) 0.8-1.2 m-do-	0.035		0.040
	(c) 1.2-1.5 m -do-	0.030		0.035
	(d) 1.5 m -do-	0.025		0.030
3.	Small drainage ditches	0.035	0.040	0.040

4.	Stony bea, weeas on banks	0.025	0.035	0.040
5.	Straight and uniform	0.017	0.0225	0.025
6.	Winding and slugish	0.0225	0.025	0.030

*(Source- Schwab et al, 1981)

The values of 'n' in Table 17 increase with poor maintenance of drains and weed growth. In newly dug channels, the value of 'n' is lower and the velocities are higher than design values.

For ease of computation, the nomograph in Fig.12 can be used for Manning's equation. Another graphic solution for higher values of R is given in Fig.13.

Channel Depth and Width

The depth should be sufficient for the design discharge. However, if the drains are meant to control the watertable, the depth of main and sub main drains should be kept between 2 m to 3 m. Effective bed levels of the channels, depend on the outfall available in the natural stream in which the main drain discharges. Borings along the drain alighment indicate the location of murum or pervious layer in the bed portion. In case the drain depth does not puncture the pervious strata, short vertical holes filled with filter material can help in releasing the groundwater flow into the drain. Such holes are made in the bed of the drain at suitable intervals. The bed width also depends on the peak design discharge at different points.

After the channel grade, depth and side slopes are selected. The bottom width can be computed for a given discharge. The bottom width for the most efficient cross section and minimum volume of excavaton is determined by the formula :

$$b = 2d \tan \theta \qquad \text{....(10)}$$

where,

b = bottom width,

d = design depth,

θ = angle of side slope

The minimum bottom width should be 1.2 m except in small laterals. It is not always possible to design for the most efficient cross section because of construction equipment limitations, allowable velocities, and increased maintenance.

Cross-section of Drain

The following factors should be considered by the designer in adjusting depth, bottom width and side slopes to obtain the required cross sectional area of a drainage channel.

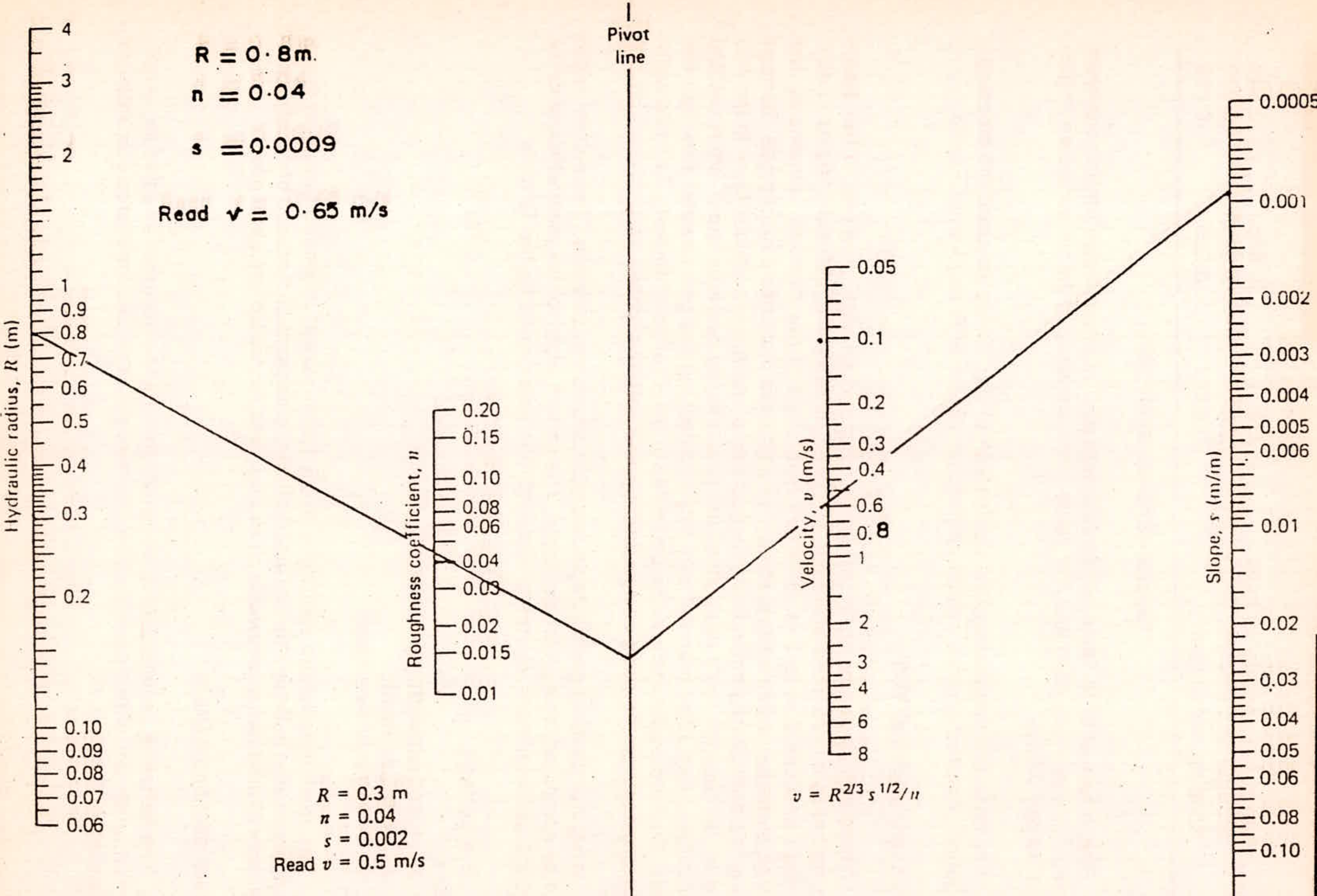


Fig. 12 Nomograph for Manning's velocity equation (I)

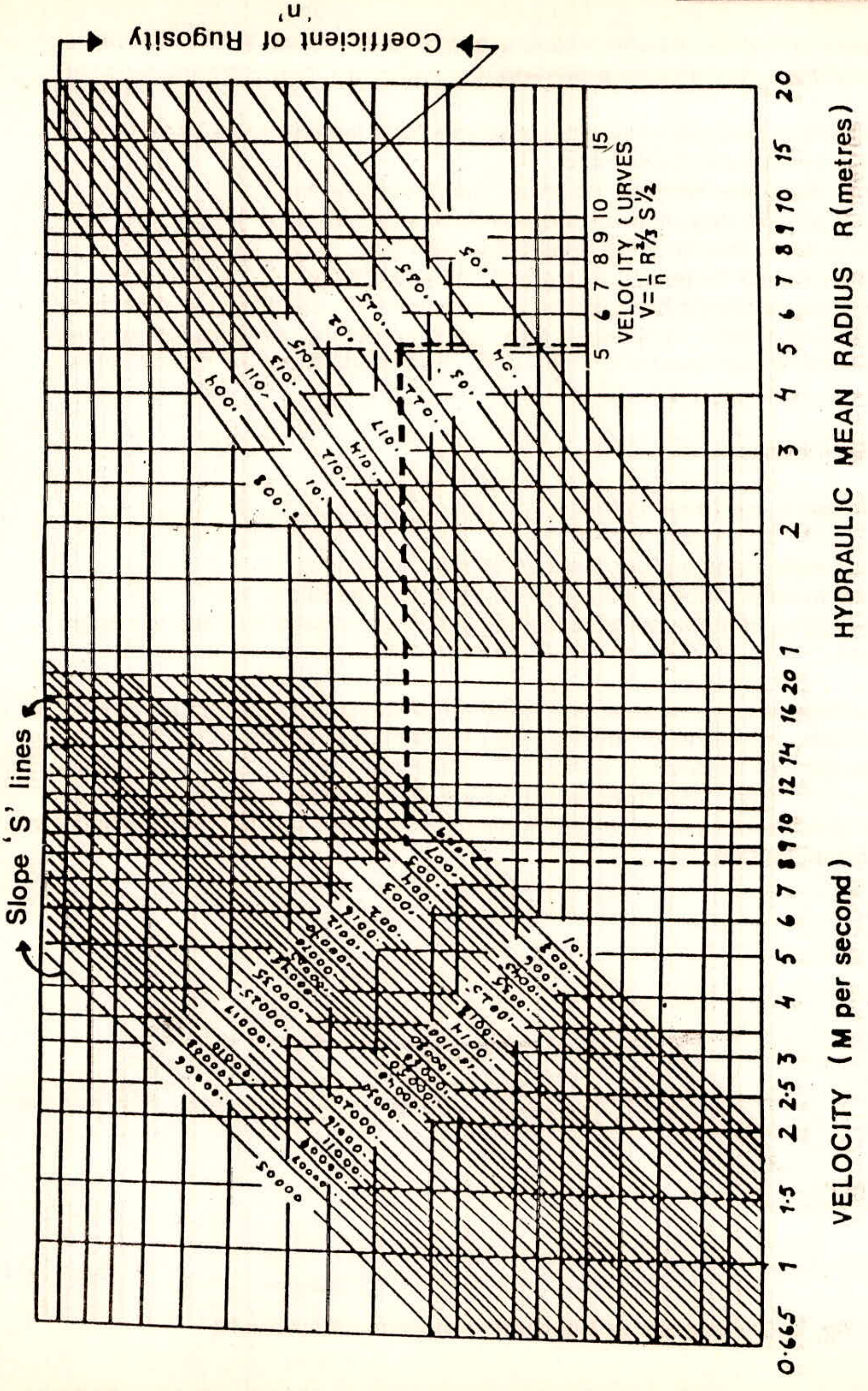


Fig. 13 Nomograph for Manning's velocity equation (II)

i) A deeper ditch gives a higher velocity than a shallow one.
ii) A deeper ditch may provide a better opportunity for future pipe drainage on farms.
iii) A deeper ditch probably will remain effective for a longer period as sediment bars may cause less obstructions.
iv) A deeper ditch requires less waterway than a shallow one.
v) A deeper section may uncover unstable layers of soil.
vi) A shallow drain may be more practical to maintain.
vii) The depth should be related to a good outlet condition.
viii) Design velocity should be selected so as to maintain the ditch cross section over a period of time. In channels that flow intermitently, some scouring may be desirable at high flows to counteract sediment deposition that occurs at low flows.

Berms and Spoil Banks

Adequate berms are required to :

i) provide for work areas and facilitate spoil bank spreading;
ii) prevent excavated material falling/rolling back into the ditch; and
iii) lessen sloughing of drain banks caused by heavy bank loads too near the edge of the bank.

Drains normally involve excavation of earth which is used in making roadway on one or both sides. Provision of roadway on one bank leaves the other bank for depositing the balance excavation as spoil. The spoil bank should have side slopes of minimum 1.5:1, (Fig. 14). However, provision of 2:1 slope shall have greater advantage of stability and greater scope for plantation of trees but has the drawback of more land requirement.

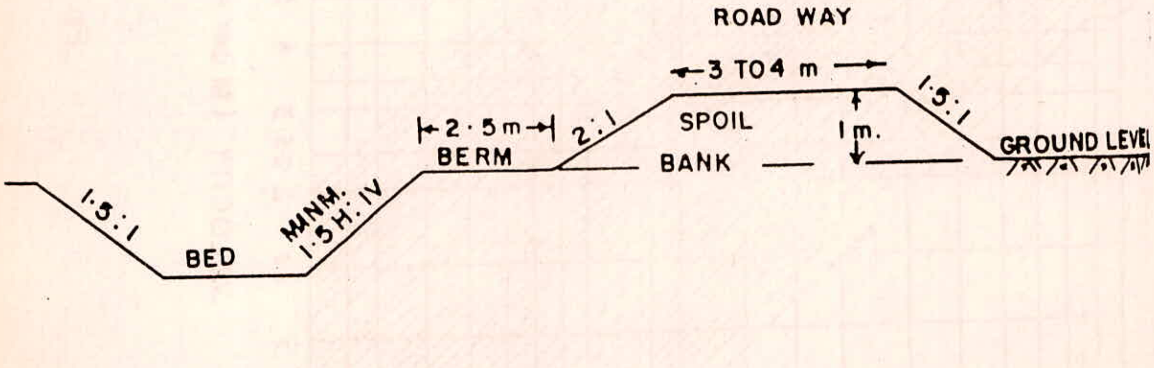


Fig. 14 Cross section of a drain showing berm and spoil bank

The berm width for drains should not be less than the depth of cutting. Minimum width of berms are given in Table 18.

Table 18
Minimum Berm Widths

Depth of Drain (m)	Minimum Berm Width (m)
0.6-1.2	1.2
1.2-1.8	1.8
1.8-2.4	3.0
More than 2.4	4.5

The berm width should be increased in unstable soils where it is feared that the drain will enlarge the section. Such locations should be shown in the longitudinal section and other drawings of the drain. The best use of the spoil and how far it can be spread are determined by the type of excavated soil, the adjacent land use, the need for roads, and the maintenance measures. In some locations, spoil banks can be spread and used to good advantage for farm and drains is kept slightly greater than required for obtaining sufficient earth for farm roads along the drain. The spoil is spread until the height is reduced to an economical figure, usually not more than 1m.

When unproductive soils occur at lower depths in large drains, the good soil should be segregated during construction, if practicable. Fertile soil may be used for land grading, shaping in the adjacent fields, or as topsoil on the spoil banks. Safe entry of surface water through the spoils into the drain should be provided. In placing and spreading the spoil, points of entry and type of inlet structure to be used need to be determined.

Freeboard

Freeboard is the additional depth above the design water level used to provide a safety factor for the design storm. Generally a freeboard of 25% of designed depth is provided.

Seepage Drains

Wherever the design water surface of a canal is above the ground level, the banks of the canal are made up of filled earth through which seepage takes place. The volume of seepage depends upon the height of water level above the ground. Part of this seepage goes into the subsoil and part comes out of the land surface, creating wetness. Excessive seepage from unlined canals in sandy/sandy loam soils results in waterlogging near the toe of the canal banks. Hence, drains are constructed along the embanked canal banks to dispose off the seepage in about top one meter of the land surface. Seepage drains should be constructed along constant running irrigation channels, i.e. main or branch canals and in some cases, along the distributaries. In heavy embankment reaches of canals with non-cohesive soils in the banks, the seepage at the toe of canal bank on one side may be about 0.1 to 0.5 cumes in a length of about 1 to 2 km of the canal. The bed width of the seepage drain to cater for this seepage volume may be small but from practical considerations, a minimum bed width of 0.6 m is dug out. It may also be mentioned that volume of canal seepage water going into the seepage drain depends on the depth of barrier layer below the ground surface. A typical section of a seepage drain is shown in Fig. 15.

Inlets from the toe of canal banks are made at about 100 m spacing to pass rain water in the seepage drains. The bed and inside slopes of the inlets are grassed to safeguard against scouring. The portion of the seepage drain, which acts as chute for the rain water from the inlet is also sodded. Normally, the outer slopes of canal banks in filling reaches have grassed surfaces for protection against damage from rain and cattle traffic. If this is not done, not only canal banks shall be damaged but it will also lead to frequent choking of seepage drains by accumulation of scoured earth from canal banks. It may be mentioned here that a seepage drain has a short length because such drains terminat in the first intermediate drain and thereafter, new seepage drains is constructed. (Example is Goverdhan Drain in Mathura District, Uttar Pradesh).

In embanked reaches, the seepage drains may be contained on the embankment. However, the embanked drains are subject to hazards as follows :

i) Heavier floods than the design storm may cause breaches which may result in heavy damage.
ii) Weeds may decrease the drain cross section and cause rise in flood water level.
iii) Man-made cuts in embankments at the time of storms to divert water to the old depressions.

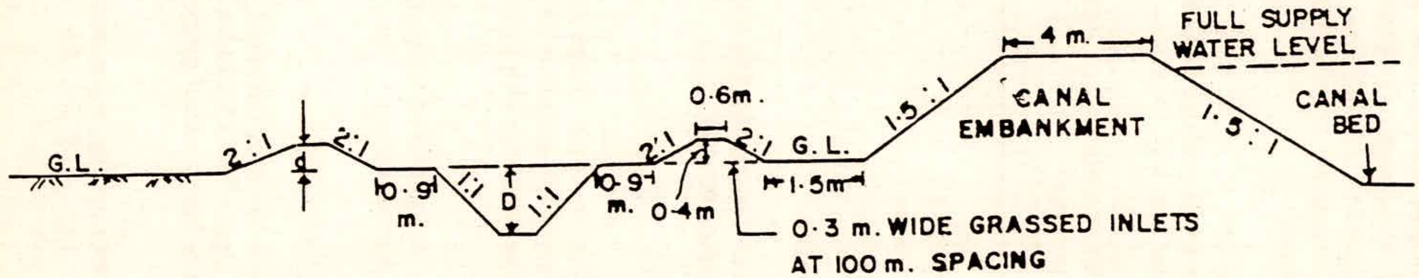
The solution to the third problem lies in lining the inside slopes and the bed of the drain or sandwiching low density polyethylene film. For such contigencies, a freeboard of upto 30% of depth may be provided.

Location, Spacing and Alignment of Drains

Draining ditches should be located so as to provide the most effective drainage and to cause the least interference with irrigation systems and farm operations. Ditches should normally be located in existing natural channels or placed in or close to the low points in depressions or swales. To improve alignment, ditches may cut through minor rises in topography. Crossings with irrigation watercourses should be avoided. Grade control and crossing structures should be minimized.

Whenever possible, smooth curves should be made for alignment (rather than sharp bends) to improve hydraulic properties and to stablize the ditch side slopes.

'd' SHALL VARY ACCORDING TO VOLUME OF EARTH, EXCAVATED FROM SEEPAGE DRAIN



DESIGN CANAL DISCHARGE CUMEC	RECOMMENDED 'D' M.
5	0·9
5 TO 50	1·0
ABOVE 50	1·2

GROUND LEVEL — G.L

Fig. 15 Typical section of a seepage drain

Gentle curves and straight sections eliminate odd-shaped areas in adjoining fields. Where curves are required, circular curve layout is satisfactory. For stable soils, the suggested minimum radii of curvature for ditches are shown in Table 19. For unstable soils, provide more gentle curves, install structures, establish vegetation on the banks, place riprap, brush mats, jetties, or piling, and/or plant trees for protection against erosion. Where sharp curves are necessary, banks should be protected by riprapping with rock or other special material.

Table 19*
Suggested Minimum Radius of Curvature for Drainage in Stable Soil Without Back Protection

Ditch size and max. top width (m)		Percent slope	Minimum radius of curvature (m)	Approximate degree or curvature*.
Small	4.5	0.06	90	19
	4.5	0.06-0.12	120	14
Medium	4.5-11	0.06	150	11
	4.5-11	0.06-0.12	200	9
Large	11	0.06	200	9
	11	0.06-0.12	250	7

* Based on the definition, the degree of curvature is the angle subtended at the centre of a circle by a 100-ft (30.48m) chord.

Inlet and Crossing Structures

Open drain structures consist of inlets to the drain, drops and chutes as well as road, railway and canal crossings. Type designs are available for these structures but actual structural design should be made in accordance with Indian Standards and on the basis of site data.

Inlets are provided whenever an open ditch crosses a natural minor depression or where there is any possibility of water accumulation.

Grass Inlets

In Maharashtra, well grassed inlets have been constructed, being cheap in first cost and easy to maintain. Type design of a grass inlet is shown in Fig.16. The grass must, however, be given every chance to establish itself properly, otherwise it will be easily scoured.

Poor design or construction of such inlets results in the depression cutting back into the fields and filling the open drain with good soil the retrieval of which is expensive.

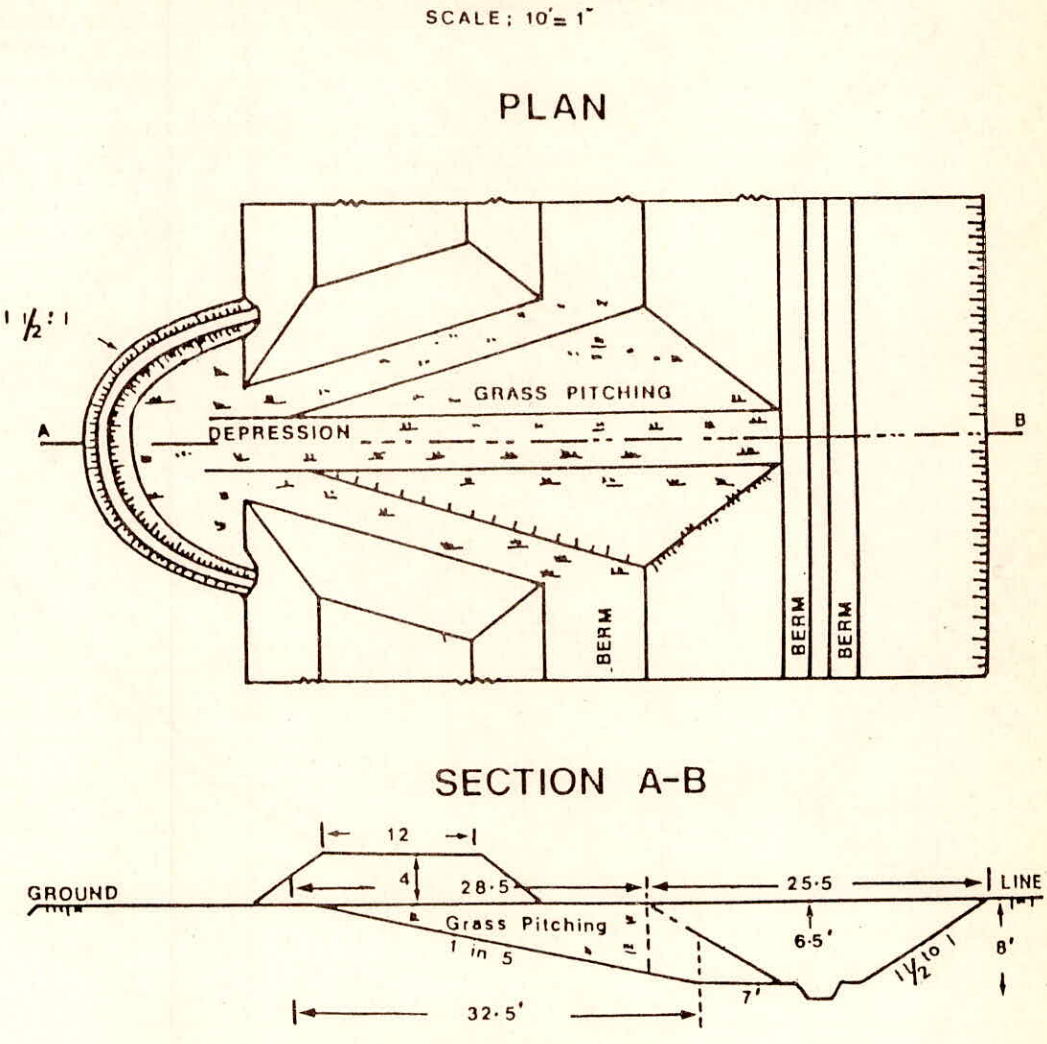


Fig. 16 Typical design for grass inlet
(Source - Irrigation Deptt., Maharashtra)

Pipe inlets

Pipe inlets are used to pass rain water flows from fields to the adjoining open field drains. Each field should have a pipe outlet drain discharging into the open drain as shown in a layout plan (Fig. 17) of Binayaka Catchment in Chambal CAD, Rajasthan, where each field is provided with an inlet point into the field drain or main drain. Sometimes, a low level is built across the top of the pipes, high enough to pass all the water through the pipe. Generally, precast cement conceret pipes of 15 cm and larger diameters are used. At the drain end, a masonary wall is often built and the pipe end is fitted in it to safeguard against dislocation.

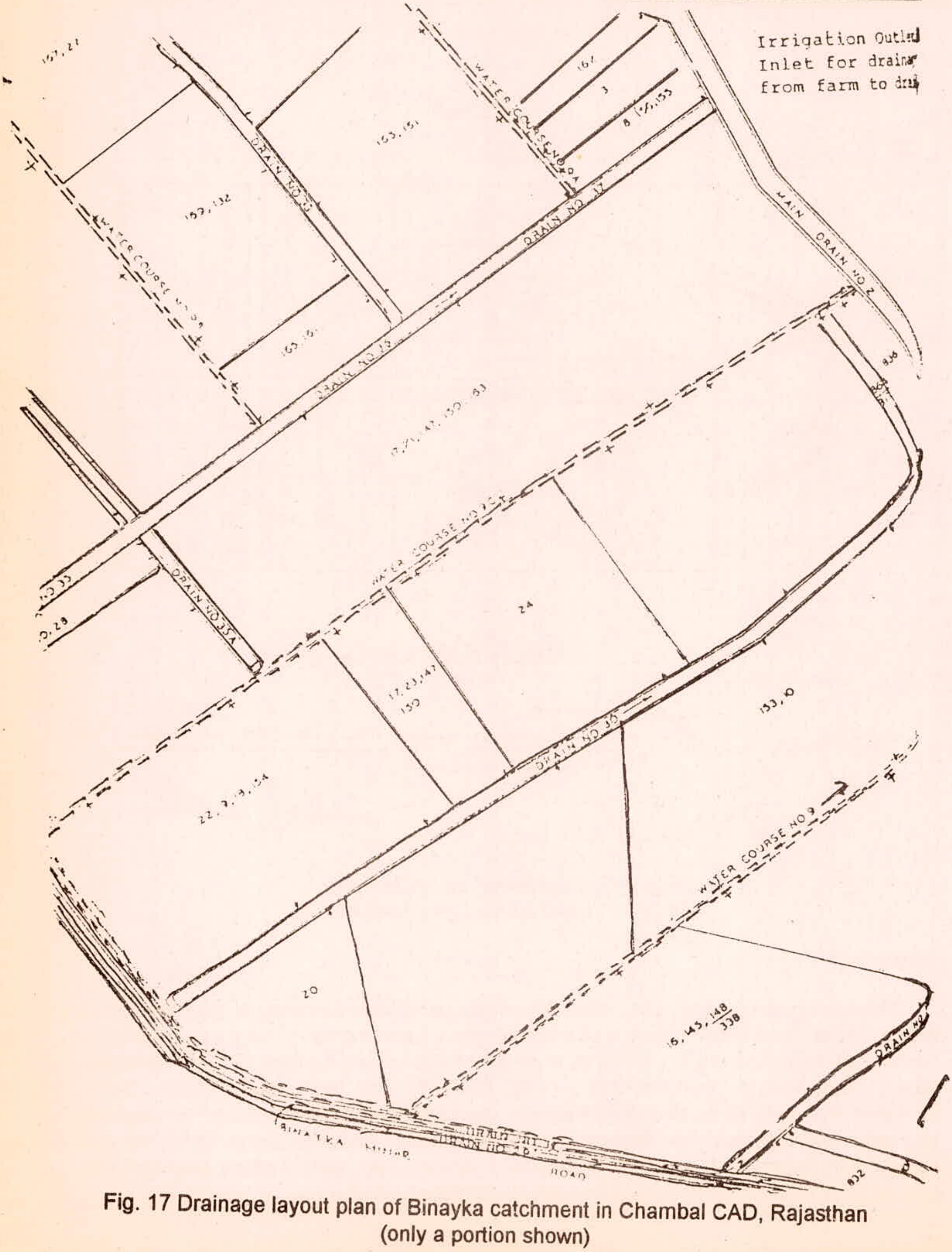


Fig. 17 Drainage layout plan of Binayka catchment in Chambal CAD, Rajasthan (only a portion shown)

Typical inlet to a drain for Chambal CAD, Rajasthan is shown in Fig. 18. It is seen that the inside drain slopes are 1:1 and are provided with grass trufing.

Drop structures

In order to keep the bed gradient of the ditch within the prescribed limits, it may be necessary to provide drops in the drains at certain points. The prupose of the drops is to dissipate energy and avoid erosion. Each drop will have to be individually designed as the capacity and sections at each location vary. A vertical open fall type drop is often found to be suitable. Such a structure is shown in Fig. 19.

Outfalls

When the subsidiary drains join bigger drains in the network, a minimum outfall (level difference) of 150 mm should be provided to ensure smooth functioning of subsidiary drains. This outfall may sometimes be greater because of steep topography or deep river\stream in the area. Suitable protective arrangements are provided to avoid scouring at the junction.

Crossing Structures

Cross drainage works are always designed for higher discharge than the cut section of the ditch. This is mainly on account of the fact that the damage caused to the structure by flows higher than the design storm, can be much more severe than to the drain. Besides, any remodelling of the structures at a later data for higher discharges will not only be costly but time consuming. The drains can, however, be remodelled without any appreciable problems.

Field Drain Crossings

For field drains crossing an existing road or a cart track, the use of pipes is convenient and cheaper than masonry or cement concrete structures. The details of a typical pipe type crossing are shown in Fig. 20 (pipe dia 60 cm). As far as possible, the gradient of the field ditch shall be maintained at the crossing. Preferably, the crossing should be at right angles to the road. Whenever feasible, a simple arrangement with necessary number of R.C.C. pipes and head walls at both ends can be adopted. The 300 mm dia should be adequate. The pipe should have the same slope as the drain bed.

Crossing at Intermediate and Main Drains

Whenever possible, bridges should be provided on intermediate and main drains in preference to pipe culverts. However, culverts are economical near the upper ends of open ditches carrying small flows and are generally used in irrigated areas with excess grade and low discharges in deep ditches. The bottom grade of the upper end

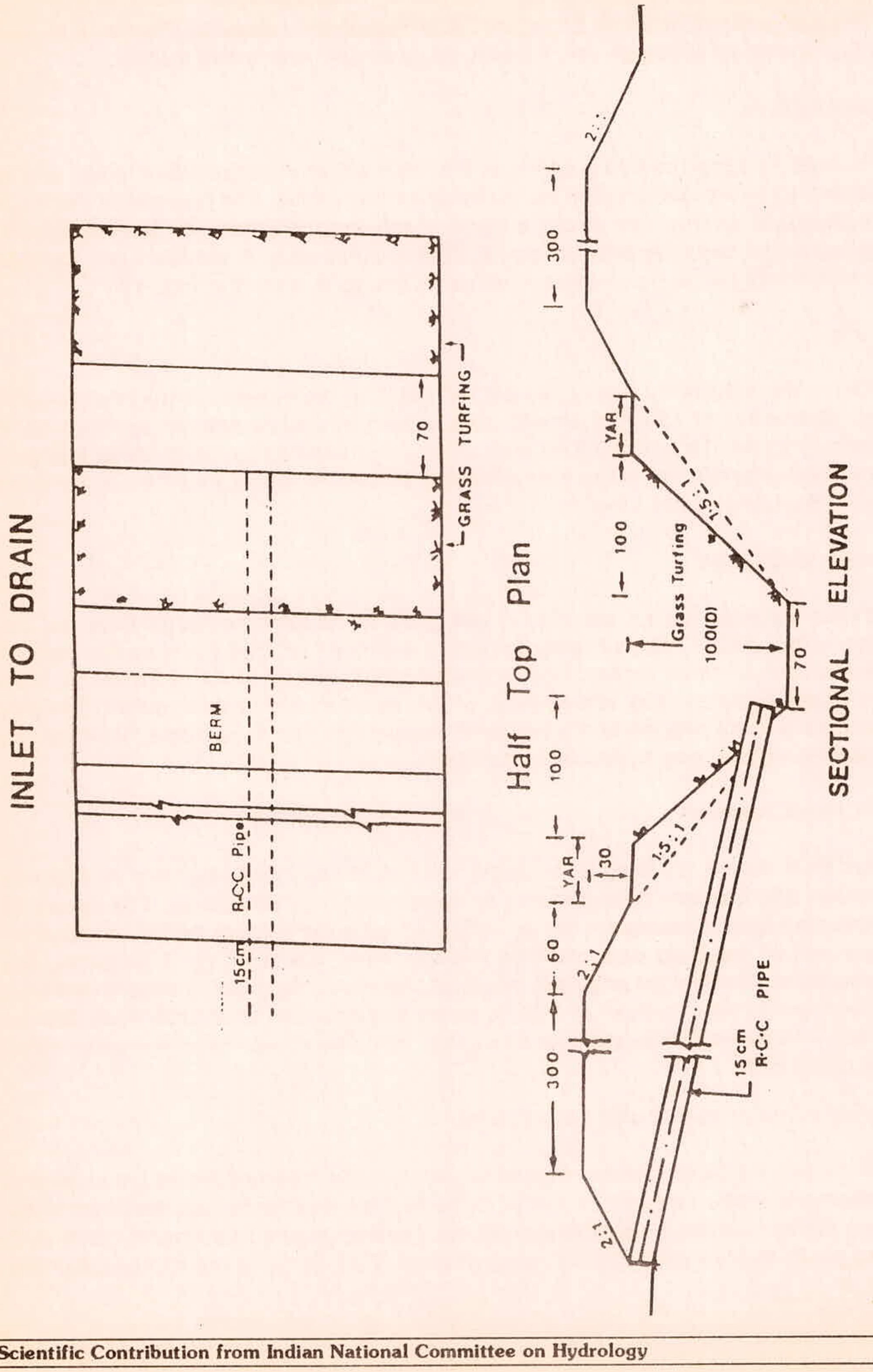


Fig. 18 Typical design for an inlet to drain (Chambal, CAD Rajasthan)

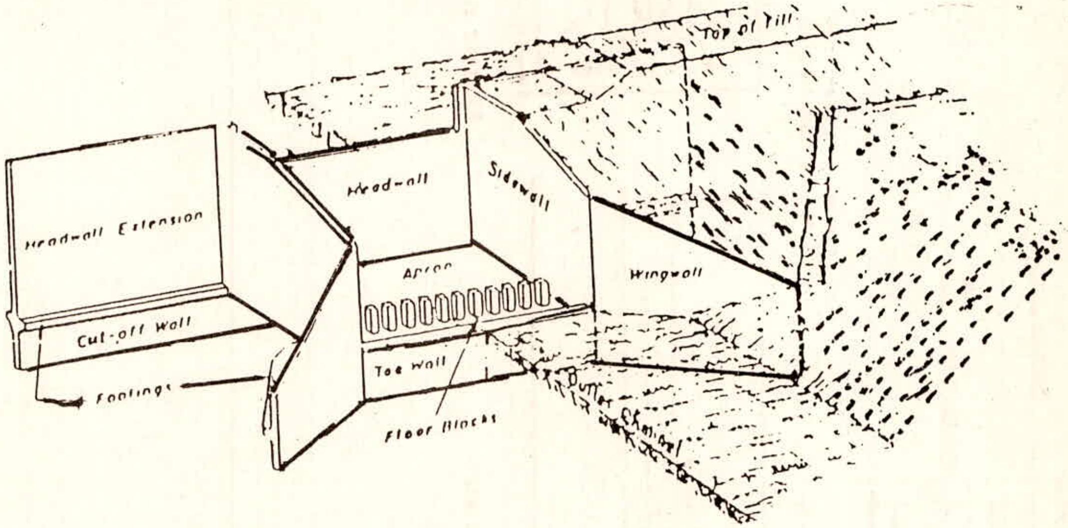


Fig. 19 Straight drop spillway (Source US SCS, 1969)

of the culvert should be flushed with the design bottom grade of the drain. The upper end of the culvert should be higher than the lower end. If the bottom grade of the culvert is higher than the bottom grade of drain, it will back up water at low stages and cause rapid sedimentation in the ditch upstream of the culvert. The future drainage requirements should also be taken into consideration while designing bridges. Class A roads are dealt with in Indian Road Congress-Publication 13 (Guideline for the design of small bridges and culverts-1982).

Drainage Outlets

A surface drainage system should end up in an adeqaute outlet. Sometimes, an off-shoot from an existing sluggish stream is planned to discharge in another stream with sufficient drop at its junction with the excavation drain. Fig.21 illustrates such a situation. In this case, the natural stream has a flat slope. As the land slope is about 1 in 5000, large areas get waterlogged due and presence of several shallow depressions. Obstruction to flood water also occurs because of the main canal siphons, causing wide submergence in the areas nearby on the upstream side. A large natural drain i.e. the river is not vary far off and has a good outlet for drainage with more than 10m drop. Hence, the new link drain will get constructed to provide relief to the areas through which it passes. Additional advantage of the Diversion Drain is that the new bed levels are about 1 to 2 m below ground surface and the local depressions can be effectively drained out even druing rainy season through appropriate inlets. When the advantage of new drain is felt, another diversion drain will be considered for providing relief to the waterlogged areas upstream of the main canal

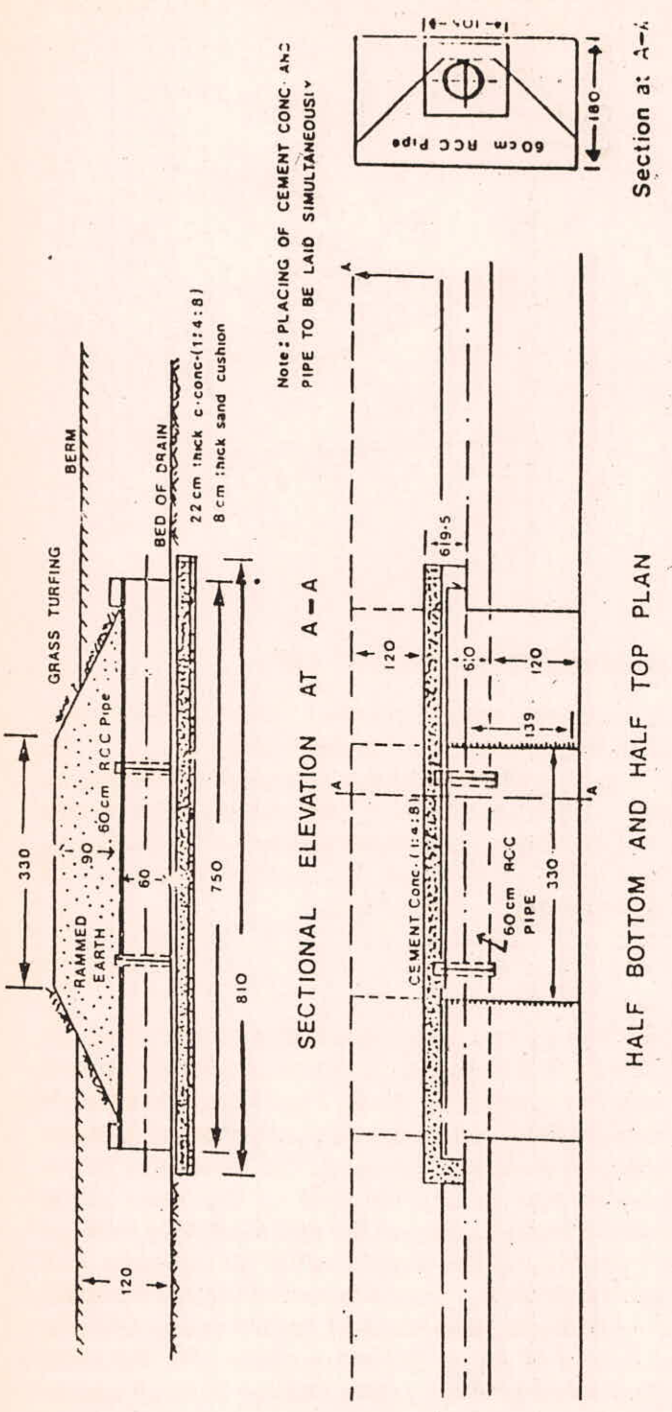


Fig. 20 Typical drawing for field drain crossing (pipe type)

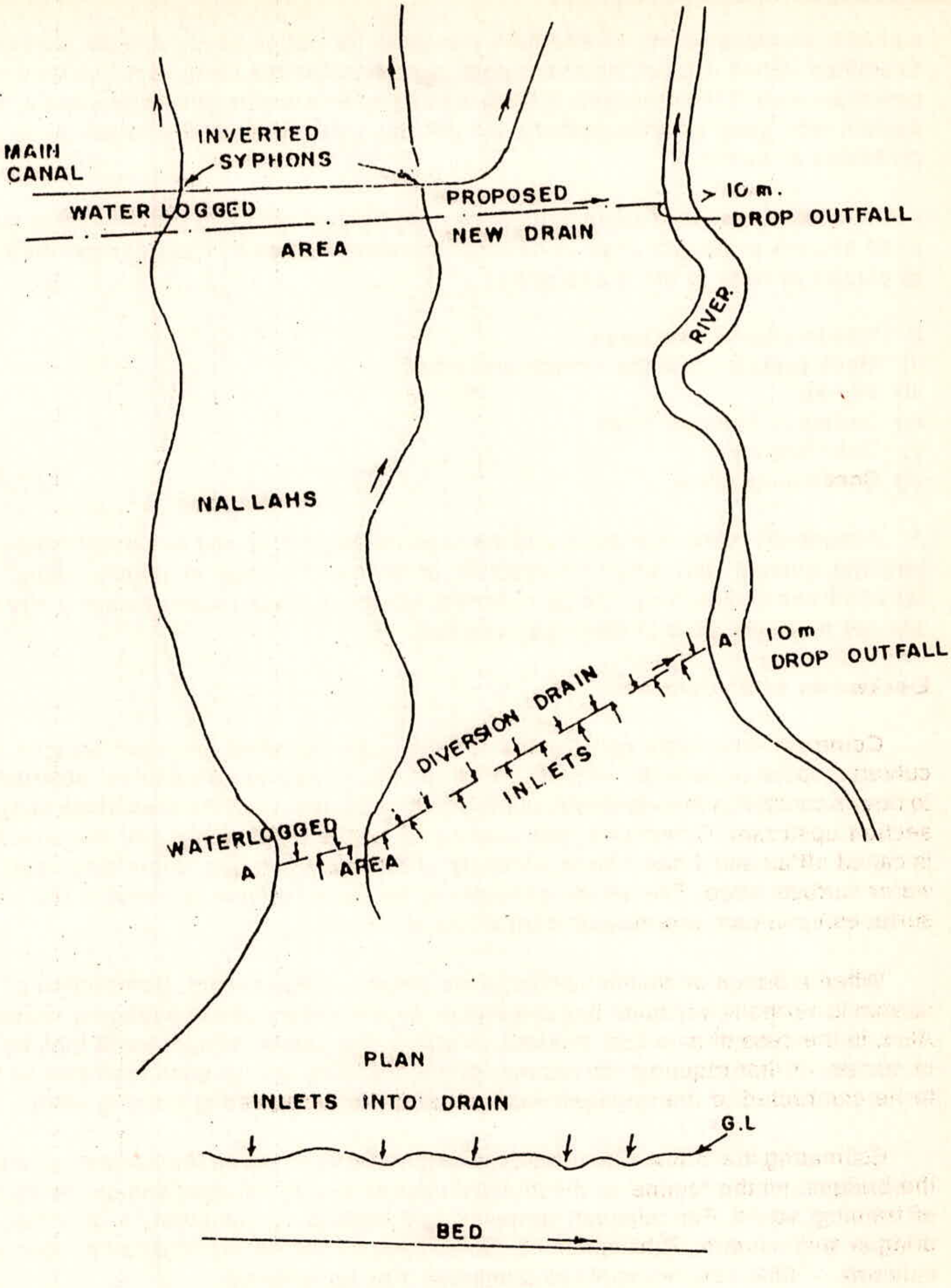


Fig. 21 Planning a drain for adequate outlet conditions

siphons. Considerations of alternate locations for outlet points should always be examined. Good drop at the outlet point compensates the inefficient functioning of new drain even if the drain gets silted and infested with weeds growth. Normally, such a drain with good outlet conditions will not have standing water and will have less problems of weeds.

In a few cases, adequate outlets may not be available and grade-control structures or bank protection may be needed to protect the drain. The principal methods to control erosion in the drains are :

i) Grade-control structures
ii) Bank protection of the stream and ditch
iii) Riprap
iv) Jetties of piling or trees
v) Tetrahedrons
vi) Continuous piling

Frequently, serious erosion and the need for vegetative and structural measures become evident only after construction of drains. The use of jetties, piling and tetrahedrons applies only to large channels. However, these measures are costly and are not normally used in drainage schemes.

Backwater at Structures

Common structures constructed for drainage schemes are road bridges and culverts, canal aquaducts, siphons and drops (falls). At these structures, obstruction to flow is caused as the water way of the structures is less than the area of the channel section upstream. Commonly, the heading up of the water surface at the structure is called afflux and it has a back water effect for some distance, depending upon the water surface slope. The afflux is measured by the difference in levels of the water surfaces upstream and downstream of the structure.

When a bridge or siphon contracts the stream, afflux occurs. Contraction of the stream is normally not done, but sometimes it is necessary due to economic reasons. Also, in the case of alluvium streams, in plains, the natural stream width may be far in excess of that required for regime. When spanning across such a stream, it has to be contracted to the required width for stability by providing training works.

Estimating the afflux is necessary to determine its effect on the 'clearance' under the bridges; on the regime of the channel upstream of the bridge; and on the design of training works. For relevant formulae and method of computation of afflux for bridges and culverts, Publication 13, 'Guidelines for the design of small bridges and culverts' - 1982 - by Indian Road Congress may be referred.

Construction

Prior to the construction, the surface drain alignments are surveyed in detail and plans and L-sections prepared. Each drain, whether seepage, field, intermediate or main drain is given a number or name. The centreline of each drain is marked in the field and benchmark pillars fixed at 100 m spacing at the centreline and on both sides at the point of intersection of inside slope of drain and the ground. The levels for this work are derived from the base level benchmarks. The field survey pillar get sometimes disturbed during construction operations and hence, the control survey points at close intervals of about 500 m are also installed. These points are located quite near to the centreline but at a safe distance from the outer fringe of work area.

Surface drains may be excavated by employing manual labour or machines or a combination of both. Mobilisation of donkeys, camels, mules and camel carts is often made in earthwork where manual labour is employed. Explosives are used in hard strata wherever encountered. As drains are generally located in the countryside, use of manpower for construction of drains provides employment to the local population. Not only this pattern fits in the programme of rural development but also is a cheaper means of construction. In India, manual labour over the years, has developed expertise for earthwork. For long, drain excavation and construction of pucca works have been carried out by manual labour and artisans. The local labour looks forward to employment opportunities in the construction projects.

Difficulties in excavation are experienced where groundwater level is high and the bed of the drain is lower than the watertable and considerable quantities of wet earthwork are involved. In such cases, the pumping equipment and draglines are used in addition to the manual labour.

An important step in the construction scheduling of a drainage system is to commence excavation from the outlet point and progress upstream. This requires excavation of main drain first, then the intermediate drains and lastly the seepage or field drains. Inlet drains are taken up for excavation when its outlet point in the intermediate or mains drain is excavated so that flows from excavation of inlet drains can easily pass down the outlet point into the connecting drain. Seepage drains along the canals are also taken up for excavation when construction of the outfall drain is over.

Earthwork Equipment

Earthwork equipment for drains should be planned on the following considerations :

i) Drain bed width-minimum bed width should be 0.6 m and the depth 1 m.
ii) Type of soil-clayey soils retain moisture and the earthwork machines may not be suitable in such strata as the equipment may be unsafe to travel.

iii) soils with low moisture content are good for movement of equipment and they execute the work faster particularly in wide drains.
iv) Wet soils in deep drains.
v) Long lead of drain excavation.

For large drains and major projects, mechanical equipment is often put into service. A wide variety of machines are commercially available. On the basis of earth-moving operations these machines may be classified as continuous or intermittent as also by their functioning either to cut and carry the soil or cut, spread, and push the soil. The most usual machines are listed by type and function in Table.20 and a few are illustrated in Fig.22. The basic functions of these machines do not change with time, although the manufactures endeavour to continually improve their design and efficiency.

Table 20
Classification of Earth-moving Equipment for Open Drain Construction

Function	Type of Action	
	Continuous	Intermittent
Excavation	Wheel excavator 'a' Plow-type ditcher Template excavator Blade grader Elevating grader 'a' Hydraulic dredger Rotary ditcher 'a'	Dragline Clamshell Clamshell Hoe or Backacter Shovel Scraper (blade) Bulldozer
Spoil spreading	Blade grader 'b' Tillage machines	Bulldozer 'b' Scraper (blade)

'a' - Continuous action except for turning at the ends.
'b' - Either continuous or intermittent action, depending on the method of operation.

Maintenance

Open drains require regular maintenance to keep them functioning as designed. The frequency and degree of the maintenance depend on the climate, amount of rainfall, and the depth at which the groundwater table must be kept below the ground surface. Shallow surface drains in stable materials require only spot clearance annually and a complete cleaning may be required from about 5 to 10 years. In unstable soils, the banks of the drains slide during heavy rains and due to human and cattle traffic. Such situations require annual cleraing during February to May i.e. before the onset of rainy season, to maintain the designed bed width and bed slope.

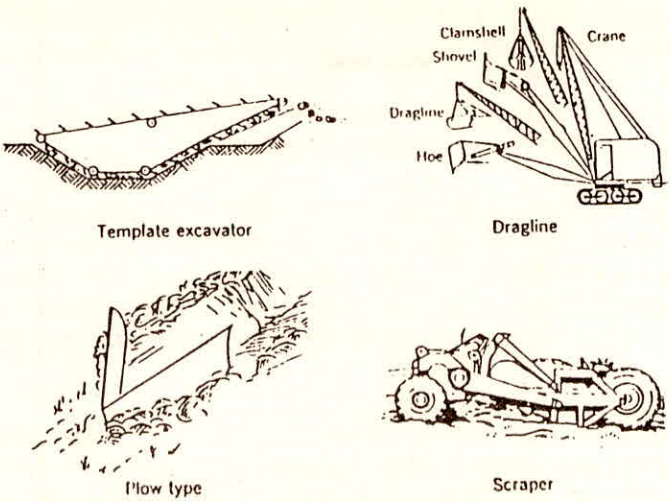


Fig. 22 Types of Excavtion equipment for open ditch construction
(Source - Schwab et. al.,1981)

Generally, canal seepage and excess farm water contribute to the flow in the open drains during non-monsoon periods. The farmers near the drain have a tendency to put earthen/bushy obstacles in the bed of a drain to pond up water and lift it for irrigation use. In addition, these small ponds are sometimes used to rear fish. The Irrigation Acts in various states prohibit such obstacles being placed and provide punishments to the defaulters. The supervisory personnel should get these osbtacles removed otherwise they contribute towards silting of bed of the drain and encourage weed growth. (Non-clearance of these obstructions from the bed of the drain before the onset of the rainy season creates quick silting of the drain beds during the early monsoon flows).

All spoil banks should be sodded, relevelled and replanted after bank cleaning. This is done mainly to stabilize the excavated material to keep it from blowing away or washing back into the drain and to provide a suitable roadway for maintenance. The side slopes of the open drains, particularly the sides above the water surface, should also be planted with grass and fertilized every 2 years. Maintenance of roads should be carried out from November onwards by filling pot holes or rain cuts. In case of heavy winter rains, spot repairs are done.

Sometimes, annual silt clearance of open drains is not adequately done due to shortage of funds and the beds of the drains starts rising every year. Simultaneously, groundwater table rises in the command area with the resultant fall in crop production. In such cases, a roster should be prepared to clean each drain at least once in 3-5 years to safeguard against severe damage to irrigated lands from waterlogging and salinity hazards. As a rule, each drain shall be taken up for silt removal from its outfall end proceeding upstream.

As a routine, each year from October to February, silted L-section of each drain should be prepared together with the observations of wells or plezometers. Areas with high groundwater table and silted drains should be accorded priority in the drain clearance. All data and information should be recorded in the specified reigisters as per Management and Information System (MIS).

Inlet openings, made through open drain banks for the disposal of surface water, are generally cement concrete pipes or lined channels. If properly installed, these inlets usually require attention only when heavy storms occur or when silt clearance in the drain bed is being done. Under no condition should an unlined cut be permitted through the drain bank. After monsoons, the mouths of pipes are inspected to remove weed growth.

All grade control structures should be inspected from October onward annually to locate scour and erosion as well as any damage to the structures. Immediate repairs should be arranged and compeleted before May. Natural streams used as drains should also be inspected after rains each year and pitching or other bank protection measures taken in to repair the eroded/scoured portions to keep the stream within its usual banks.

Culverts, bridges, aqueducts etc. should be inspected annually after monsoons for the needs of maintenance. Damage to foundations are to be specially noted for future record. A register of performance of pucca structures should be maintained at all levels in a Division and in the MIS cell in the office of Chief Engineer. Repairs carried out at each structure and its cost together with the period of repairs should also be noted in the history sheets.

Weed control

Before irrigation is introduced in an area, the surface drains (nallahs and other natural streams) are dry after monsoon and seldom suffer from weed menace. With the introduction of irrigation water flows in the drains even after the monsoons and weeds appear in almost the entire length of drains. During monsoon flows, the water is turbid and the weeds obstruct the flow to some extent with the result that silt is deposited in the bed of drains.

Removal of weeds is carried out manually where the bed is not too slushy. Otherwise, backhoe/dragline equipment should be used in uprooting the weeds as well as removal of silt from the bed.

Certain chemicals kill weeds but the weeds should be removed immediately after chemical application.

In field and connecting drains, paragrass plantation in the bed and side slopes overpowers the weeds like typha and Ipomiacornia which are common in India. This grass serves as fooder for cattle and should be cut every 2-3 months. In Chambal

Project, Kota, paragrass has been planted in some drains with advantage. However, paragrass itself becomes a menace if allowed to remain without cutting for a long time.

Certain weeds grow quite thick in the bed and sides near the cross-structures. This growth must be removed before the onset of monsoons, otherwise scour and damage to the structures may occur.

Cost Estimates

Cost estimates of a new drainage system or estimates for the improvement of an existing systems are based on site surveys, data collection, construction modes, materials for construction, design drawings, knowledge of rates of the materials at site, personnel required, maintenance needs etc. It may be difficult to list each and of every item required for estimating the cost of a drainage project. However, a list of items, generally provided in a drainage cost estimate, is given in the following paragraphs. Items, such as, bridges, aqueducts, siphons etc. are not typical and require special estimate for each structure. It will be realistic to work out present cost per metre of one type of structure and make an assessment of costs of different pucca structures. For smaller structures, like, pipe culverts, inlets etc., type designs are used for cost estimates and total costs of all structures included in the estimates.

Items ot be Include in a Drainage Project

1. Direct Charges

I. Works

A. Preliminary
   i) Cost of surveys including aerial survey for the command area and cathment area as required.
   ii) Investigation and testing of materials.
   iii) Collection of hydro-meteorological soils, geological, groundwater and other related data.

Costs under preliminary head are taken as 1% of the total cost of works as based on past experience.

B. Land
   Cost of land acquisition, land compensation etc.

C. Works
   Costs of all pucca works, inlets etc.

D. Earthwork
   Costs of earthwork pertaining to drains

E. Buildings
   Costs of permanent buildings required for inspection, office use, residence etc.

F. Plantation
Cost of planting trees along the drains and other places.

G. Miscellaneous
Costs of temporary buildings, civil amenities, workshop, other construction facilities etc. (It is usually 1% of C-works costs).

H. Maintenance (adopted as 1% of C-works cost).

I. Special Tools and Plants (T & P)
Adopted as 3% of C-works costs. Includes earthmovers, trenchers etc.

J. Communication
Costs of roads, telegraph/telephone/wireless arrangements for communicating messages between site of works and to important message centres in the project area.

II. Establishment (11% of works costs)
Costs of all personnel required on the project on regular payrolls. The costs of workers engaged on short term basis for site jobs (work-charged staff) are included in the items under individual works.

III. Tools and Plants (1% of C-works costs)
Costs of furniture, drawing equipment etc.

IV. Suspense (10% of works costs)
Covers costs of stock, book transfers within the project etc. Normally, noninal amount is included under this item at the completion stage of the project.

V. Receipts and recoveries
Amount required for rents, water supply, electricity etc.
Total Direct Charges = I + II + III + IV + V

Indirect Charges

Audit and account charges are the only indirect charges and are taken as 1% of the total cost of Direct Charges.

Total Project Cost = Sum of Direct and Indirect Charges

Computer Use in Drainage Systems

Earthwork Volumes

The engineer who designs open channels is faced with the laborious task of computing the volume of excavation. Normally, the volume is determined by plotting cross sections along the channel and measuring the area between the existing and design sections. The average of these areas between two consecutive stations along the drain when multiplied by the distance between the two stations gives an estimate of the excavation volume.

A digital computer solution for this problem has been developed by Hoover (1972). The engineer establishes the design grade, side slope, bottom width, proposed centreline location, and the unit excavation cost. The computer is programmed to determine the grade elevation (channel bottom) at each station (location of a cross section), to generate the design cross section, to compute the cross-sectional area, to determine the volume to be excavated, and the total cost of excavation. Field data can be fed directly into the computer which will make the necessary calculations and plot the cross sections for the existing and the design data, as welll as the as-built sections. Alternate alignments for a proposed drain may be easily and quickly compared. Such comparisons are very difficult to make by manual methods. Accuracy of the computations is improved over hand methods and the programme easily incorporates changes in grade, bottom width, side slope and unit costs. Intersection points on the cross sections of two slopes are made by exact algebraic methods. With hand methods errors in plotting and calculating areas are unavoidable.

Computer Applications in Drainage Design

A drainage system design requires great deal of time and efforts. Four recent technological advancements are helping to expedite the preparation of drainage guides, improve recommendations, and reduce the cost of preparing or updating them. The advancements are described in the following paragraphs :

(a) DRREC : A computerized system for storage and retrieveal of existing drainage recommendations and for the retrieval of associated detailed soils data from other computerized files (Wenberg, 1979).

(b) SOILSORT : A computer programme devised for use by U.S. Soil Conservation Service to utilize information obtained by the Cooperative Soil Survey (SCS, 1974; Lucas, 1981). With this programme, the user can obtain pertinent information from the soil interpretation records, as well as from specialists, to sort soils into drainage recommendation groups. Information regarding general drainage practices applicable to the group of soils and, if appropriate, the theoretical subsurface drain depth and spacing can also be obtained.

(c) DRAINMOD : A computer model developed to provide accurate and specific information on the soil-water-plant system's response to individual drainage design and recorded weather data (Skags 1975, 1978 and 1980).

(d) DRAINABILITY STUDIES : Field programmes to determine the drainability of soils that have shallow restrictive layers and for heavy clay soils (Patronsky and

Schwab, 1979). Past drainage recommendations for these soils have not been very accurate. Much more information has been obtained now, and sound recommendations can be made for many of these soil areas.

These tools are being used by SCS to improve drainage guides for humid areas and to improve drainage system designs.

(a) Drainage Recommendations (DRREC)

The drainage recommendation (DRREC) compter programme (Wenberg 1979) is a system for storage and selective retrieval of drainage recommendations and soils data. The purpose of the system is to facilitate coordination of drainage design criteria and provide the available pertinent soils information for updaing drainage guides. The programme is intended for use in the humid region.

A ll drainage recommendations are related to a specific soil series and may be refined for specific land use for both surface and subsurface drainage parametrs. Relevant information from soil interpretation records, developed as a result of the Cooperative Soil Survey (SCS 1971) and previously computerized, are related internally to the drainage recommendations. This information is referred to as "estimated soil properties". The main items used from individual soil interpretation records are soil texture and permeability by depth, flooding potential and duration, depth to water table and season, and depth to bedrock.

Printouts can be obtained from the DRREC programme to facilitate review and revision as well as to provide sheets for direct printing of revised drainage guides. One printout provides an effective and efficient means of comparing drainage recommendations for an individual soil made at other places having the same soil.

This programme has been used by at least 20 humid-area states in the U.S. and is expected to provide a great deal of help in future years, and evaluation of drainage coefficients by Wenberg (1980) was facilitated by using the DRREC programme.

(b) Soilsort

The computer programme for sorting soils, SOILSORT, was developed by Lucas (1981). It utilizes information in the soil interpretation, records along with the three drain-spacing formulas to sort soils into drainage recommendation groups. Supplementary information that facilitates the soil-sorting process is entered into the compter with other needed data. This programme provides a means by which an area's entire list of soils can be recorded in less than a day. For this investment in time, the user takes advantage of the wealth of information obtained through the soil surveys. The SOILSORT programme uses most of the same information from individual soil interpretation records as used in the DRREC programme.

The SOILSORT programme can determine the drain depth and spacing relationship using the following steady-state drainage formulas :

(1) Ellipse Formula (SCS 1971) - used if the distance between the drain and the barrier is 0.3 m or less.

(2) Hooghoudt Formula (Hooghoudt, 1940) - used for most soils and is particularly applicable to drains in homogeneous soils.

(3) Ernst Formula (Ernst, 1954) - used for soils that have two layers with differing permeabilities, where the permeability of the upper layer is less than that of underlying layer.

The SOILSORT programme provides a relatively inexpensive and quick means of estbalishing or checking drainage recommendation groups and calculating the theoretical subsurface drain depth and spacing. It is valuable when used to update drainage guides.

(c) Drainmod

The DRAINMOD computer model, developed by Skaggs (1975, 1978 and 1980), provides a sound method for designing and evaluating drainage and othe water management systems for soils in humid areas. This model provides valuable and accurate recommendations which improve the confidence level of drainage guides. It also provides good design checks for improving recommendations for drainage systems involving subsruface irrigation and drainage recommendations for waste water disposal sites.

The basis of this computer simulation model is a water balance at the midpoint between two parallel drains in soils that have a shallow water table (a finite depth to the restrictive layer). Using the approach of successive steady-state equilibrium, the unsteady and transient water movement in the soil profile are analyzed as steady-state flow at sufficiently small time increments. Each term in the water balance equation is individually eveluated from input data and brought into the water balance at the end of each time period. If the proper climatological and physical properties of the soil and crop growing information are provided, the model is capable of determining the hour-by-hour, day-by-day moisture fluctuations in the soil profile for a defined water management scheme.

(d) Drainability Studies

The field programme described by Patronsky and Schwab (1979) provides field procedures to evaluate drainability and develop recommendations for soils with a shallow restrictive layer and heavy clay soils. These soils have been a problem for many years, and drainage recommendations generally have been limited to surface drainage. The soils are being drained now, using combination of surface and subsurface drainage systems. Recommendations in drainage guides are being adjusted as investigations are completed to reflect the new findings.

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