COMPARISON OF AGRICULTURAL DRAINAGE DESIGN TECHNIQUES

A DISSERTATION

Submitted in partial fulfillment of the requirements for the award of the degree

of

MASTER OF TECHNOLOGY

in

IRRIGATION WATER MANAGEMENT

By

SUKHADEO RADHAKISAN KALE

DEPARTMENT OF WATER RESOURCES DEVELOPMENT AND MANAGEMENT
INDIAN INSTITUTE OF TECHNOLOGY ROORKEE
ROORKEE -247 667 (INDIA)
JUNE, 2006

CANDIDATE'S DECLARATION

I hereby declare that the work which is presented in this dissertation entitle **"Comparison of Agricultural Drainage Design Techniques"** is being submitted by me in partial fulfillment of the requirements for the award of the degree of **Master of Technology** in **"Irrigation Water Management "** and submitted in the **Department of Water Resource Development and Management, Indian Institute of Technology, Roorkee,** is an authentic record of my own work carried out during the period from July 2005 to June, 2006 under the supervision of **Dr. S.K.Mishra,** Assistant Professor, Department of Water Resource Development and Management, IIT Roorkee and **Dr. V.K.Choube,** Scientist F, National Institute of Hydrology, Roorkee.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree.

Date: 19/6/2006

Place: Roorkee

(Sukhadeo Radhakisan Kale)

This is to certify that the above statement made by the candidate is correct to the best if my knowledge.

Dr. S.K.Mishra
Assistant Professor
Department of
Water Resource Development & Management
Indian Institute of Technology
Roorkee

Dr.V.K.Choubey
Scientist F
National Institute of Hydrology
Roorkee

ACKNOWLEDGEMENT

It gives me a great pleasure to record my sincere vote of thanks to Dr. S.K. Mishra, Assistant Professor, Department of Water Resource Development and Management, Indian Institute of Technology, Roorkee and Dr. V. K.Choube, Scientist F, National Institute of Hydrology, Roorkee for their critical guidance and encouragement in completing my dissertation work. It would have been impossible to complete this work without their help. I am equally grateful to Dr. S.K.Tripathi, Head and Professor and Dr. U.C.Choube, Professor, Department of Water Resource Development and Management, Indian Institute of Technology, Roorkee for their necessary help during my admission to this course. I sincerely record my vote of thanks to Dr. Deepak Khare in the capacity of Chief Warden and Official In charge of Study Tour for his cooperation and help. I am thankful to all my teachers namely Dr. G.C. Mishra, Prof. Ram Pal Singh, Prof. Raj Pal Singh and Dr. M. L. Kansal for their efforts in imparting advance knowledge to us during this course curriculum. I really enjoyed the teaching of Dr. Tanuja Shrivastava and Dr. Agrawal while learning the course of Mathematics. I'd like to get a proficiency of their level to profess the teaching.

My parents have always been my inspiration source and I feel very grateful for them in entire process of my education. My classmates namely Shri. Raghu Shreshta and Shri Ajay Jha have been very cordial and helpful throughout the two years course work and I take this opportunity to acknowledge their help. Shri. Meghnath Sharma has always been a helping hand and a good deal of intellectual association and therefore, I extend my vote of thanks to him. My friends Shri. Vijay Thorat has taken lot efforts to take care of my official matter at my Institute level and made me free from many tensions. I deeply record my sincere thanks to him. Thanks also due to Dr. J.S. Dhekale for his help in statistical part of this dissertation.

Shri. Avinashkumar Sharma, Accountant and Shri. Mohan Singh, Manager, Khosala International Hostel deserves a vote of thanks from my side for their friendly attitude and all other help that made my stay comfortable. Last but not the least, I extend my sincere thanks to my wife Surekha for taking total responsibilities at home front. My son Salil has always been curious about my study this late age and he deserves appreciations.

IIT, Roorkee

19 20th June 2006

(S.R.Kale)

ABSTRACT

Drainage forms to be a crucial universal problem as about 70 percent of the irrigated global area is either affected with this problem or prone to it. In this study different available surface and subsurface drainage design techniques are compared using the data of **KAL** irrigation project command area located in West Coast Konkan region of Maharashtra State (India). Field data of rainfall, cropping pattern, soil characteristics and ground water table were used to compute various design parameters like runoff, drainage coefficient, and evapotranspiration etc. using appropriate methods, and surface and subsurface drainage systems designed for the study area. The time distribution method that computes runoff for design of surface drainage was more suitable for the study area than the rational and Curve Number (CN) methods. The runoff rate of 3.24 m^3/sec computed from the time distribution method is recommended for use in design of surface drainage in the study area. The Manning's equation was found to be superior to regime theory for design of drainage channel, for it resulted into non-silting and non-erosive velocity of the flow through channel. The velocities of flow in channel design by regime theory were very low (0.30 to 0.39 m/sec), and therefore, these were not considered for the study area. For subsurface drainage design, the drainage coefficient of 0.60 cm/day computed by USDA empirical formula was appropriate compared to 0.28 cm/day by the Netherlands equation. For design of drain spacing in surface drainage, the Hooghoudt's equation computed the highest drain spacing of 51 m from the Hooghoudt equation was adopted.

CONTENTS

CHAPTER I

INTRODUCTION

All agriculture crops need water to grow. Natural precipitation does not always meet the full plant water requirements and, wherever possible, irrigation is introduced to overcome this problem. According to FAO (1989), 15.4 percent of the 1474 Mha of cultivated land was irrigated in 1987. Notably, this relatively small area produced one-third of the world's food supplies, and average agriculture produced from a unit of irrigated area was more than two times of that from an average rained land. The World Food Summit (1996) estimated 60 percent of the extra food requirement to sustain the world in future and it must come from irrigated agriculture.

Irrigation of agricultural land has a long and well-documented history and it will play an important role in keeping the future world population supplied with its food, fibre, bio-energy and bio-industrial feedstock needs. However, the unrestricted irrigation can also affect negatively the 'natural resource base'; waterlogging and increase in soil and groundwater salinity are associated with poor drainage.

Changes in land use and irrigation development especially, one of the most drastic and conceivable land use changes, nearly always upset the natural hydrological balance. In dry land agriculture, the introduced plants and crops rarely have the same rooting depth and annual evaporative potential as the natural vegetation they replace. In the case of irrigation, the component of applied water that is not used by the plants further adds to the water entering the water table. The hydrological changes caused by land use modification lead to changes in salt-balance. Under rainfed conditions this often results in a lateral redistribution of salts in the landscape. Under irrigated conditions, the extra salts imported via irrigation water have to be removed from the root zone to avoid long-term accumulation. This process is often referred to as 'leaching'.

In the past, drainage has often been neglected. On the other hand, it is now widely recognized as essential and integral to any irrigation system design. The history of the Assyrian civilization in Mesopotamia presents an example of the earliest reported event where the whole population was forced to abandon the region because of rising groundwater table and salinity (Jacobsen and Adams, 1958). Other examples are quoted in Glassman *et al.* (1995) and Ritzema (1994).

The present dissertation work attempts to review the different techniques used for design of drainage system for agriculture lands preferably applicable to Indian condition. These techniques will be used to design the surface as well as subsurface drainage system suitable for agroclimatic conditions of west coast saline lands of Raigarh District of Maharashtra State of India in general. The parameters of drainage systems as designed by different methods will be compared following appropriate statistical test for their suitability for the region. Data available on rainfall, soil type, groundwater table and topographic features will be used and analyzed to derive the design parameters of techniques under consideration. The surface and subsurface drainage systems will be designed for an area of 50 ha representing the case study area.

A lot of research has been/is being carried out on different aspects of drainage and the associated problem. There exist several approaches, along with their modifications, in literature for design of drainage systems. In the present study, an attempt is made to apply different techniques to design surface and subsurface drainage for the study area. The following two commonly used systems are considered:

i. Horizontal surface ii. Horizontal subsurface (pipe drainage)

While selecting the techniques, attempt has been made to select the latest version of the available technique. The drainage system is designed according to different techniques and the design parameters are compared. Thus, the objectives of study are:

I. To select some appropriate drainage design techniques from the literature survey.
II. To collect and process the agro-climatic data of the region and use in derivation of the design parameters of the above drainage techniques.
III. To revisit various components of the available drainage design techniques.
IV. To determine the drainage parameters for given field layout using different design techniques.
V. To compare the application results and decide their suitability to the region.

ORGANIZATION OF WORK

Chapter II presents a brief review of literature available on surface and sub-surface drainage design techniques.

Chapter III describes the selected agriculture drainage techniques available in literature. An attempt has been made to choose the latest version.

Chapter IV takes a review of problem in study area and documents relevant data on rainfall. Ground water table, soil characters and cropping patter followed in study area.

Chapter V deals with different approaches to derive parameters required for surface drainage design and explains details about latest versions of surface drainage design techniques.

Chapter VI deals with different methods of computing drainage coefficient as well as drain spacing and pipe diameter.

Chapter VII analyses the results obtained by different methods of drainage design.

Chapter VIII summarizes and concludes the study.

CHAPTER II

REVIEW OF LITERATURE

Drainage is a serious problem all over the world. Based on the data up to 2000, the International Commission on Irrigation and Drainage (2001) reported 190 Mha area (out of 271.68 Mha irrigated global area) to be either affected with drainage problem or prone to it. In Asia out of 183.51 Mha irrigated area, about 54.72 Mha area is drainage affected, and in India, out of 54.80 Mha area, about 5.80 Mha area is drainage affected As an example, in Western Europe, agricultural intensification has led to the reclamation of more than 50 percent of waterlogged areas through the use of subsurface drainage measures. The proportion of drained land is the largest in Europe and North America (20-35 percent of total cultivated land), moderate in Asia, Australia and South America (5-10 percent) and lowest in Africa (0-3 percent). On the contrary Lesaffre and Zimmer, (1995) quoted the "drainage" as a "dirty word" and consequently, its implementation has been restricted or even prohibited, especially in environmentally sensitive wetland regions. As an example, the very high annual rate of installation of subsurface drainage of the 1980s (300000 ha/year) has fallen to about 150000 ha/year during the 1990s. The following text provides a brief review of some case studies around the world

The Nile Delta and the Nile valley of Egypt are one of the oldest agricultural areas in the world, and these have been under continuous cultivation for at least 5000 years. The Delta of the Nile is now one of the most fertile and intensively cultivated regions in the world, due to the mud brought down by the Nile from the Ethiopian plateau. The agricultural sector accounts for more than 30% of the gross national product (Anonymous). At the turn of the 19th century, perennial irrigation was introduced in the Nile River Delta and Valley of Egypt. This led to rise in groundwater table, and increased problems of water logging and salinity. Consequently, the productivity of the agricultural land decreased. If subsurface drainage was not provided as and when needed, crop yield was reported to be reduced by as much as 20 percent with in a few years, from inception of drainage conditions. It would be uneconomical to cultivate land with this reduced productivity (Johnston, 1976). In response to this challenge, the government gave high priority for installing drainage systems. In Egypt, it is estimated that up to 1995, approximately 4.3 million Feddans (1 Feddan = 0.42ha) have so far been drained by subsurface and another 2.1 million Feddans will be implemented between 1996 and 2010 (Advisory Panel on Land Drainage, 1996). One of the main advantages of constructing subsurface drainage system in the Nile Delta is increasing the productivity of crops actually by 138%, 48%, 75% and 10% for Wheat, Berseem, Maize and Rice, respectively.

Research from two long-term field studies (Anonymous) indicated that there was significant increase in the yield of corn and soybean with subsurface drainage on poorly drained soils compared to no-subsurface drainage on the same soils. Studies conducted on Toledo silty clay at the North Central Branch Station of the Ohio Agricultural Research and Development Center (OARDC) in Sandusky County evaluated crop yields, soil physical properties, and water quality parameters over a 20-year period for untrained conditions compared to surface drained, subsurface drained, and combination conditions. It was observed that there was variation in the yield to the extent of 80%, 64% and 83% in undrained and combination of surface and subsurface drains in case of corn soyabean and oat, respectively. It is observed that increase in yield was maximum due to combination of surface and subsurface drainage in all three crops viz corn, oat and soybean, respectively followed by subsurface drainage, surface drainage and undrained area, respectively.

Research conducted on Hoytville silty clay at the Northwest Branch Station of OARDC in Wood County (Anonymous) evaluated the effects of drainage, rotation, and tillage practices on corn and soybean yield. Results from the 11-year study indicated that subsurface drainage improved corn yields by 20 to 30 bu/acre and soybean yields by 7 to 14 bu/acre, on both plow and ridge tillage treatments regardless of tested crop rotation. Crop rotation treatments included continuous corn, continuous soybean, and corn-soybean rotation.

Drainage water quality evaluated over a 14-year period on Toledo silty clay, indicated (Anonymous) that subsurface drainage reduced the losses of sediment, phosphorus and potash by 40, 50, and 30 percent, respectively, compared to surface drained cropland. However, Nitrate (N) losses increased by 40 percent. Over a 17-year period, runoff from land that was subsurface drained was lower than that from land that was not subsurface drained and peak runoff was reduced by about 32 percent.

Oosterbaan (1991) was able to establish a critical value of the seasonal Number of High Water (NHW) level days in the open collector drains (NHW, above 90 cm below the soil surface) by relating it to the production of sugarcane. The critical NHW value was found to be 7 days, below which the production was not affected but above which the production showed a declining trend. On this basis Naraine (1990) determined estates which had excessive, good, and deficient drainage systems and he could recommended remedial measures where required. Use of the water level (instead of the discharge flow) as a criterion for agricultural land drainage. Once this criterion is established, the corresponding discharge can be determined by the standard hydrological procedures. The criterion required cautious and restrained application in the sense that drainage measures were proposed only in a few necessary instances, while excessive drainage in other instances was clearly earmarked.

According to Ritzema et al. (1994), the level of water table is not influenced much by a deeper pipe drainage system because of the soil's decreasing hydraulic conductivity with depth. Further, much irrigation is saved by introducing gates into the drainage system. These gates can be closed when rice is grown in ponded fields. Such checked, restrained drainage systems prevent excessive drainage without negatively affecting the crop production. They further assessed their applicability to areas under crops other than rice and found that yield of maize decreased from 8.2 ton/ha under water table of 0.5 m to 6.0 ton/ha when water table increased to more than 1.0 m. However, yield of wheat was unaffected from variation of water table from 0.5 to 1.5 m.

Oosterbaan (1991) conducted studies on a pilot area near Drayton, U.K., to relate the effect of average depth of water table on yield of winter wheat, because water logging problems occurred only during winter (when evaporation is little), not in summer (when evaporation is higher). The relation showed that the production only decreased when the average water table depth in winter was less than about 0.5 m deep. When the water table was deeper, the production was not affected (Oosterbaan 1991). Thus, it is beneficial to install a drainage system only when the depth is less than 0.5 m. Otherwise drainage is not required.

Early studies by Penman (1938) found that citrus trees remained healthy for the first 8 to 10 years in water table conditions within 1.2 m of the soil surface; however, after this age a deeper water table depth was required to maintain tree health. Minessy *et al.* (1971) studied the effects of high water tables on citrus in the Middle East. They found a positive linear relationship between water table depth and yield, with water table depths down to 1.75 m.

On the basis of the data collected from the Mashtul Pilot Area of Nile Delta by Christen and Hornbuckle (1990) and its employment to hydro-salinity model, Oosterbaan and Senna (1990) found that a modestly deep water table (about 0.8 m as a seasonal average) was sufficient to control the soil salinity at a safe level. More intensive drainage (i.e. by imposing deeper water levels) would be more costly and would have the negative side effect and irrigation efficiency would be lower. The simulated effect of different values of drainage parameters are given in Table 2.1. Depending upon the drainage objective and method used, the drainage design criteria observed to be varied, including the target water table depth after irrigation or rainfall and drainage coefficient. They derived the following conclusions from their study.

- New drainage design criteria that provide adequate protection for crops (with clear delineation of waterlogging and salinity control objectives) while minimizing drain water salinity and volume of water as leaching requirement are required.
- Saline drainage water disposal is a key issue across all regions, which may severely restrict future implementation of subsurface drainage in irrigated agriculture. This may then be the greatest constraint to the sustainability of many irrigated areas.
- Reassessment of drainage design criteria for many regions is required in light of recent changes in land use and irrigation management.
- Management of subsurface drainage systems is being reviewed or is requiring review in many regions. Integrated subsurface drainage and irrigation management is in its infancy.
- Subsurface drainage has been effectively designed and implemented for long periods in many irrigated regions of Australia. This has been conducted on a need

basis as problems appear. Thus, no region has a detailed plan of the subsurface drainage required to protect all areas with potential or existing drainage problems.

- Subsurface drainage has historically been limited to perennial horticulture, which is the highest value irrigated crop. More recently subsurface drainage has been extensively applied to perennial pasture, as the dairy industry has become highly profitable. The cost benefit ratio of subsurface drainage for other crops is unclear.
- Subsurface drainage is usually completely or partially funded by the landholder, thus restricting its implementation to high value crops. Subsurface drainage is still often subsidized as part of Land and Water Management Plans by government grant or by low cost government loans. This recognition of the importance of subsurface drainage to irrigation sustainability needs to be continued.

Table .2.1 Target design criteria for subsurface drainage system.

Region	Drainage type	Targeted water table depth	Drainage coefficient	Long term drainage rate
Burdekin	vertical	3m	-	1.5
Emerland	vertical	>1.2m cotton root zone	-	-
Kerang	Vertical horizontal	- >1.2 m	0.25 to 0.5ML/yr/ha 2.5mm/day	3-4 1-2
McAlister	vertical	-	-	0.5
Murray	vertical	>1.5 to 2	0.6 to ML/yr/ha	0.3 -0.6
Murrimgegee	vertical	-	1 ML/yr/ha	3
Riverland	horizontal	0.45 to 0.75 m/day	5mm/day	0.5-2
Shepparton	vertical	none	1 ML/yr/ha	3
Sunraysia	vertical	0.9-1.1	2-5 mm/day	1-1.5
SWIA	horizontal	<0.3m	10 mm/day	5

Hussein and Atfy (1999) compared conventional and modified drainage designs using the data of two large pilot projects .(Mahmoudiya 1 and Nashart). On the basis of unit prices, the differences in construction costs between the two systems were calculated (DRI, 1985, 1986b). The total length of pipes in the modified system was greater because of the introduction of sub-collectors which, together with the installation of closing devices, lead to extra costs. On the other hand, the lower design rate implies a reduction in the size of the collector pipes as compared to the current design norms and thus leads to cost savings. Savings in maintenance costs and the benefits of a more reliable system have not been considered in the analysis.

Mahmoudiya 1 was the first area where the modified system was introduced on a large scale. It was constructed in 1982. Based on 1983 prices, the costs of the modified system were 12% higher than those of the conventional system. This difference can be attributed to relatively small size of the sub-collector units in the modified system and design rate for the collector drains in the modified system was 3 mm/day, which is quite high compared with the design rate for non-rice areas (2 mm/day). The design rate for the conventional system was 4 mm/day. Based on the experiences obtained in the Mahmoudiya area, Eng Hussein and Atfy (1999) concluded that to reduce irrigation water losses from rice area without restricting the subsurface drainage from "dry-foot" crops, a modified design for the subsurface drainage system is required. The introduction of the modified layout of the subsurface drainage system in rice-growing areas in the Nile Delta resulted in

- Savings in irrigation water up to 30%. This irrigation water would otherwise be lost through the subsurface drainage system: the difference in drainage rates from rice fields between the conventional and modified drainage system amounts to 1 to 3 mm/day over a growing season of approximately 100 days;
- Protection of the drainage system from justifiable, although unauthorized and improper, interference by farmers to stop irrigation water losses from rice fields through the subsurface drainage system, and thus reduce the maintenance requirements.
- Protection of crops other than rice from the damaging effects of improperly blocked conventional collector drains;
- These benefits were obtained without any negative effects on either soil salinity or crop yield and with no increase in costs compared with the conventional system.

Christen and Hornbuckle (1990) provided some guidelines for design of drainage of Emerald Subsurface Drainage Project on the basis of survey of affected area. This involved excavating test holes in a 100 m grid to ascertain the extent of the affected area and soil profile information. Maps of the affected area were prepared and used to design the subsurface drainage layouts. Due to the topography and layout of the farms and the location of the affected areas, individual interception drainage schemes were required. Also, because of the complex and variable geology of the basaltic materials, hydraulic properties and accession rates were highly variable. Average figures were considered sufficient for first approximations and preliminary designs, but final designs were based on accurate field data. A set of design rules was required to achieve "adequate" drainage, which is defined as the amount of drainage necessary for agriculture to be successfully and permanently maintained. They adopted the following design rules derived from field investigations:

- Provide, in general, for interceptor subsurface drains.
- Aim to maintain the water table at least 1.2 m below the ground surface.
- Locate the highest lateral (interceptor) no more than 40 m down-slope from the location of the highest summer 1.2 m depth to water table line.
- Make drains as deep as the relatively harder basalt barrier as conditions permit, e.g. at typical depths of 2.5 to 4.0 m.
- Locate extra interceptors at spacing of 150 to 200 m if necessary.
- Orient the interceptors to use available paddock slope to best advantage. Drain gradients should be no flatter than 0.15 m per 100 m.
- Provide the minimum number of outlets to the commission's drainage system.
- Use continuous pipes without perforations, slots or open joints at the bottom of slopes, and at outlets where the depth of cover is less than 2 m to stop root growth from blocking the drains.
- Use junction boxes or manholes where two or more drains join or an at 200 m intervals. If the junction point is in cultivation, the top of the box should be at least 900 mm below the ground, sealed, covered with soil and its location referenced so that it can be found.
- Adopt a minimum diameter of interceptor drains of 100 mm with main carrier drains of 150 mm. Individual drainage schemes were designed by the Water Resources Commission or by consulting engineers to commission standards.

Construction of each subsurface drainage scheme began after the landholder had approved the design and agreed to monitor a system of observation bores. Laying pipes at depths of between 2 and 4 m required either trench benching or the use of trench shoring to provide a safe working environment.

Christen and Hornbuckle (1990) also studied the unique problems encountered in the Kerang Region and required special attention to the employment of drainage criteria. It was observed that the areas those were frequently irrigated with low saline water generally did not develop the salinity problem, despite the development of high water table. In the experimental tile drainage system at Kerang, a drain design rate of 2.5 mm/d with a water table 0.3 m below ground surface was used for estimating drain lateral spacing. However, these criteria relate to drain design for waterlogging control under the steady rainfall conditions of Europe. It was an inappropriate criteria for subsurface drainage for salinity control in Australia. The experience in the district was that very low drainage rates associated with groundwater pumping together with irrigation to leach accumulated salts was effective for salinity control. Low drainage rates could be sufficient to control a small rate of upward seepage, and allowed a small leaching fraction (say 2 to 5% of the applied water). They have suggested that the drainage design should be based on the observed upward seepage rate, while maintaining the water table at or below the critical depth. For instance, at the Kerang site design criteria of 0.8 mm/d with a water table maintained at a depth of 1.2 m was suggested. This would allow substantially wider drain spacings (~160 m), and reduced costs, as well as a reduced need for groundwater disposal.

During the reclamation phase the drainage rates can be expected to be very high (2 to 5 ML/ha/year during the first two years of operation). Peak drain flow rates ranging from 2 to 4 mm/d can be expected during this period. After reclamation, drainage rates reduced. The attainable leaching fraction was determined by the development of a throttle in the subsoil at a depth varying from 0.3 to 1.0 m. Drainage system rates were in the range of 1 to 2 ML/ha/year in the post-reclamation phase, and peak drain flow 1–2 mm/d. Experiments showed the subsoil, deeper than 1 m, to retain a relatively high hydraulic conductivity (0.3 to 0.5 m/day) in post-reclamation. In the post-reclamation period, drainage rates are affected by the internal drainage of the soil profile between 0.3 and 1 m rather than the dewatering performance of the drainage system. For instance, while in the reclamation phase water table level rose by more than 1 m after irrigation, whereas in the post-reclamation phase, water table level rise was only a few centimeters after irrigation. Baseflow rates recorded at Kerang during periods without irrigation varied from 0.5 to 0.8 mm/d. These rates were attributed to upward seepage from an underlying artesian aquifer, with a pressure head of about 1 m above ground surface. At the Pyramid Hill site the water table level falls below the tile drain lines when the area is not irrigated and there is no consistent baseflow rate.

Polkinghorne,(1992) reported that high water tables can be effectively controlled in horticultural developments by 'tile' drainage installed from 1.8 to 2.0 m deep. Traditional deep subsurface 'tile' drainage systems were designed to protect the plant root zone from waterlogging and salinization by maintaining a deep water table. These drains were installed at a depth of around 1.8 m and from 20 to 50 m apart, depending on the soil permeability, and were designed to flow freely with no management of drainage effluent. These early horizontal subsurface drainage systems in the Australia were built solely with cylindrical unglazed earthenware tiles 0.3 m long.

While relating to the yield of canned peaches in the MIA in a survey of factors, Balaam and Corbin (1962) found that soil type and water table depth each contributed from 25 to 30% of total variation, with management practices accounting for a further 25%. During September a positive relationship between water table depth and yield was also found and continued to a depth-to-water table of 2.1 m. In reviewing these studies it was noted by Van der Lely (1978a) that the experiments involved a number of dependant and independent variables, difficult to separate, and salinity effects may be confused with the effects of high water tables. The design criterion depends on the tolerance to waterlogging conditions of the crop to be protected. In the MIA these crops were mainly peaches, citrus and grapes. Peaches proved the most sensitive and on that basis the aim has been to develop a criterion which would provide its protection. Citrus and grapes would automatically be protected if standards adopted for peaches were sufficient.

The design criterion proposed by Maasland and Haskew (1958) has been widely adopted for subsurface drainage in the MIA to protect against waterlogging on a 1 in 100 year basis (CSIRO 1965). This is equivalent to about 5 mm/day when considered the March 1956 average monthly rainfall. Drainage design in the MIA is based on the assumption that the water table midway between tile lines should be lowered from a level of 0.45 to 0.75 m below the soil surface in a period of three days. For economic and technical reasons, connected with trenching machinery and the necessity to guard against salt damage, the depth of drains was standardized at around 1.8 m, although in some cases reduced due to the presence of a shallow impermeable layer. With the depth of drains decided, the design of subsurface drainage depended only on determining two key soil parameters, the hydraulic conductivity of the soil and the depth to the impermeable layer, as discussed above.

The water table response compared with theory was studied by Talsma and Haskew (1959) who found that the design (criterion) discharge rate occurred when water tables was at 0.45 m below the surface, and the soil drainable porosity of about 8%, which applied for the lighter textured soils. However, in heavier soils with a lower drainable porosity of about 4% the reduction in water table target would be achieved if the discharge coefficient was as little as 2.5 mm/day (Talsma and Flint, 1958, Van der Lely, 1978a). The lower design criterion was adopted for heavier soils with lower drainable porosity, assuming that infiltration rates would be less and half the excess rainfall would be removed by effective surface drainage management.

Van der Lely (1978) reported that non-steady state equations of drainage discharge involve variable rates of recharge to the water table and a fluctuating water table. This is the actual situation in the field. These equations could also be used for drainage design, but they are less simple in their practical application. Field observations of daily water table behavior and day-to-day simulation based on non-steady equations found this not to be necessary. The steady state approach to drainage design provides a satisfactory degree of water table control in all but the most extreme conditions.

Robertson' (1980) provided details of subsurface design criteria with a number of design, construction and tailings management considerations to establish effective subsurface drainage systems. The design considerations include capacity calculations of subsurface drainage systems, spacing of outlets, spacing of parallel drains, use of geotextiles and alternative drainage systems specifically for tailing impoundments. Poor control during construction of drains and during first filling with tailings usually leads to the loss of dewatering capacity, and even complete clogging of drains. Some practical considerations are discussed, such as the influence of bottom surface slope of tailings impoundment, depositional procedures to minimize drain clogging and installation of subsequent drains at higher levels in the tailing impoundment. The Drainage Design Procedures (2005) utilized the concept of overland flow. An overland represents the area composed of segments with varying cover and/or slopes. The summation of the time of concentration for each segment will tend to over-estimate the overland flow time, "t_0". In this case it may be more appropriate to use an average runoff coefficient "C" and an average ground slope in the Overland Flow Chart. Sheet flow is assumed to occur for no more than 300 feet after which water tends to concentrate in rills and then gullies of increasing proportion. This type of flow is classified as shallow concentrated flow. The velocity of shallow concentrated flow can be estimated using the following relationship:

$$V = 3.281ks^{0.5}$$

where V = velocity (fps), k = intercept coefficient, s = overland slope (%). The intercept coefficients are given in Table 2.2

Table 2.2 Intercept coefficients for different surfaces

Type of surface	Intercept coefficient k
Forest with heavy ground litter	0.076
Minimum tillage cultivated wood land	0.152
Short grass pasture	0.213
Cultivated straight row	0.274
Poor grass untilled	0.305
Grassed waterway	0.457
Unpaved area bare soil	0.491
Paved area	0.619

The shallow concentrated flow generally empties into pipe systems, drainage ditches, or natural channels. The velocity of flow in an open channel or pipe can be estimated using the Manning's equation. The travel time for both shallow concentrated and open channel (or pipe) flows is calculated as:

$$t_s or\ t_d = \frac{L}{60V}$$

where t_s = travel time for shallow concentrated flow (min), t_d = travel time for open channel, L = flow length (ft), V = velocity (fps). Where a contributing drainage area has its steepest slope and/or highest "C" value in the sub-area nearest the point of concentration, the discharge computation from rational method for this sub-area may be greater than if the entire contributing drainage area is considered. The maximum runoff rate for a sub-area should be considered only if greater than that for the entire area. The rational formula can be used to find runoff with values of C as given in Table 7

$Q = CIA$

where Q = discharge (cubic feet per sec), C = coefficient of runoff, I = average rainfall intensity(inch/hr), A = Drainage area (acre). The coefficient of runoff in above equation is a dimensionless decimal value that estimates the percentage of rainfall that becomes runoff. Where two values are shown, the higher value ordinarily applies to the steeper slopes. The weighted coefficient is obtained by averaging the coefficients for different types of contributing surfaces.

Table 2.3 Coefficients of runoff (C) for different surfaces

Type of surface	Coefficient C
Pavement and paved shoulders	0.9
Berms and slopes 4:1 and flatter	0.5
Berms and slopes steeper than 4:1	0.7
Contributing areas	
Residential (single family)	0.3to0.5
Residential (multi family)	0.4 to 0.7
Woods	0.3
Cultivated	0.3 to 0.6

As a consultant to Ministry of Agriculture, Fisheries and Food for British Colombia, Farmer Ranch (1999) provided an elaborate discussion on the design of pipe drain. Drainage coefficients (Table 2.4) are recommended for subsurface drainage systems where no surface water is admitted directly into the system. Table 2.5 is recommended for subsurface drainage where surface water is to be admitted into the system through surface inlets. Higher drainage coefficients as indicated in Tables 2.4 and 2.5 should be used for high value truck crops, as they are more vulnerable to damage caused by standing in water for 2 to 4 hours during hot weather. A drainage coefficient of 12 mm/day (0.5 in/day) has been traditionally used in the Lower Fraser Valley.

Table 2.4Drainage coefficient for subsurface drainage

Soil Type	Drainage coefficient (mm/day)	
	Field crops	Truck crops
Mineral	10to 13	13to 20
organic	13to 20	20 to 38

Table 2.5 Drainage coefficient for subsurface drainage where surface water contributes to water table.

Soil	Drainage coefficient (mm/day)			
	Field crops		Truck crops	
	Blind inlet	Open inlet	Blind inlet	Open inlet
Mineral	13to20	13to25	20to25	25to38
organic	20to25	25to38	38to50	50to100

According to Farmer Ranch (1999), the depth and spacing of drains varies greatly, and are dependent on the soil permeability (hydraulic conductivity), crop and soil management practices, type of crop and the extent of surface drainage. Generally, the narrower the spacing, the better the control of water table in the ground. However, selection of the most economic systems calls for determination of the maximum drain spacing which can be tolerated by the crops to be grown. Typically, drain spacing in the Lower Fraser Valley ranges form 9 to 20 m. If the hydraulic conductivity is known through estimation or measurement, the drain spacing can be calculated using Hooghoudt's equation. For homogeneous soils, the equation can be expressed as: $S^2 = \frac{4K(2d_e h + h^2)}{R}$ and for two layered soil as: $S^2 = \frac{8K_b(2d_e h + 4K_a h^2)}{R}$

Where S = spacing between drain laterals (m), k = saturated hydraulic conductivity (m/day), de = equivalent depth or effective flow depth below drains (m) and h = water table height above the drain center at mid-spacing (m).

It is recommended that the depth of the drains (DD) be in the range of 0.9 to 1.2 m. This may be reduced to 0.8 m where depth of outlet or subsoil is limited. The minimum cover to protect a subdrain from breakage by farm machinery is 0.6 m. The parameters referred above are shown in Figure 2.1.

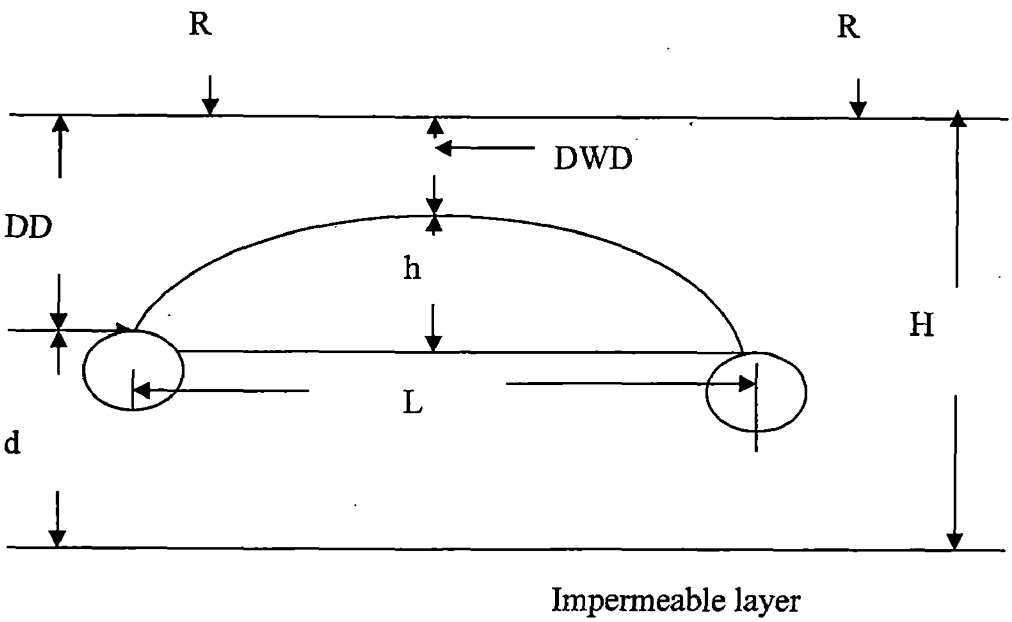

Fig.2.1 Definition sketch for Hooghodt's Equation

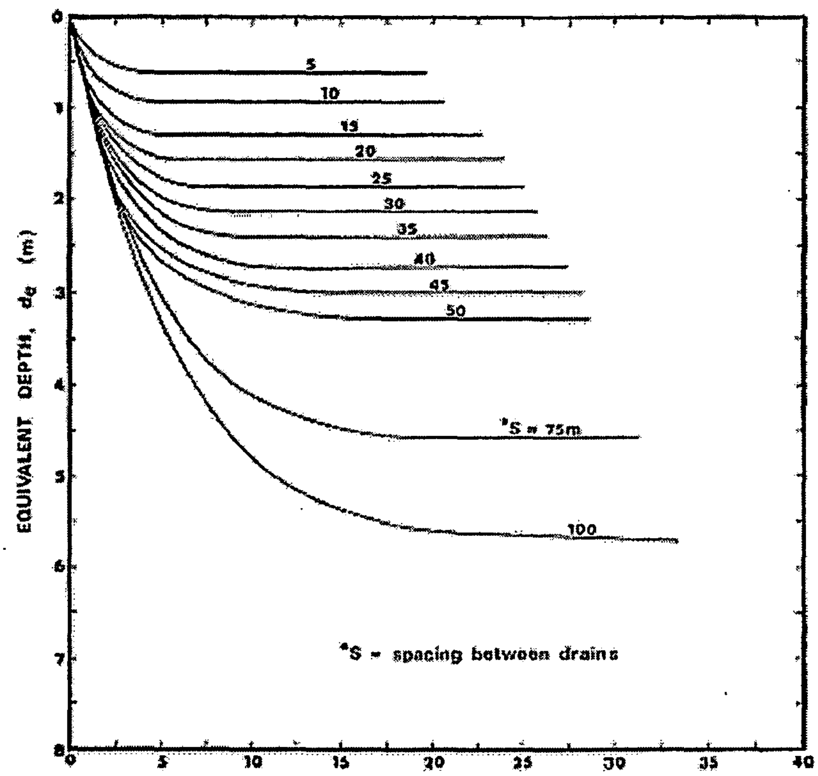

Fig. 2.2 Relationship between d and de where S is spacing between drains and drain diameter for 80 mm pipe.

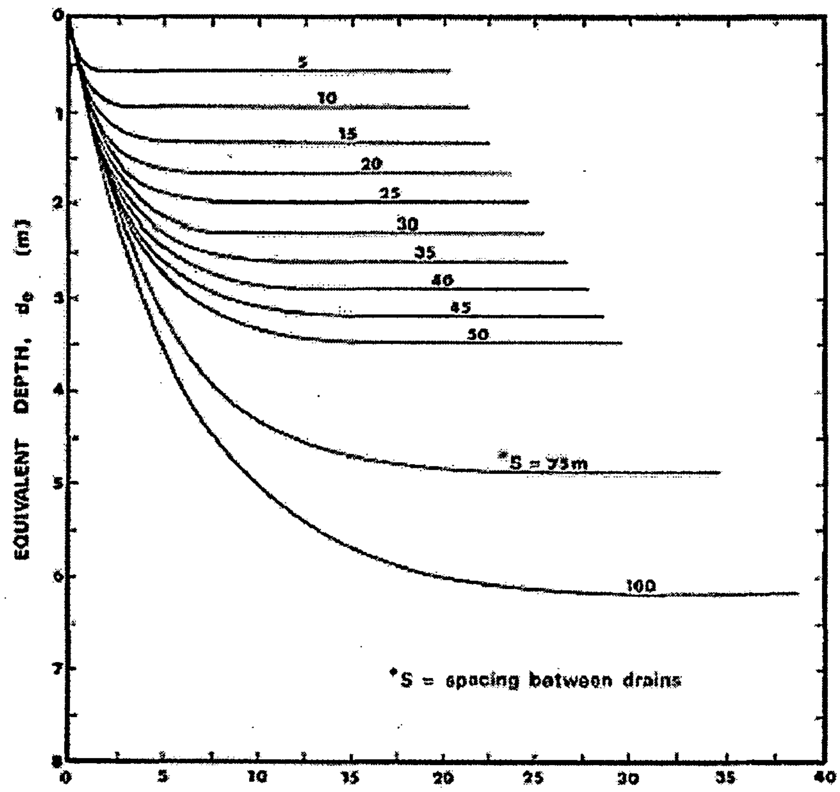

Fig. 2.3 Relationship between d and de where S is spacing between drains and drain diameter for 100 mm pipe.

CHAPTER III

AGRICULTURAL DRAINGE TECHNIQUES

"Agricultural drainage systems" are systems that make it easier for water to flow from the land, so that agriculture can benefit from the subsequently reduced water levels. The systems can be made to ease the flow of water over the soil surface or through the underground, which leads to a distinction between "surface drainage systems" and "subsurface drainage systems". Both types of systems need an internal or "field drainage system", which lowers the water level in the field, and an external or "main drainage system", which transports the water to the outlet. A surface drainage system is applied when the waterlogging occurs on the soil surface, whereas a subsurface drainage system is applied when the waterlogging occurs in the soil. Although subsurface drainage systems are sometimes installed to reduce surface waterlogging and vice versa; this practice is however not recommended. Under certain conditions, however, combined surface/subsurface drainage systems are quite feasible. Agricultural drainage systems do not necessarily lead to increased peak discharges. Although this may occur, especially with surface drainage, the reduced waterlogging can lead to an increase in the temporary storage of water on or in the soil during periods of peak rainfall, so that peak discharges are indeed reduced. A drainage engineer should see that the flow of water from the soil occurs as steadily as possible instead of suddenly. Sometimes (e.g. in irrigated, submerged rice fields), a form of temporary drainage is required whereby the drainage system is only allowed to function on certain occasions (e.g. during the harvest period). If allowed to function continuously, excessive quantities of water would be lost. Such a system is therefore called a "checked drainage system". More usually, however, the drainage system should function as regularly as possible to prevent undue waterlogging at any time. It is often termed as “regular drainage system" or sometimes as "relief drainage".

The above definition of agricultural drainage systems excludes drainage systems for cities, highways, sports fields, and other non-agricultural purposes. Further, it excludes natural drainage systems. Agricultural drainage systems are artificial and are only installed when the natural drainage is insufficient for a satisfactory form of agriculture. The definition also excludes such reclamation measures as "hydraulic erosion control" (which aims at reducing the flow of water from the soil than enhancing it) and "flood protection" (which does not enhance the flow of water from the soil, but aims rather at containing the water in watercourses). Nevertheless, flood protection and drainage systems are often simultaneous components of land reclamation projects. The reason is that installing drainage systems without flood protection in areas prone to inundation would be a waste of time and money. Areas with both flood protection and drainage systems are often called "polders". Sometimes, a flood-control project alone suffices to cure the waterlogging. Drainage systems are then not required. In literature, one encounters the term "interceptor drainage". The interception and diversion of surface waters with catch canals is common practice in water-management projects, but it is a flood-protection measure rather than a drainage measure. The interception of groundwater flowing laterally through the soil is usually not effective, because of the low velocities of groundwater flow (seldom more than 1 m/d and often much less). In the presence of a shallow impermeable layer, subsurface interceptor drains catch very little water and generally do not relieve waterlogging in extensive agricultural areas. In the presence of a deep impermeable layer, the total flow of groundwater can be considerable, but then it passes almost entirely underneath the subsurface interceptor drain. A single interceptor drain cannot intercept the upward seepage of groundwater. Here, a regular drainage system is required.

The different drainage techniques generally used for agriculture drainage with their merits and demerits as well as their suitability under varying field and agro climatic conditions are elaborated foregoing text.

3.1 Drainage Methods

3.1.1Conventional Drainage Systems

a. Horizontal Surface Drainage

The surface drainage is described by the American Society of Agricultural Engineers as “the removal of excess water from the soil surface in time to prevent damage to crops and to keep water away from ponding on the surface” (ASAE 1979). The term surface drainage applies to situations where overland flow is the major component of the excess-water movement to major drains or natural streams. The technique normally involves the excavation of open trenches/drains. It can also include the construction of broad-based ridges or beds, as grassed waterways, with water being discharged through the depressions between ridges. Surface drainage is most commonly employed in heavier soils where infiltration is slow and excess rainfall cannot percolate freely through the soil profile to the water table. The technique has also been applied in more permeable soils to de-water areas having a shallow groundwater table. It is the most important drainage technique usually practices in humid and sub- humid zones.

b. Horizontal Subsurface Drainage

The horizontal subsurface drainage involves removal of water from below the surface. The field drains can either be open ditches, or more commonly a network of pipes installed horizontally below the ground surface. These pipes used to be manufactured of clay tiles, with the water entering the pipes through the leaky joints (thus the term tile drains). In 1968 flexible corrugated plastic drainage pipe was introduced and this product is now widely used around the world. In spite of the usage of different materials, the term tile drains is still in common use.

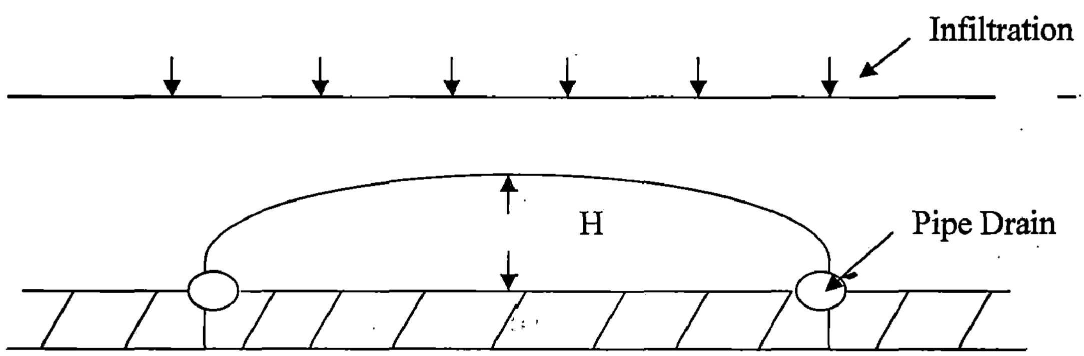

Figure 3.1 Typical layout of pipe drain

The horizontal subsurface drainage has the efficacy to control the rise of groundwater tables to enable productive agriculture. Drawbacks however are that it is relatively expensive to install, operate and maintain. Also the disposal of drainage water that can contain high concentrations of pollutants (nutrients and/or toxic elements such as boron) can create problems.

c. Mole Drains

Mole drains are unlined cylindrical channels which function like clay or plastic pipes and are formed using an implement called a mole plough, which consists of a cylindrical foot attached to a narrow leg. Connected to the back of the foot is a slightly larger diameter cylindrical expander. The foot and expander form the drainage channel as the implement is drawn through the soil and the leg leaves a slot and associated fissures. The fissures extend from the surface and laterally out into the soil. Any surplus water above moling depth can therefore move rapidly through these fissures into the mole channel.

It is noted that successful mole drainage depends on the water being able to rapidly enter the mole drain and flow unimpeded down the channel and exit the system either via an open ditch or into a deeply set pipe system. Because mole drains are only formed out of soil, they deteriorate over time. As a guide, for practical and economic reasons, the mole channels usually remain open for at least five years before remoling is required.

The success of a mole drainage system depends, more than any other drainage technique, on paying close attention to detail. Short cutting the system, especially with relatively unstable soils, will result in a failure. Success depends on working with the correct soil type, and installing the mole drainage at the right depth and spacing. It also depends on using an appropriate design for the whole system and doing the work at the appropriate time of the year and soil moisture content.

d. Vertical subsurface drainage

The vertical subsurface drainage involves removal of groundwater through pumped boreholes or tube wells, either in single or multiple-well configurations. The common problem with this technique is that deeper, often more saline, water can be mobilized which can cause disposal problems. Also, as the water is commonly used for irrigation, rather than for disposal, salt is recycled through the soil profile and groundwater salinity increases inevitably over time. Low-yielding, large diameter open wells, or skimming wells, explore lenses of fresh water overlying deeper, more saline groundwater.

Vertical drainage with reuse of the extracted groundwater for irrigation is effective where the groundwater is of good quality and easily accessible (well-developed aquifers). However, this approach does not remove salts from the region. The long-term sustainability of vertical drainage without drainage disposal for salt-balance is therefore questionable.

Historically, the horizontal drainage is advantageous in most situations for it controls the rise in the groundwater table and enables productive agriculture. However, it is relatively expensive to install, operate and maintain. Another serious drawback is the issue of drainage effluent disposal that can pollute surface water bodies, especially where a direct outlet to the sea is not available. Water quality usually restricts the use for irrigation. Even the disposal to evaporation ponds can create environmental problems.

3.1.2 Non-conventional

The limitations and shortcomings of the conventional drainage techniques call for alternative approaches for long term sustenance of agriculture. Alternative techniques must be effective, affordable; socially acceptable, environmental friendly, and they should not cause degradation of natural land and water resources. Bio-drainage is one of these alternative options. The absence of effluent makes the system attractive. However, for bio-drainage systems to be sustainable, careful consideration is required of the salt-balance under the bio-drainage crops.

a. Bio-drainage

The term bio-drainage is relatively new and it is defined as using some plant species which can withdraw water from root zone at a faster rate and release it to atmosphere through evapotranspiration. The absence of effluent makes the system attractive. However, for bio-drainage systems to be long-term sustainable, careful consideration of the salt-balance is required under the bio-drainage crops. The first documented use of the term bio-drainage can be attributed to Gafni (1994). Earlier, Heuperman (1992) used the term bio- pumping to describe the use of trees for water table control. Another term relating to the "bio" aspect of soil water removal is bio-disposal, which refers to the use of plants for final disposal of excess drainage water (Denecke, 2000). In response to the increased interest in bio-drainage, a special session on the topic was organized at the Eighth Drainage Workshop of the International Commission on Irrigation and Drainage (ICID) in January/February 2000 in New Delhi, India.

The need for drainage is not restricted to irrigation areas only. In rainfed areas without irrigation, water (and salt) balances, disturbed by land use changes, often need to be managed to minimize negative environmental impacts. As the land use in these areas is often less intensive than in those using irrigation, economic considerations prevent the adoption of expensive engineering inputs. This fact makes the bio-drainage approach especially attractive for the management of drainage problems.

3.1.3 Effect of drainage condition

A drainage condition imposes changes in physical and chemical properties of soil and subsequently has adverse effects on crop production. Some of the important effects are narrated as below

a. Greater soil compaction: When subjected to continuous cultivation or frequent machinery traffic at optimum moisture contents, even the most resistant soils can become densified to the extent that internal drainage rates are diminished. Densified layers can form at the soil surface, where machinery wheels contact soil, and extend downward, or they can form at the base of the tillage operating plane. For example, rototilling at optimum moisture levels but repetitious depths can create a densified layer, commonly referred to as a "traffic pan" or "plow sole," at that depth: this layer can extend downward nearly twice that depth. Under such conditions, soil water contents can reach a saturation level above the densified layer whereby most of the pore space is filled with water and soil air is excluded.

b. Impaired chemical and biological conditions:

Detrimental effects of saturated soils are:

(1) Low pH levels and excess soluble manganese, which can become toxic to plants.
(2) Retardation of organic matter decomposition and mineralization of organically bound nutrients.
(3) Release of organic sulfur as toxic hydrogen sulfide;
(4) Denitrification, which converts nitrates to volatile forms of nitrogen (N) that are lost from the soil.
(5) Promotion of pathogens.

c. Increased runoff and erosion: When infiltration rates are reduced, the opportunity for surface runoff increases dramatically. Erosion may not be significant within the wheel track zone, where this condition would be expected to occur, but runoff waters can either inundate adjacent areas or provide the energy to cause erosion on downslope areas. In seedbeds where percolation rates are diminished, soils become increasingly wetter, lose their resistance to detachability, and increase their susceptibility to transport.

3.1.4 Benefits Of drainage system

a. Enhanced operational efficiency: Well-drained soil profiles can permit considerable flexibility in farm operation either manually or with machinery. Installing a shallow drainage system with closely spaced pipelines, along with soil-management practices such as sub soiling, can increase downward water movement.

b. Warmer soil temperatures: Properly drained soils warm earlier in the spring, permitting earlier sowing. Wet soils warm more slowly because water requires 4 to 5 times more heat to raise a unit weight by 1° C than is needed for the same weight of mineral soil. Plant growth and all chemical reactions are slowed approximately by 25% for each 10°F drop in temperature.

c. More uniform soil moisture: Proper drainage allows soil moisture to be distributed more evenly over the entire field, eliminating wet spots. This permits earlier, more predictable, and more efficient tilling. Layered soils with different textures and structures can temporarily restrict water movement. However, drainage installations with closely spaced pipelines favor the disruption of these layers and increase downward water movement, resulting in a uniform soil moisture profile.

d. Decreased soil-N losses: Saturated soils create anaerobic (lacking oxygen) conditions which favor denitrification. Although some N_2 is lost through the drainage systems themselves, most of those losses are not nearly as significant as the ones attributed to the combined effects of denitrification and lack of oxygen in wet soils.

e. Fewer soil pathogens: Some diseases are particularly enhanced by excessive soil moisture or an irregular water supply. For example, Pythium and other damping-off fungi. Well-drained soils tend to favor a balanced mixture of biotic populations, rather than to promote a few species.

f. Reduced surface erosion: The loss of topsoil and the effect of that loss on productivity are difficult to assess. At present, the U.S.D.A. Soil Conservation Service has proposed soil-erosion tolerance levels for agricultural lands which allow from 3 to 5 tons/acre/year of topsoil to be lost. Erosion can be reduced on a well-drained soil by increasing the soil's capacity to hold water, thereby reducing runoff.

3.1.5 Design Consideration for Agriculture

If soil moisture level increases beyond field capacity, it tends to saturation level i.e. gravitational water which is supposed to be drained at deeper soil profile seizes to move further for some obvious reasons and air pores in soil mass starts getting filled with water molecules. It leads to reduced air spaces through which roots of plants derive oxygen for their respiration. Plants start suffocating for want of air and their growth is hampered. If process of saturation continues till all air spaces get filled in, except crops like rice, all other crops show wilting symptoms and plant dies in due course of time. These soil moisture levels are depicted in Figure 3.2

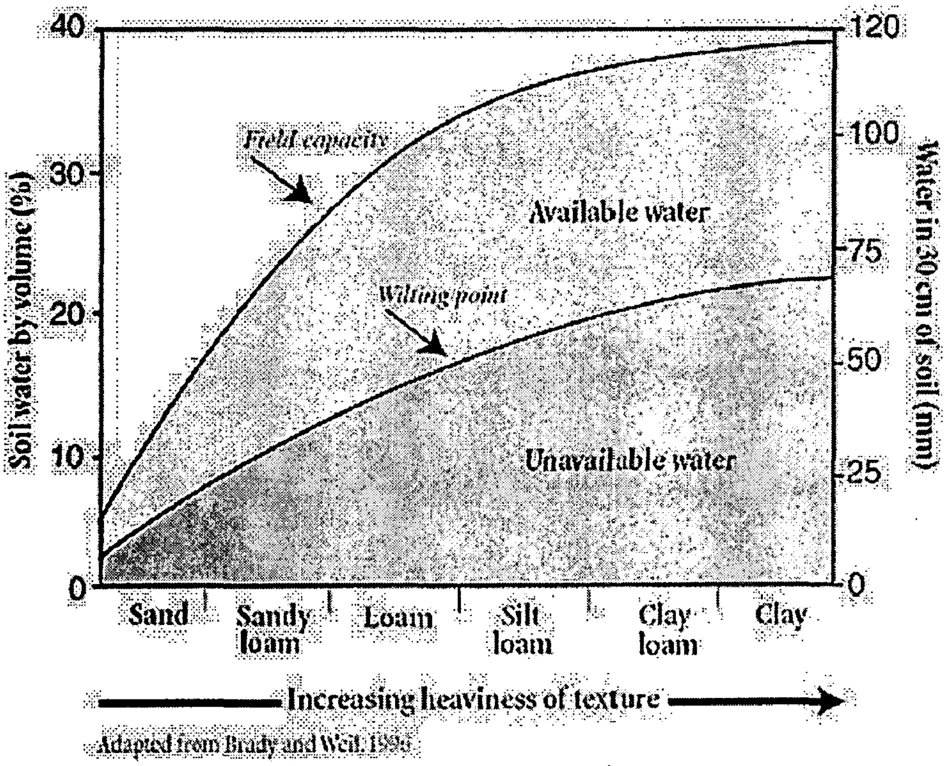

Figure 3.2 Soil moisture status of different soils

Generally soil saturation starts from impermeable layer as gravitational water moves towards lower strata and when obstructed by impermeable layer, the soil water starts accumulating on impermeable layer and in the process the saturation zone moves towards root zone. When it approaches near root zone, then the soil is supposed to be drainage affected soils. This process is explained in figure 3.3

Tanwar B.S. (1998) provided following guidelines for categorization of drainage areas.

I Waterlogged area	Water table within 2m from land surface
II Potential area for waterlogging	Water table between 2-3m from land surface
III Safe area	Water table below 3m from land surface

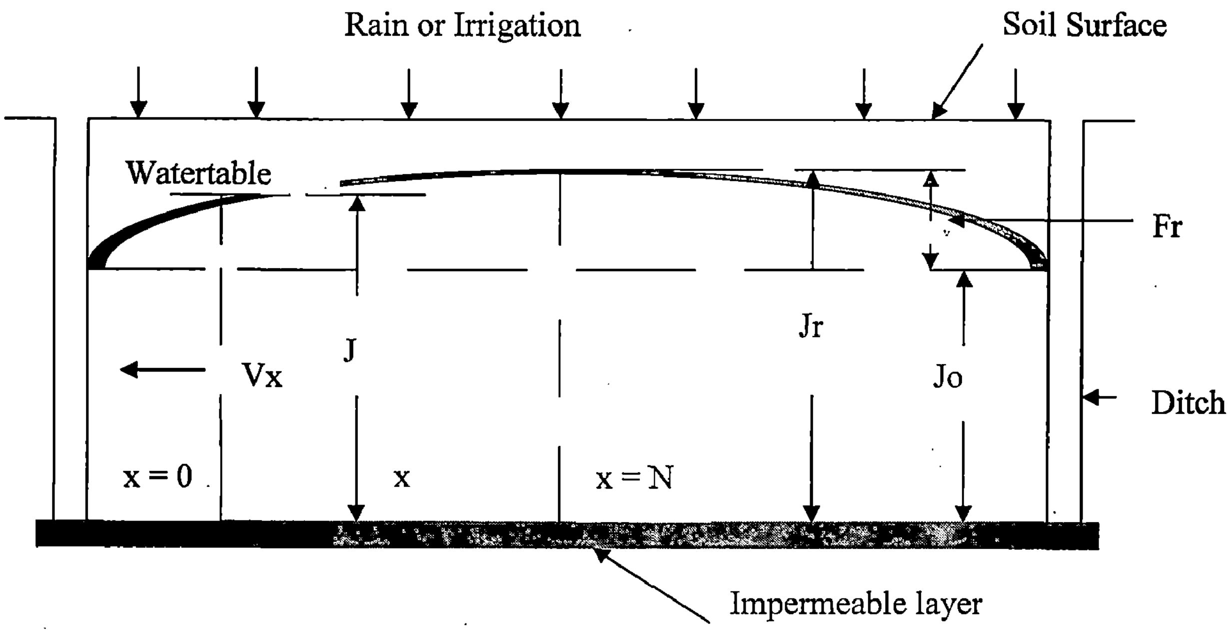

Figure 3.3 A definition sketch of waterlogged area

A typical soil moisture profile is shown figure 3.2.In this figure,

J = level of the water table at distance X, taken with respect to the level of the impermeable base of the aquifer (m), Jr = reference value of level J (m), X = distance in horizontal direction (m), Vx = apparent flow velocity at X in horizontal X-direction (m/day), Kx = horizontal hydraulic conductivity (m/day) R = steady recharge by downward percolating water stemming from rain or irrigation water (m/day), dX = small increment of distance X (m)

dJ = increment of level J over increment dX (m), dJ/dX = gradient of the water table at X (m/m).

Under drainage conditions, since moisture is readily available in upper parts of the soil profile, and therefore, evapotranspiration is found to be accelerated at potential level.. It develops a sort of capillary continuity and salts at lower level of root zone are brought to the soil surface. The proportion of salts in active root zone increases beyond tolerance limit for good crop growth and yields of crops grown in this area starts declining. This problem is found to be more pronounced in arid zone where evaporation rate is very high, rainfall is relatively low and drainage problem is associated with irrigation systems in the region. The arid zone of Ahmednagar district of Maharashtra under Pravara command, Baramati area of Pune district (M.S.) under Neera command and most part of Rajasthan under Indira Canal system are distinct examples of this type of drainage problem (Tanwar,1998).

3.1.6 Field Investigations

If a drainage problem is suspected, a field investigation should be initiated to determine which one or combination of possible soil-water or environmental conditions cause the problem. To gain an overview of the entire situation, both small and large-scale aerial photographs should be obtained. In addition to this, images obtained by remote sensing techniques can also be used for identification of drainage affected area.

Occasionally, problems at a particular site can be related to distant, off-site conditions like contributions of runoff waters from lands adjacent to problem area, underground seepage from canal system etc. Sometimes, localized problems are induced due to land development, roadways, railways, culvert etc. Similarly, the transmission of waters from distant or upslope watersheds into alluvial-colluvial fans or toe slopes lacking well-defined channels can be a hidden source of drainage problems. Water will follow old, obscure channels and emerge as seepage. Stream flow configuration can indicate possible water movement from upstream or side stream channels. Sinuous or meandering streams frequently have higher water-table levels within the adjacent lands than do "straight" streams. Old meander channels are often hard to detect on the ground but are usually observed in tonal differences as well as topographic depressions on aerial photographs.

3.1.7 Subsoil investigations

Subsoil and substrata conditions are evaluated by traversing the land and boring holes in the soil. Borings can be made randomly or according to established grid spacing. Large scale aerial photographs may be the basis for selecting where the random borings should be made according to changes in topography or tonal expressions on the photos. If borings expose saturated soil conditions or free water within the top 5 feet, then a problem exists. Abrupt changes in soil texture and structure which can be natural or induced by traffic often indicate pronounced reduction in soil-water movement. Examining subsoil colors can be revealing. Blues and grays predominate in saturated soils in which insufficient oxygen causes soil minerals to be chemically reduced.

3.1.8 Data required

The information on the following aspects will be required for proper design of drainage within a region:

I Description of local and/or regional hydrogeology

II Type of crop or crops to be grown and their agronomy

III Description of drainage problem

IV Description of drainage method used

V Drainage design, including site investigations

VI Drainage water quality, quantity and disposal

VII Drainage system management and monitoring

VIII Funding arrangements

IX Current issues and trends

X Research requirements.

3.1.9 Selection of drainage system

The following drainage systems were described in earlier paras of this Chapter.

i. Horizontal Surface

ii. Horizontal subsurface

- pipe or tile
- mole

iii. Vertical

iv. Biodrainage

After having understood the assimilation of drainage problem and its pros and cons, it will be appropriate to understand design criteria for good drainage system. Before actual design is taken up, it is necessary to decide the type of drainage to be used for the given field from above options

a. Horizontal surface drainage

This is in general used for the removal of excess rainwater or other source of water, which is impounding in cropped land and causing ill effects to crop growth or even creating hindrances to cultivation activities in the field or watershed. It is an established practice used for roads, cities and other urban habitats as also commonly used for agriculture watersheds. The design of horizontal surface drainage requires the following data:

i. Runoff causing drainage or ponding

ii. Drainage coefficient

iii. Soil characteristics like

- Soil texture
- Soil structure
- Soil depth
- Infiltration rate

iv. Crop to be grown

v. Tolerance limit of crop for ponding water

With the above information, the surface drainage system can be designed for following parameters

i. Layout of drainage system

ii. Geographic parameters of drain

a. Shape

b. Bottom width

c. Side slope

d. Depth

e. Bed gradient

There is no bar on type of layout and it will depend on farm size, location of outlet, crop type etc. In general drainage layouts are of the following nature.

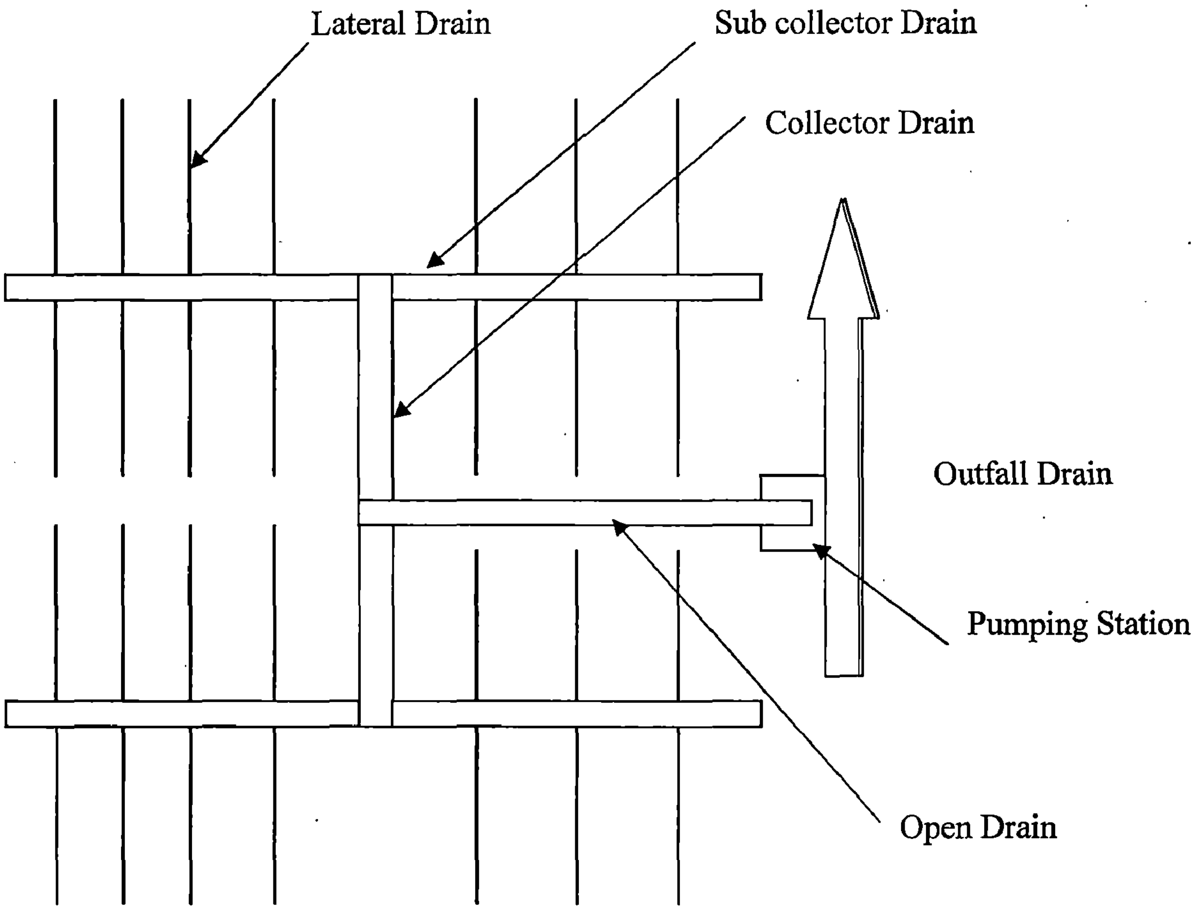

Figure 3.4 General layout of drainage system.

b. Horizontal subsurface drainage

There are two options viz; tile or pipe drain and mole drain. Mole drain is site specific and it is generally used generally used where there is localized hindrance to soil water due to compaction of lower layer in heavy soils. It is a type of temporarily type drainage.

However, tile or pipe drain is commonly and widely used method of drainage. It addresses the problem of saturation of root zone of crop. It creates artificial gradient for soil moisture or gravitational water in root zone and evacuates it through pipe conduit from root zone to natural drainage system. The general layout of pipe drain is as shown below.

For design of pipe drainage, the information as stated in horizontal surface drainage is required. In addition to this, it also requires the following data:

i. Hydraulic conductivity

ii. Water balance study of watershed

iii. Ground water data

iv. Ground water contribution to soil moisture

v. Availability of outlet

The design consideration varies for steady state and unsteady state condition of ground water.

c. Vertical Drainage

This method deals with pumping of ground water that has encroached in root zone by digging wells in command area. Depending on quality of water, it may be used in command as irrigation water or may be pumped out of command at suitable location. It is generally a preferred system, where the quality of water is suitable for irrigation and there is reliable supply of electric power in command area. Even it can be used as conjunctive use with canal water. Design engineer should have the following information of command area is required for design of vertical drainage:

i. Spatial and temporal ground water status

ii. Quality of ground water

iii. Aquifer characters like

   a. Specific yield of aquifer
   b. Storativity of aquifer
   c. Depth of aquifer
   d. Hydraulic conductivity of aquifer strata

Then with the help of well functions, pumping hours and yield of well, the wells at different location are designed, constructed and operated.

3.1.10 Design of surface Drainage

It is common phenomenon that ponding of water on surface of agriculture lands leads to drainage problems. Crops sensitive to high moisture content in root zone or absence of soil air in root zone affects the yield. The source of water attributing to drainage may be one or more from the followings: Rainfall, canal seepage, excess irrigation, seawater intrusion and groundwater encroachment due to capillary rise.

The source of water causing drainage problem may be single or multiple depending upon the situation of watershed. Therefore, estimation of maximum possible quantum of water over the given period of time forms the first step towards design of any type of drainage system. This falls under hydrological design of drainage system. After having designed the runoff, geometrical parameters of drainage system are dealt under hydraulic design.

a. Hydrologic Design

In case of agriculture land, runoff resulted from rainfall is in general prime cause of drainage. Runoff is governed by rainfall amount, rainfall intensity, and continuity of rainfall on one side and geomorphologic parameters of watershed on the other side. Since rainfall is a random variable and exact prediction of rainfall and subsequently runoff is a difficult task. Further, runoff is influenced by heterogeneity of geomorphologic parameters within the watershed and due consideration is required to be given while estimating runoff. Water moves from higher elevations, to lower elevations and therefore, accumulation of runoff water is more at low reaches. Different crops have different response to ponding of water in fields and rate of removal of drainage water depends on sensitivity of crop under consideration. It is always not necessary to drain out water as quickly as it is required in case of reservoir after it is filled in. Every crop has an inbuilt capacity to sustain the drainage conditions for a certain period of time and this feature of crop needs to be explored while designing the drainage system. If maximum runoff is accumulating @ of R mm/day and tolerance limit of the crop is 3 days, then water can be removed @ R/3 mm/day. It implies that drainage capacity need not be equal the to rate of incoming runoff.

b. Drainage Coefficient

It is the rate of removal of water expressed in terms of depth over a period of one day. In case of agriculture lands, water needs to be removed depending upon tolerance of crop to drainage conditions. It ranges from 1-3 days but in general 6 hours is a typical in India Therefore, drainage coefficient is a ratio of peak rate of runoff to submergence tolerance index.

c. Hydraulic Design:

This part deals with design of geometrical aspects of surface drainage like,. type of drain; drain geometry like width, depth, and slope etc., surface drainage network; location of outlet, if available naturally; and type of outlet i.e. controlled (gated or pumped outlet). These design procedures are discussed in detail in the foregoing text.

3.1.11Different techniques of hydrological design

As seen earlier, estimation of runoff is important in design of surface drainage. The process of runoff is a very complicated phenomenon. In general, runoff is initiated as soon as rainfall intensity exceeds infiltration rate of soil at given time. When soil is dry more water is absorbed in soil profile and in due course of time, as soil moisture increases, infiltration rate decreases and finally attains a constant value. Once soil attains minimum constant infiltration rate then water will be absorbed at this rate and remaining part of rainfall will appear as runoff.

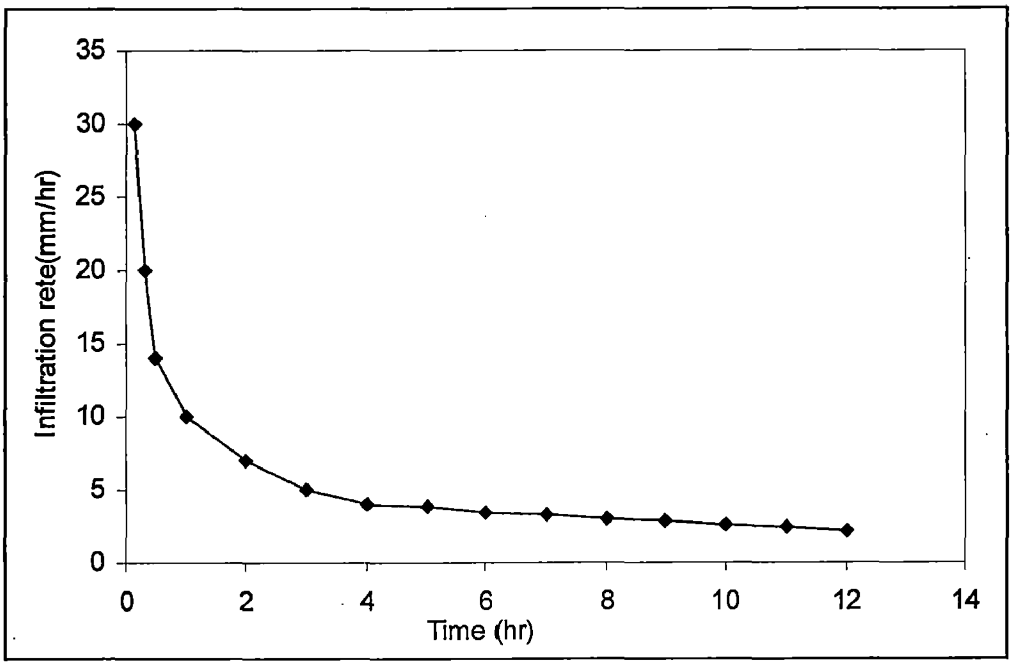

Figure 3.1 Typical infiltration characteristics of soil

Runoff can be either actually measured in the field or can be estimated using empirical or analytical methods. There are following methods to estimate runoff by measurement:

(i). Volumetric (ii) slope area method (iii) velocity area method (iv) salt dilution method (v) L-tube (vi).Different runoff measuring devices like flumes, weirs etc.

(vii). Stage discharge relationship In surface drainage, generally point source of runoff is not responsible for drainage conditions. Even if the cause of drainage is seepage through canal or reservoir, water enters in land through seepage front and runoff measurement along the front is not as such desirable. Therefore, methods of runoff measurement become irrelevant. However, since drained water is made to pass through a known dimension of drain, it is more convenient to monitor drainage water by runoff measuring methods. Further, surface drainage problems of agriculture lands exist predominantly in plain areas where rainfall precipitating over an area tends to accumulate due to flat slopes. Under these situations, instead of direct measurement of runoff, estimation of runoff using some analytical empirical method becomes inevitable. There are several methods to predict the runoff, as for example Rational method, Unit hydrograph, Simple linear correlations and regression, multiple linear correlation and regressions and hydrological soil cover complex method etc. Out of these, following three methods are compared for a given watershed for estimating runoff: Rational method, Simple linear correlations and regression and Hydrological soil covers complex method. These methods are explained in detail and then runoff of watershed under case study is estimated using this method separately.

a. Rational Method

This method was proposed by a Italian hydrologist, Ramser and is known as Rational Method. It does not give the total runoff but it gives peak rate of runoff as

$Q = CIA$

Where, Q = Peak rate of runoff (m^3/sec), C = Coefficient of runoff, I = Uniform rainfall intensity over whole of the watershed for time of concentration (cm/hr), A = Area (hectare). This formula is based on following assumption:

"Storm having uniform intensity all over the areas and which can continue for minimum time equal to time of concentration will make such a situation that all runoff water that has initiated at the most remote point from outlet would start passing through the outlet resulting into peak rate of runoff for the given storm."

Time of concentration is the time taken by runoff water to travel from the most remote point in the watershed to the outlet. It is given by,

$Tc = 0.0195\ L^{0.77} S^{-0.0385}$

Where, Tc = Time of concentration (minute), L = Length of longest flow path (m)

S = slope of flow path (m/m).

Time of concentration is also given by

$$Tc = 0.0195 \quad (A^2/S)^{0.2} (L/D)$$

Where, A = Area (hectare) and D = Diameter of circle having area equal to area of watershed.

i. Intensity of rainfall

One hour rainfall maps of 2, 5 and 10 years recurrence interval are available in literature. Thus according to the desired recurrence interval, the intensity of one hour rainfall can be derived for the given location of watershed. Then this intensity is converted to the intensity for time of concentration from the monograms.

Among others, Babu et al. (1979) derived relationship between intensity and duration of return period dividing India into five zones as shown in Table 3.1

Table No. 3.1 Relationship between intensity and duration of return period

I Northern Region	$I = \frac{5.9143(T)^{0.1623}}{(t+0.5)^{1.0127}}$	Where I = rainfall intensity (cm/hr) , T = Recurrence interval (years), t = rainfall duration i. e. value of Tc (hours)
II Central Zone	$I = \frac{7.4645(T)^{0.1712}}{(t+0.75)^{0.9599}}$	
III Western Zone	$I = \frac{5.974(T)^{0.1647}}{(t+0.75)^{0.7327}}$	
IV Eastern Zone	$I = \frac{6.933(T)^{0.1353}}{(t+0.5)^{0.8801}}$	
V Southern Zone	$I = \frac{6.311(T)^{0.1523}}{(t+0.5)^{0.9465}}$	

Thus, either from monogram or using above relation (Table 3.1), the intensity for time of concentration can be computed for use in Rational formula.

b. Hydrological Soil Cover Complex Method (Curve Number Method)

This method was adopted by Soil Conservation Services of United State Department of Agriculture for estimating runoff from small agriculture watershed. It is referred to as

SCS-USDA curve number method. Since runoff is an interactive process greatly influenced by soil type, soil wetness, land cover, vegetation and growth condition of vegetation as well as nature of cultivation practices, these parameters are assigned with CN number and lumped together. The CN numbers vary in the range of 0 to 100.

i. Theory

If a graph of rainfall and the corresponding runoff is plotted, it will be a straight line with 1:1 slope passing through origin.

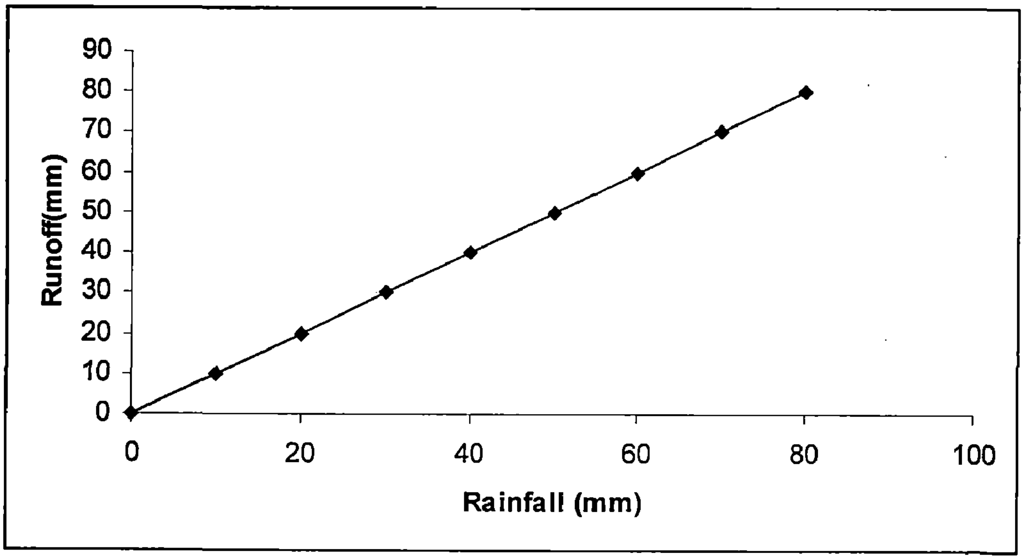

Fig 3.2 Definition sketch of CN method

It holds for rainfall on completely impervious layer and without any loss will yield into equal amount of runoff. The graphical representation will be a straight line (Figure 3.2) and it will carry CN value of 100. While, in case of plain and bounded field, all rainfall will be accommodated within the field and runoff will be 0. It is expressed by the X- axis and CN will be 0. The response of a watershed to rainfall occurs in-between these two extreme conditions, which can be expressed in terms of CN number from 0 to 100. These lines do not pass through origin since, before initiation of runoff, there occurs some initial abstraction in the soil. The basic assumption in this method is that "Ratio of actual to maximum possible runoff is equal to ratio of actual to maximum possible abstraction."

Thus if, P = Rainfall, R = runoff, S = Potential maximum retention.

$$\frac{R}{P} = \left(\frac{(P-R)}{S}\right)$$

Central Unit of Soil Conservation Ministry of Agriculture, Government of India, have suggested the relations between initial abstraction and maximum possible abstraction:

Ia = 0.1S for black soil region with AMC II and AMCIII

Ia = 0.2S for black soil region with AMC I (watershed soils are dry)

Ia = 0.3S for all other soils

ii. Antecedent Moisture Conditions (AMC)

It is the measure of wetness or dryness of watersheds when rainfall occurs for which runoff is to be predicted.

Table 3.2 Categorization of AMC

AMC I	Preceding 5 days rainfall < 12 mm (for dormant season) < 36 (for growing season)
AMC II	Preceding 5 days rainfall 12-28 mm (for dormant season) 36-53 (for growing season)
AMC III	Preceding 5 days rainfall >28 mm (for dormant season) >53 (for growing season)

From Table 3.2, depending on rainfall situation of preceding 5 days, AMC group of soil can be ascertained. To this end, CN number for AMCII is transformed to AMCI or AMCIII according to Table 3.2.

iii. Hydrological Soil Group

Soils of the watershed are further classified into four groups according to their infiltration capacities (Table 3.3).

Table 3.3 Classification of hydrological soil groups

Group	Infiltration characteristics	Probable soil type	Runoff potential
A	High infiltration rate (>25 mm/hr)	Deep sands	Very low
B	Moderate infiltration rate (12.5 – 25 mm/hr)	Deep coarse sands	Moderately low
C	Low infiltration rate (2.5 – 12.5 mm/hr)	Shallow fine sands	Moderately high
D	Very low infiltration rate (<2.5 mm/hr)	Clayey, shallow soils	Very high

It is appropriate to actually find the infiltration characteristics of soil to decide the hydrological soil group.

iv. Land Use

The following land use patterns are considered in this method: I. Cultivated land ii Orchards iii Forest iv Pasture and trees Wasteland vi. Non metallic road vii Hard surface area

v. Cover Condition

The agricultural systems are categorisd in the following crop cover conditions.

i. Contour cultivation ii. Straight up and down cultivation iii.Terraced lands

vi. CN Number:

A suitable value of Curve Number can be taken from Table 3.4

Table 3.4 CN values for different conditions of land use and soil groups.

Land use	Cultivation type	Cover condition	AMCII			
			Hydrological soil group			
			Ia = 0.3S		Ia = 0.1S	
			A	B	C	D
Fallow	Poor		77	86	91	94
Row crop	Straight	Poor	72	81	88	91
		good	67	78	85	89
	contour	poor	70	79	81	88
		Good	65	75	82	86
	Terraced	Poor	66	74	80	82
		good	62	71	78	81
Forest		Dense	26	40	58	61
		Open	28	44	60	64
Pasture		Poor	68	79	86	89
		Fair	49	69	79	84
		good	39	61	74	80
Orchard		Average	40	54	68	72
Paddy		-	95	95	95	95

The CN value from Table 3.4 stands for AMC II. Then Table 3.5 is used to convert it to desired AMC level. According to the morphological characteristics of watershed, weighted value of CN number can be ascertained.

Table No. 3.5 Relationship between three AMC group.

AMC	Curve number									
I	100	78	63	51	40	31	22	15	9	4	0
II	100	90	80	70	60	50	40	30	20	10	0
III	100	96	91	85	78	70	60	50	37	22	0

Then

$$S = \left(\frac{1000}{CN} - 10\right) x\, 25.4$$

$$R = \frac{(P - 0.3S)^2}{(P + (S - Ia))}$$

Where, P = Rainfall, R = Runoff, CN= curve Number, S = Potential maximum retention.

c. Time distribution of runoff

This method is based on the following assumptions:

i. Agriculture watersheds have time of concentration not exceeding 6 hours

ii. 24 hour rainfall is convertible to 6 hour rainfall by multiplying the former by a factor varying in the range of 0.5 to 0.7.

iii. Time distribution of rainfall within 6 hours exhibits a certain pattern.

iv. In a chosen time increment, the runoff is predictable by CN method.

v. Time to peak (Tp) is a function of time of concentration (Tc) as follows:
Tp=(0.5 to 0.7) Tc.

vi. The plot of time ratio (T/Tp) and runoff ratio (Q/Qp) yields a unique dimensionless hydrograph. The computations are shown in Tables 3.6 and 3.7.

Table No 3.6 Relationship between T/Tp and Q/Qp

T/Tp	0	0.25	0.5	0.75	1	1.25	1.5	1.75
Q/Qp	0	0.11	0.42	0.82	1	0.88	0.66	0.46
T/Tp	2	2.25	2.50	3	3.5	4	4.5	5
Q/Qp	0.32	0.23	0.16	0.105	0.075	0.035	0.018	0

(Source: Bhattacharya et al. 2003)

WMO (1974) provides the distribution of 6 hour rainfall as shown in Table 3.7.

Table No 3.7 Distribution of 6 hour rainfall (WMO 1974)

Time(Hr)	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6
Rainfall (%)	0	2	8	15	22	60	70	78	84	88	92	96	100

(Source: Bhattacharya et al.2003)

Black soil(arid and semi arid)	2.970	0.519	0.372
Eastern red soils	3.396	1.050	0.734
Southern red soils	2.622	0.565	0.356
Assam valley	2.970	0.927	0.446

Source; Gupta et al. (1971)

3.1.12Design drainage Coefficient:

Drainage coefficient is defined as the amount of water to be removed from the cropland in one day so that the plants are not stressed due to excess water. It is expressed as mm/day or cm/day. Conceptually drainage coefficient represents flow rate that will be less than the peak rate of runoff accumulating in watershed. Therefore, drainage coefficient can be adjusted in such a way that at this rate water can be removed or drained from the watershed over a period for which the crop under consideration sustains drainage conditions without economical loss to crop yield.Gupta et al.(1972) reported tolerance indices for submergence for different conditions and crops for India as shown in Table 3.8.

Table 3.8 Submergence tolerance of various crops

Site	Crop	Submergence tolerance indices (days)	
		Threshold	DS_{50}
Delhi	Pigeon pea	1.6	3.8
Hisar	Cowpea	0.8	8.4
Hisar	Pigeon pea	0.5	6.0
Karnal	Wheat Pearlmillet	0.00.0	7.2 9.4
Ludhiyana	Wheat	1.9	7.3
Pusa	Groundnut Maize	0.0 0.2	5.6 5.5

(Source: Gupta et. al. 1992)

CHAPTER IV

STUDY AREA AND DATA AVAILABILITY

The design of surface and subsurface drainage techniques is taken for a representative plot area in command area of **Kal** project in Raïgarh district of Maharashtra State. This project supplies water for summer rice from December to April. The area comes under heavy rainfall in humid. non -lateritic zone with average annual rainfall of 3267 mm. Kharif rice followed by summer rice is a typical cropping pattern in the **Kal** command. Crops like pulses, finger millet and some seasonal vegetables are grown in uppers reaches of canal. As rice cropping based on rainfed pattern is uneconomical in Asian countries due to various reasons (FAO, 1972),the rice yield of this area varies from 20 to 25 quintals per hectare which is below the national average of 30 quintals per hectare. Some of the factors attributing for low yields are: i. Excessive leaching due to heavy rainfall ii inadequate nutrient supply iii low yielding varieties of rice . iii abrupt moisture conditions due to erratic monsoon iv poor or inadequate financial support to agriculture, and iv Lack of willingness amongst the farmers for adoption to new techniques.

The command area of this project is about 90 - 120 Km from Mumbai and only 75 Km from Vashi market which is one of the famous markets known for vegetable export. There are two big industrial hubs namely Roha and Mahad developed by Maharashtra Industrial Development Corporation (MIDC) in command area of this project. There is rapid urbanization around these hubs, and therefore, there is a good deal of demand for vegetables and fruits. Vegetables and fruits fetch very attractive prices in Mumbai, suburb of Mumbai and above industrial zones. Therefore, farmers are shifting their cropping pattern from rice to seasonal vegetables like ridge gourd, spinach, snake gourd, tomato, cucumber, watermelon and some local leafy vegetables. Similarly Konkan region of West Coast of Maharashtra is known for its world famous alphonso mango and cashew. Cultivation of cashew, banana, areca nut, coconut and mixed crops of spices taken in orchards are gaining momentum in this area. The ambitious horticultural scheme of state government where 100 % subsidy is given for plantation of cashew, mango, coconut and spices is also contributing to a shift of cropping pattern at the accelerated rate. Many farmers as well as corporate sectors are establishing mango, coconut and cashew orchards in command of this project. However, the ground water in the command has risen to a very critical level. Entire command can be categorised as waterlogged to potentially waterlogged area as per FAO (1984) guidelines (Table 4.10), a limiting factor to the growth of these crops.

During monsoon period, vegetable crops suffer from flooding of field. New plantations of orchard crops having very shallow root depth are wilted out due to waterlogging conditions, which persist beyond their tolerance limit. Thus, the established orchard gardens in this command experience reduced yields due to shallow watertable. Some attempts are being made to introduce surface and subsurface drainage for orchards of coconut, mango and cashew by some enterpenual farmers from corporate sector in this area. It is however necessary to develop a decision support system which will be useful in designing best possible drainage package for this area. In view of this a location namely Mangaon approximately in centre of this project is selected and data pertaining to Mangaon is analysed to derive the drainage parameters. Appropriate data are assumed, where ever felt necessary.

The data were obtained from the following sources.

1. Dr. Balasaheb Sawant Konkan Krishi Vidyapeeth, Dapoli.
2. Regional Rice research station, Karjat Dist. Raigarh
3. Regional Agril. Research Station, Repoli Dist. Raigarh
4. Publications and research papers related to this area.
5. Command Area Development Authority, Kal Project.
6. Google earth
7. www.fallingrain.com
8. www.agri.mah.gov.in
9. www.fao.com

The salient features of location based on data collected are listed in Table 4.1

Table 4.1 Salient features of study area.

Sr.No	Particular	Details
1	Location:	Mangaon, District Raigarh
2.	Latitude	18^{0} 13' 60" N
3	Longitude	73^{0} 16' 60" E
4.	Altitude	12 m
5.	Average annual rainfall	3267 mm
6	Average daily rainfall for recurrence interval of 10 years	Table 4. 2
7	One day maximum rainfall	Table 4.3
8.	Five days consecutive rainfall during rainy season (10 years recurrence interval)	Table 4.4
11.	Physicochemical properties of soil	Table 4.5
12.	Water table status	Table 4.6
13.	Crop tolerance to soil salinity (expressed as ECe)	Table 4.7
14	Root zone depth of different crops	Table 4.8
15	Maximum and minimum temperature	Table 4.9

A hypothetical field of 50 hectare area is considered for design and layout of the field as shown in Figure 4.1.

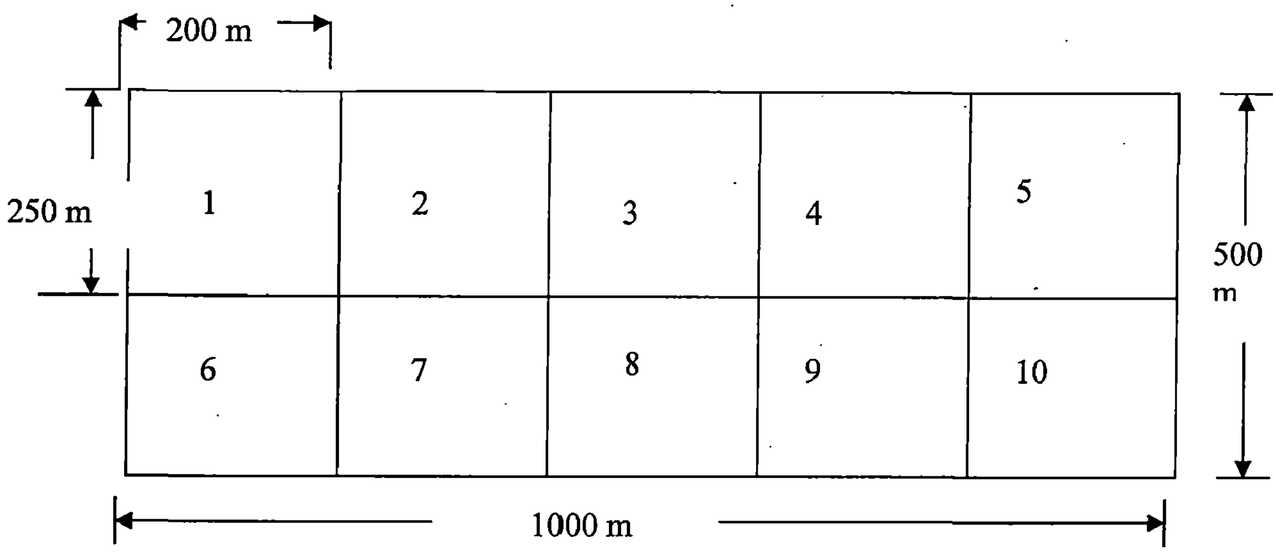

Figure 4.1 Plan of field

Table4.2 Daily rainfall of Mangaon, Dist. Raigarh (10 years average)

Day	Jan	Feb	March	April	May	June	July	Aug	Sep	Oct	Nov	Dec
1.00	0.60	0.00	0.00	0.00	0.00	1.57	44.17	42.57	17.29	6.86	0.00	0.00
2.00	0.00	0.00	0.00	0.00	0.00	2.57	35.86	51.90	11.86	2.57	0.00	0.00
3.00	0.00	0.00	0.00	0.00	0.00	2.00	59.57	34.14	16.07	4.57	0.00	0.00
4.00	0.00	0.00	0.00	0.00	0.00	0.00	35.51	52.57	16.64	1.29	0.00	0.00
5.00	0.00	0.00	0.00	0.00	0.00	0.83	44.14	59.57	10.71	1.00	0.86	0.00
6.00	0.00	0.00	0.00	0.00	0.00	3.71	9.86	43.29	12.57	3.71	0.00	0.00
7.00	0.00	0.00	0.00	0.00	0.00	7.00	12.00	32.29	7.14	11.71	0.00	0.00
8.00	0.00	0.00	0.00	0.00	0.00	16.43	43.57	40.14	21.39	11.43	0.00	0.00
9.00	0.00	0.00	0.00	0.00	0.00	6.86	51.71	42.29	11.00	13.86	1.29	0.00
10.00	0.00	0.00	0.00	0.00	0.00	13.00	28.71	54.00	12.79	8.57	1.86	0.00
11.00	0.00	0.00	0.00	0.00	0.00	9.29	27.89	38.14	19.43	5.43	3.43	0.00
12.00	0.00	0.00	0.00	0.00	0.00	47.00	18.57	54.43	11.14	11.29	0.00	0.00
13.00	0.00	0.00	0.00	0.00	0.00	9.14	23.43	14.07	21.29	3.86	0.00	0.00
14.00	0.00	0.00	0.00	0.00	0.00	20.46	38.86	31.90	11.57	1.00	0.00	0.00
15.00	0.00	0.00	0.00	0.00	0.00	36.43	88.43	14.10	25.29	7.71	0.00	0.00
16.00	0.00	0.00	0.00	0.00	0.00	32.71	55.90	27.29	12.14	4.43	0.00	0.00
17.00	0.00	0.00	0.00	0.00	0.10	27.14	42.86	14.93	33.57	12.03	0.00	0.00
18.00	0.00	0.00	0.00	0.00	0.00	39.86	30.47	11.57	10.29	0.00	0.00	0.00
19.00	0.00	0.00	0.00	7.00	1.43	55.29	23.86	10.00	6.00	0.00	0.00	0.00
20.00	0.00	0.00	0.00	0.00	0.00	21.43	19.14	19.79	9.29	0.00	0.00	0.00
21.00	0.00	0.00	0.00	0.00	0.86	43.71	35.29	15.64	12.86	0.00	0.00	0.00
22.00	0.00	0.00	0.00	0.00	0.00	26.14	39.71	14.71	18.14	0.29	0.00	0.00
23.00	0.00	0.00	0.00	0.00	0.43	51.14	37.14	13.29	6.86	0.00	0.00	0.00
24.00	0.00	0.00	0.00	0.00	1.00	36.86	50.43	22.86	16.86	0.00	0.00	0.00
25.00	0.00	0.00	0.00	0.00	4.93	51.21	55.29	24.00	1.00	0.00	0.00	0.00
26.00	0.00	0.00	0.00	0.00	0.00	43.14	77.04	11.00	7.00	0.00	0.00	0.00
27.00	0.00	0.00	0.00	0.00	0.00	35.87	50.39	13.29	12.00	0.57	0.00	0.00
28.00	0.00	0.00	0.00	0.00	0.71	48.47	36.81	13.71	7.90	2.00	0.00	0.00
29.00	0.00	-	0.00	0.00	2.29	49.86	29.00	14.57	19.00	0.00	0.00	0.00
30.00	0.00	-	0.00	0.00	0.14	31.86	37.70	13.36	18.96	0.00	0.00	0.00
31.00	0.50	-	0.00	-	0.86	-	39.00	13.36	-	0.00	9.93	0.00
Ave	1.10	0.00	0.00	7.00	12.74	770.98	1222.31	858.77	418.05	114.18	17.37	0.00

Table 4.3 One day maximum rainfall of Mangaon Dist: Raigarh

Year	1995	1996	1997	1998	1999	2001	2002	2003	2004	2005
Rainfall (mm)	198	240	213	182	268	217	148	170	268	357

(Source: www.agri.mah.nic.in accessed on 10-2-2006) (Note: data of 2002 not available)

Table 4.4 Five consecutive days cumulative rainfall of 10 years recurrence interval at Mangaon

Consecutive days	Rainfall (mm)	Consecutive days	Rainfall (mm)
1/6 to 4/6	2.40	4/8to9/8	101.86
5/6to9/6	16.71	10/8to14/8	85.90
10/6to14/6	45.71	15/8to19/8	98.10
15/6to19/6	54.14	20/8to24/8	42.64
20/6to24/6	94.93	25/8to29/8	38.57
25/6to29/6	75.00	30/8to3/9	29.43
30/6to4/7	88.31	4/9to9/9	38.03
5/7to9/7	38.57	10/9to14/9	32.29
10/7to14/7	116.31	15/9to19/9	32.96
15/7to19/7	75.04	20/9to24/9	21.86
20/7to24/7	90.57	25/9to29/9	12.86
25/7to29/7	88.09	30/9to4/10	24.76
30/7to3/8	91.57		

Table 4.5 Physico-chemical properties of soils at Mangaon

Sr.No	Property	Value
I	**Physical properties**	
1.	Sand	17.90 %
2.	Silt	39.33%
3.	Clay	43.77 %
4.	Soil type	Clay loam
5.	Soil depth	60 to 120 cm
5.	Bulk density	1.29 gm/cc
6.	Saturated hydraulic conductivity	0.62 m/day
7.	Total porosity	47.88
8.	Available moisture	17.93
II	**Chemical properties**	
1	pH	6.60
2.	Ece	21.15 (dS/m)
3.	Ece of canal water	2.13 (dS/m)

Table 4.6 Average monthly ground water table

Month	Year wise monthly water table depths (m)				
	2000	2001	2002	2003	Average
January	1.35	1.32	1.38	1.29	1.34
February	1.60	1.64	1.58	1.58	1.60
March	1.65	1.64	1.59	1.60	1.62
April	1.75	1.70	1.69	1.64	1.70
May	1.80	1.78	1.73	1.70	1.75
June	0.70	0.82	0.70	0.72	0.74
July	0.50	0.49	0.45	0.46	0.48
August	0.50	0.48	0.44	0.44	0.47
September	0.65	0.62	0.55	0.59	0.60
October	0.66	0.62	0.61	0.60	0.62
November	1.00	1.05	1.10	1.06	1.05
December	1.25	1.23	1.30	1.33	1.28

Table 4.7 Crop tolerance to Ece for 100 % yield

Sr. No	Crop	Ece (dS/m)
1	Tomato	5.7
2	Brinjal	9.8
3.	Cauliflower	15
4	Ridge gourd	3.2
5.	Cabbage	9.7
6.	watermelon	9
7.	Muskmelon	9
8.	Grape	4

(Source Tanwar, 1998)

Table 4.8 Safe root zone depth for design spacing of subsurface drainage

Crop	Steady state		Non-steady state	
	Fine texture soils	Light texture soil	Fine texture soils	Light texture soil
Field crops	1.2	1.0	0.9	0.9
Vegetable crops	1.1	1.0	0.9	0.9
Tree crops	1.6	1.2	1.4	1.1

(Source: FAO Manual No. 38)

Table 4.9 Maximum and minimum temperature at Mangaon (50 Years average)

Month	Minimum	Maximum	Lowest recorded	Highest recorded
Jan	19.3	29.6	13.5	35.6
Feb	20	29.6	14.6	36.9
Mar	22.6	31.1	16.1	40.2
Apr	25	32.3	21.1	39.4
May	27	33.4	23.3	39.5
Jun	26.3	32	22.2	35.4
Jul	25.3	30.1	22.2	32.4
Aug	24.9	29.6	22.6	33.6
Sep	24.9	30.5	19.9	34
Oct	24.8	32.5	21.4	37.5
Nov	23	32.9	17.8	38.2
Dec	20.9	31.6	13.7	35.7

(Source: http://app.nea.gov.sg/cms/htdocs/article.asp?pid=1111 accessed on 13-2-2005)

Table 4.10 FAO guidelines for drainage classifications

I Waterlogged area	Water table within 2m from land surface
II Potential area for waterlogging	Water table between 2-3m from land surface
III Safe area	Water table below 3m from land surface

Using this data, following parameters for surface and subsurface drainage are considered for evaluation. Some parameters like slope, gradient etc. were directly taken from the tables applicable to study area while parameters like evapotranspiration; runoff, drainage coefficient, etc. are derived using appropriate techniques.

The considered parameters thus are:

1. Evapotranspiration rate 2. Runoff 3. Drainage coefficient 4. Land use pattern

5. Hydrological soil cover group 6. Antecedent Moisture Conditions (AMC) 7. Side slope of surface drain 8. Permissible velocity of flow in surface drain and 9. Allowable gradients to pipe drain

Accordingly, following parameters of surface as well as subsurface drainage systems are considered in design techniques.

A. Surface drainage

The parameters are:

1. Drainage coefficient 2. Design discharge 3. Block wise discharge 4. Depth of drain 5. Bed width of drain 6. Side slope 7. Discharge through design drain as a check

B. Sub surface drainage

The parameters are

1. Drainage coefficient 2 Design discharge 3 Block wise discharge 4. Spacing of drain 5. Diameter of pipe drain

CHAPTER V

DESIGN OF SURFACE DRAINAGE

Chapter III and IV discussed the structure of proposed studies, data availability of study area as well as various design aspects related to the study. This chapter applies various techniques for design parameters required for design of surface drainage for given conditions of study area at Mangaon Dist. Ratnagiri. The design runoff, drainage coefficient are computed using the relevant data. Surface drainage system is designed based on these parameters for a hypothetical field layout shown in Figure 4.1.

5.1 Determination of runoff

Runoff is determined by Rational, CN and Time Distribution methods.

5.1.1 Rational Method

Runoff by this method is given as:

$$Q = \frac{CIA}{360} \qquad \text{...(5.1)}$$

Where, Q = Peak rate of runoff (m^3/sec), C = Coefficient of runoff, I = Uniform rainfall intensity over whole of the watershed for time of concentration (mm/hr), A = Area (hectare). While,

$$Tc = 0.0195 \quad L^{0.77} S^{-0.0385} \quad .... \qquad \text{...(5.2)}$$

where Tc = Time of concentration (minute), L = Length of longest flow path (m), S = slope of flow path (m/m).

a. Case Study

i. Location: Mangaon, Distt; Raihagd (M.S.)

ii. Area = 50 ha

iii. One hour rainfall for 10 years recurrence interval (Tideman, 2003) = 80 mm

For given field layout (Figure 5.1), L= 1000 m and S = 0.50 %.

Substituting the values in above relation, we get Tc = 30.61 minutes

From the monograms, one hr rainfall of 80mm and Tc of 30.61 minutes give intensity for time of concentration as 105 mm /hr.

v. Coefficient of runoff = 0.3

Substituting these values in Rational formula, runoff Q = 4.375 m^3/sec

II As per Babu et al. (1979) the relation between intensity (I) for time of concentration and return period (T) for Southern zone is $I = \frac{6.311(T)^{0.1523}}{(t+0.5)^{0.9465}}$ (Table 3.1) **...(5.3)**

So from the above relation, for T = 10 years, I = 8.87 cm/hr and t = 30.31 minutes Say 88.76 mm/hr and Q = 3.70 m^3/sec.

5.1.2 CN Method

a. For soil infiltration rate = 3.26 mm/hr, hydrological soil group C, Preceding 5 day rainfall for rainy season > 53 mm. Therefore, AMC III condition is applicable (Table 3.5)

b. One day maximum rainfall = 268 mm (Table 4.3)

c. Although soils are not black but contain high clay and therefore Ia = 0.1S

Land use pattern with following condition: Cultivated, row, terraced, good and,

Ia = 0.1S. Therefore CN for AMC III = 78 (Table 3.5) and subsequently CN for AMC II = 82.4 (Table 3.5). Substituting the values in $S = \left(\frac{25400}{CN} - 250\right)$ and

$R = \frac{(P - 0.1xS)^2}{(P + 0.9xS)}$ we get S = 54.25 mm and R = 217.61 mm/day.

The depth of 217.61 mm/day over an area of 50 hectarescyields discharge equal to 1.26 m^3/sec.

5.1.3 Time Distribution Method

This method is described in details in Chapter No III and is applied for the data of study area to compute runoff as follows:

a. Maximum 1day rainfall for 10 years return period = 268 mm (Table 4.3)

To convert 24 hours rainfall to 6 hours rainfall, assume the coefficient value as 0.5.

Thus, 6 hours rainfall = 0.5x 268 =134 mm.

The distribution of the above 6 hour rainfall as per WMO (1974) can be given as shown in Table5.1. Accordingly for 134 mm rainfall, the distribution and time incremental runoff by CN method is given in Table 3.4.

b. Qpeak is computed as follows:

i. ⊲ Runoff = runoff in i^{th} time interval – runoff in i_{t-1} time interval.

ii. Time to peak (hr)(Tp) = (0.5 to 0.7) x Time of concentration (Tc) or as actual

Incremental runoff over a period of 6 hours and time distribution of peak rate of runoff are shown in Tables 5.1 and 5.2, rsespectively. The peak rate of runoff is 560.54 mm/day. Thus, the peak rate of runoff at the outlet of 50 hectare watershed will be 3.24 m^3/sec.

Table 5.1 Time distributions of rainfall and runoff

Time (hr)	Rainfall (%)	Rainfall	Runoff	Delta R	Qp=delta R/2.5(mm/hr)	Qp (mm/day)
0	0	0	0	0	0	0
0.5	2	2.68	0.15	0.15	0.06	1.40
1	8	10.72	0.47	0.32	0.13	3.12
1.5	15	20.1	3.12	2.65	1.06	25.47
2	22	29.48	7.39	4.27	1.71	40.95
2.5(Tp)	60	80.4	43.50	**36.11**	**14.44**	**346.66**
3	70	93.8	54.76	11.26	4.50	108.10
3.5	78	104.52	64.04	9.28	3.71	89.06
4	84	112.56	71.12	7.08	2.83	68.01
4.5	88	117.92	75.90	4.77	1.91	45.83
5	92	123.28	80.71	4.81	1.92	46.18
5.5	96	128.64	85.55	4.84	1.94	46.50
6	100	134	90.42	4.87	1.95	46.79

Table 5.2 Computation of runoff by Time Distribution method

T/Tp	Q/Qp	Qp (mm/day)	Runoff →	1.40	3.12	25.47	40.95	346.66	108.10	89.06	68.01	45.83	46.18	46.50	46.79	Qpeak (mm/day)	Qpeak (mm/hr)
0.00	0.00	0.00	0x1.4	0.00												0.00	0.00
0.25	0.11	1.40	0.11x1.4	0.15	0.00											0.15	0.01
0.50	0.43	3.12	0.43x1.4	0.60	0.34	0.00										0.95	0.04
0.75	0.82	25.47	0.82x1.4	1.15	1.34	2.80	0.00									5.29	0.22
1.00	1.00	40.95	1x1.4	1.40	2.56	10.95	4.50	0.00								19.42	0.81
1.25	0.88	346.66	088x1.4	1.23	3.12	20.89	17.61	38.13	0.00							80.98	3.37
1.50	0.66	108.10	0.66x1.4	0.92	2.75	25.47	33.58	149.06	11.89	0.00						223.67	9.32
1.75	0.46	89.06	0.46x1.4	0.64	2.06	22.41	40.95	284.26	46.48	9.80	0.00					406.61	16.94
2.00	0.32	68.01	0.32x1.4	0.45	1.44	16.81	36.04	346.66	88.64	38.30	7.48	0.00				535.81	22.33
2.25	**0.23**	**45.83**	**0.23x1.**	**0.32**	**1.00**	**11.72**	**27.03**	**305.06**	**108.10**	**73.03**	**29.24**	**5.04**	**0.00**			**560.54**	**23.36**
2.50	0.16	46.18	0.16x1.4	0.22	0.72	8.15	18.84	228.80	95.13	89.06	55.77	19.71	5.08	0.00		521.47	21.73
2.75	0.11	46.50	0.11x1.4	0.15	0.50	5.86	13.10	159.46	71.35	78.37	68.01	37.58	19.86	5.12	0.00	459.36	19.14
3.00	0.08	46.79	0.08x1.	0.11	0.34	4.08	9.42	110.93	49.73	58.78	59.85	45.83	37.87	20.00	5.15	402.07	16.75
3.50	0.04		0.04x1.	0.06	0.25	2.80	6.55	79.73	34.59	40.97	44.89	40.33	46.18	38.13	20.12	354.60	14.77
4.00	0.02		0.02x1.	0.03	0.12	2.04	4.50	55.47	24.86	28.50	31.28	30.25	40.64	46.50	38.37	302.56	12.61
4.50	0.01		0.01x1.4	0.01	0.06	1.02	3.28	38.13	17.30	20.48	21.76	21.08	30.48	40.92	46.79	241.32	10.05

5.2 Determination of Drainage Coefficient

Drainage coefficient is defined as quantity of water to be removed from root zone depth over a period of one day expressed in terms of depth as mm/day or cm/day. Hypothetically, the rate of runoff as computed above can be taken as drainage coefficient in design of surface drainage for cities or habitat. In case of agriculture, the main objective of surface drainage is to evacuate land from runoff water accumulated due to rainfall to avoid submergence and subsequent reduction in yields of crop. However, the field trials revealed that every crop has some tolerance to submergence wherein crops yield is not affected. The maximum time of submergence for which given crop do not show any sign of reduction in yield is called as threshold submergence tolerance index of crop while the period of submergence for which there is 50 % reduction in yield of crop is called as DS_{50} index and expressed in terms of days. Gupta et al. (1992) reported threshold as well as DS_{50} (Table 3.8) for different crops at different locations.

Since the design of surface drainage intendeds to facilitate vegetable crops in rice based cropping pattern, the values of threshold tolerance indices of Cowpea and Pigeon pea (Table 5.6) are adopted for computing the drainage coefficient. The average of 0.8 and 0.5 is 0.65 day. Thus, peak rate of runoff arrived by above method can be drained out over a period of 0.65 day i.e. 0.65 x 24 =15.6 hours without affecting on the crops yield. Thus design drainage coefficient (mm/day)

$$= \frac{Peak\ rate\ of\ runoff\,(m3/\sec) x 24 x 3600 x 1000}{threshold\ tolerance\ index\ in\ hr\ x 50 x 10000} \quad \text{...(5.4)}$$

Table 5.3 Runoff by different methods

Sr.No	Method	Runoff (m3/sec)	Drainage Coefficient (mm/day)
T1	Rational with intensity based on Time of concentration	4.37	48.41
T2	Rational with intensity based on empirical relation	3.70	40.98
T3	CN	1.26	13.96
T4	Time distribution	3.24	35.89

5.3 Determination of block wise runoff

The hypothetical field considered is shown in Figure 5.1. The area is divided into 10 blocks of 5 ha each while layout of lateral and collector drain is shown in Figure 5.2and the tree diagrams of various junctions in order to find discharges are shown in Figure 5.3 (a-e).

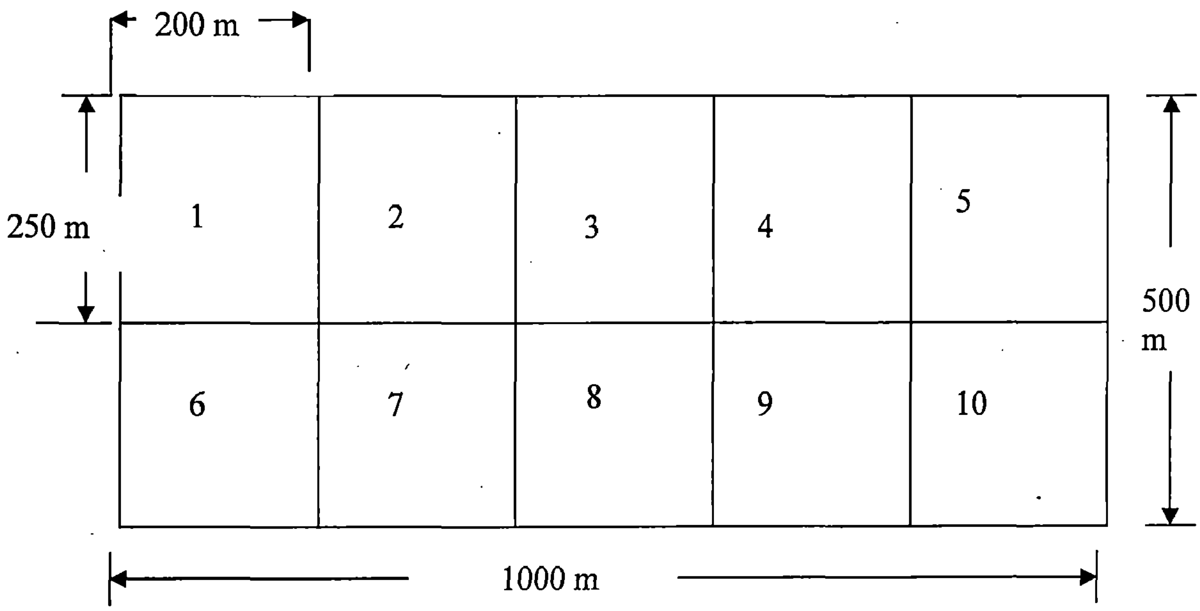

Figure 5.1 Plan of field

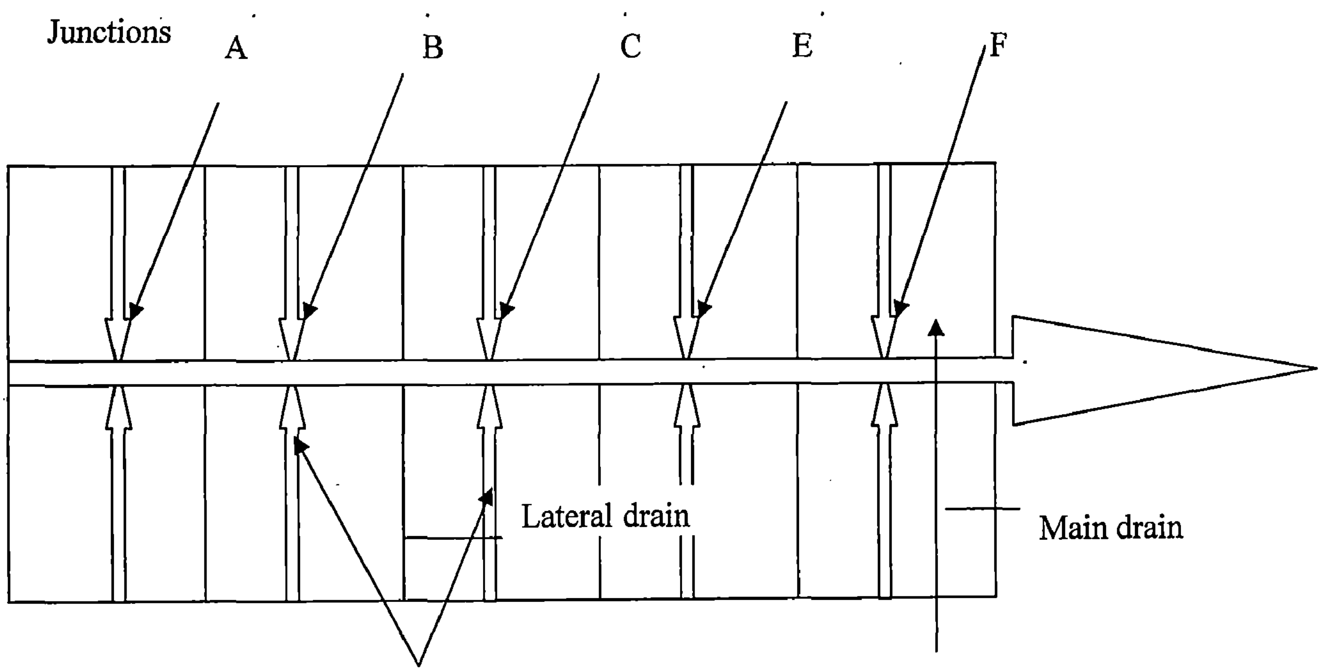

Figure 5.2 Layout of lateral and main drain.

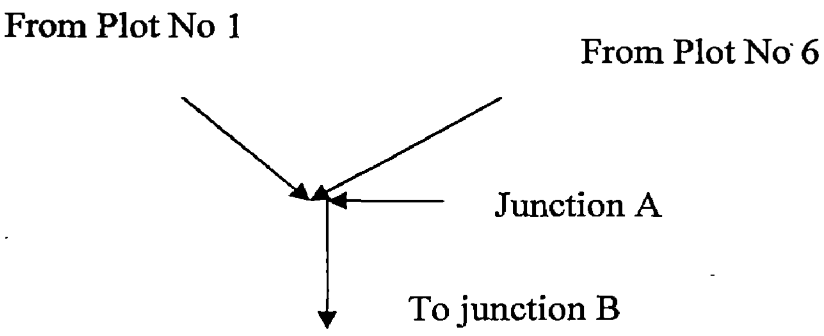

Figure 5.3 (a) Tree diagram

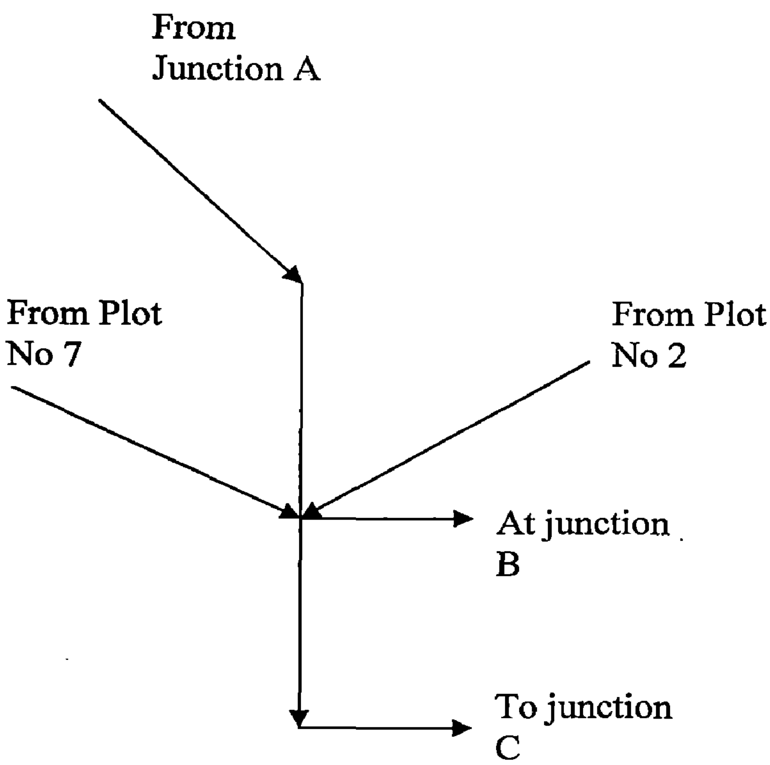

Figure 5.3 (b) Tree diagram

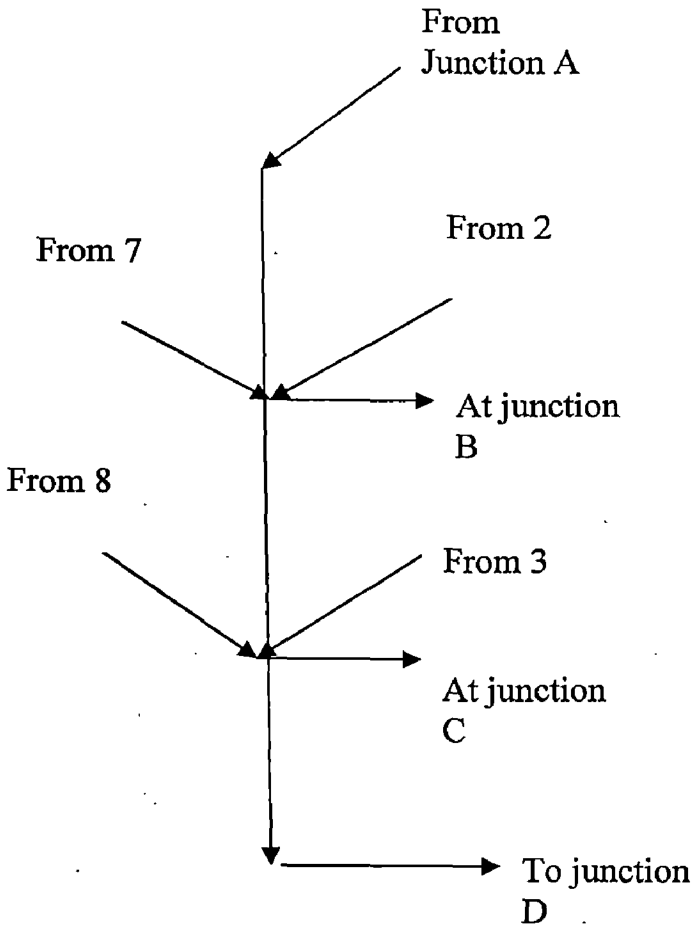

Figure No. 5.3 (c) Tree diagram

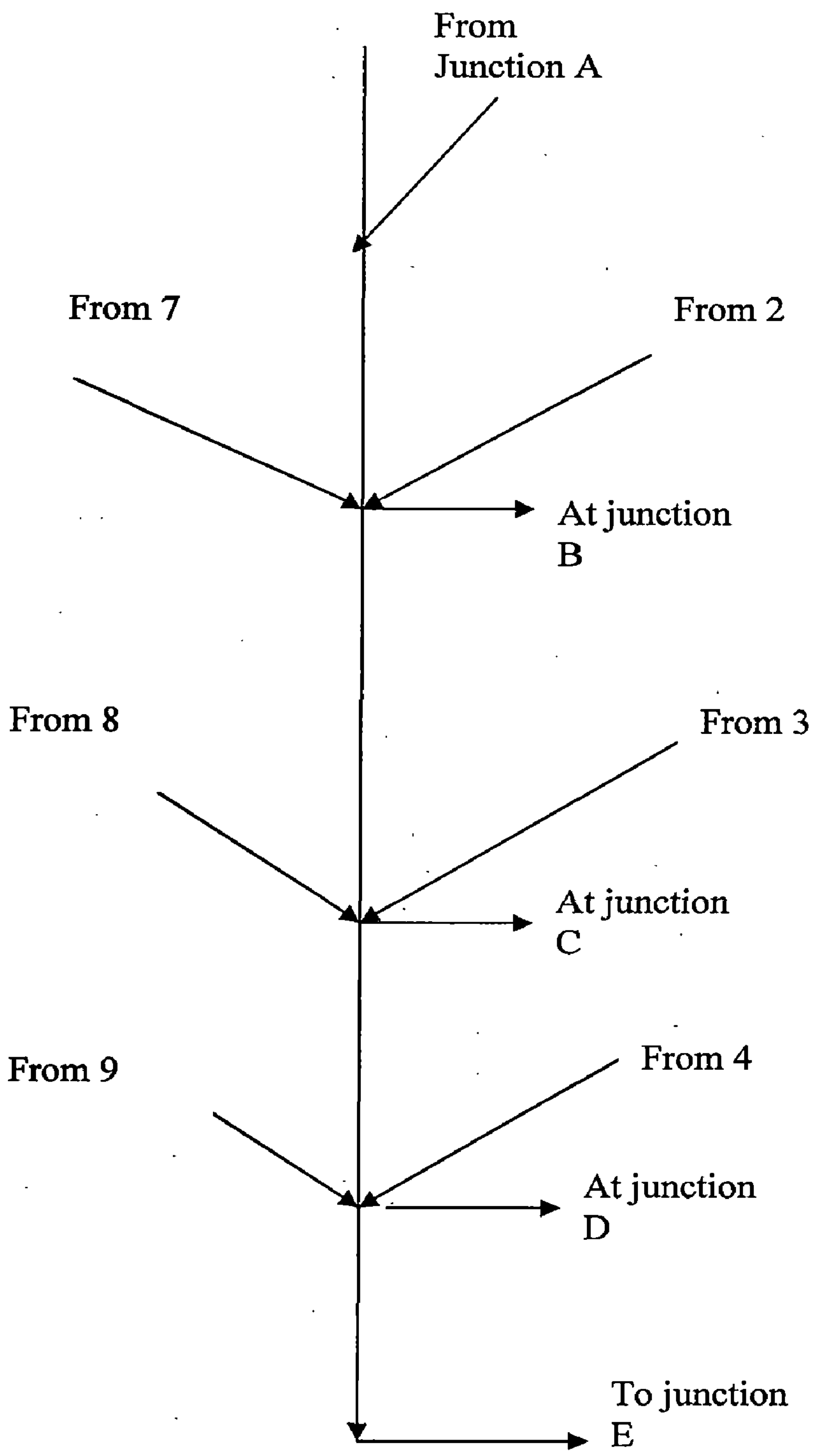

Figure 5.3 (d) Tree Diagram

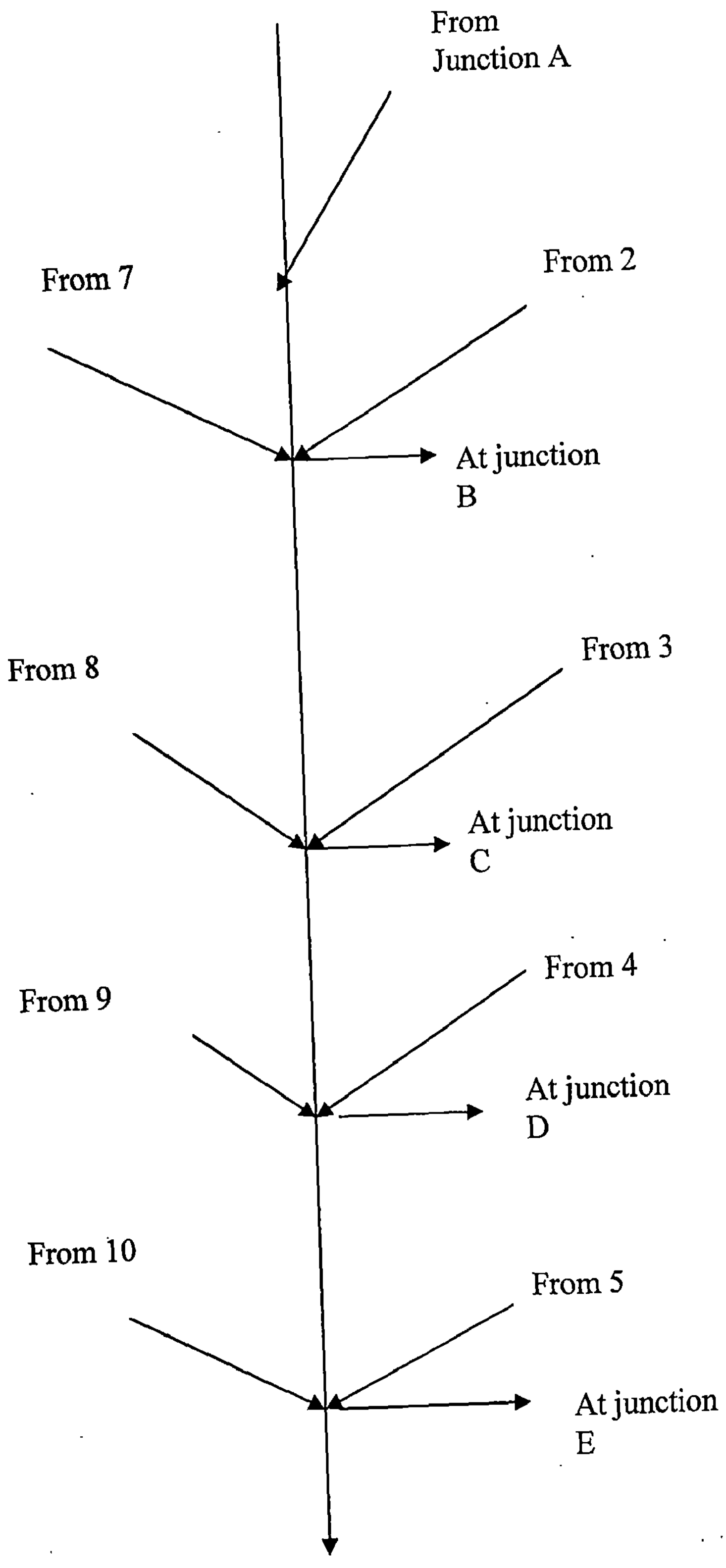

Figure 5.3(e) Tree Diagram

I If two areas drain their discharges at a junction and if area of one drain is less than 20% of the total area at the junction, then total area is taken for discharge estimation.

II If one of the contributing areas is in between 20% and 40%, then discharge is calculated as follows.

i. Compute discharge for total area

ii. Find % of area in between 20-40 as 30/130 = 0.23 i.e. 23 %

iii. Find this % as % between 20-40 as (23-20)/ (40-20) =0.15 = 15%

Then Q = Q of 130 ha + 0.15 {Q of 100 ha + Q of 30 ha – Q of 130 ha)

III If at any junction the additional area draining lies in between 40 -60 %, and then discharge for each area is calculated separately and added together to get total discharge.

Table 5.4 Junction wise discharges by different methods

Area(ha)	Discharge by different methods (m3/sec)			
	T1	T2	T3	T4
5	0.03	0.02	0.01	0.02
10	0.06	0.05	0.02	0.04
20	0.11	0.09	0.03	0.08
30	0.17	0.14	0.05	0.12
40	0.22	0.19	0.06	0.17
50	0.28	0.24	0.08	0.21

5.4 Design of drainage channel

Drainage channels can be designed by adopting any appropriate method commonly used for design of irrigation channel, such as Manning's equation, Kennedy's theory, Garret Diagram, Lacey's silt theory, Regime theory and some soft wares.

In general for small discharge, Manning's equation yields most economical section. Regime theory has also been used successfully in India. Therefore, these two methods are used for channel design. While discharge determined by four methods as explained above is considered for channel design. The Manning's equation can be better applied in non-silting and non-erosive velocity of flow. On the other hand, in regime theory, the bed slope of channel is calculated from the regime equation and therefore, velocity depends on the design bed slope.

Table 5.5. Categorization of junctions as per 20:40 rule

Junction No	Plot No	Area Of Plot (ha)	Total Area (ha)	% of each plot	Rule applicable	Formula applicable
A	1 6	5 5	10	50 50	III	Q1+Q6
B	A 2 7	10 5 5	20	50 25 25	II	Q20 – C (Q10+Q5+Q5-Q20) Where $C=-\frac{(25-20)}{(40-20)}=0.4$
C	B 3 8	20 5 5	30	66.66 16.66 16.66	I	Q 30
D	C 4 9	30 5 5	40	75 12.5 12.5	I	Q40
E	D 5 10	40 5 5	50	80 10 10		Q50

The discharges at different junctions are computed as Tables 5.4 and and Table 5.5.

5.4.1 Manning's Equation:

Manning's equation is given by,

$$V = (1/n)\, R^{2/3} S^{1/2} \qquad \textbf{...(5.5)}$$

where, V= velocity of flow (m/sec), n = Manning's regosity coefficient, R= hydraulic radius (m), R = A/P, P= weighted perimeter (m) , S = channel bed slope (m/m). Also for most economic section; b=2d tan (θ/2) where, θ = angle made by slopping length with horizontal (°), soils of study area are clay;, depths is more than 1.3m, and therefore, the batter slope of 1:1 (Table 5.6). For given z =1, θ=45°,b=2dtan (45/2) = 0.82d and for trapezoidal section having z=1, A = (b+d) d.

Table 5.6 Side slopes of open ditches according to soil texture and drain depth.

Soil	Channel less than 1.3 m deep	Channel greater than 1.3m deep
Heavy clay	1½ : 1	1 : 1
Clay or silt loam	1 : 1	1½ : 1
Sandy loam	1½ : 1	2 : 1
Sand	2 : 1	3: 1

(Source:http://www.dpiwe.tas.gov.au/inter.nsf/ThemeNodes/EKOE-4ZG66F accessed on 16-01-06)

5.4.2 Regime Theory:

From Lacey's theory (Sharma, 1984),

$$S= \frac{0.00035}{Q^{0.1651}} \quad ..(5.5)$$

$$P = 4.30\ Q^{0.5231} \quad ..(5.6)$$

$$R = 0.515\ Q^{0.3406} \quad ...(5.7)$$

$$V = \left(\frac{Qf^2}{140}\right)^{1/6} \quad ..(5.8)$$

where, S= Channel bed slope (m/m), Q= Design discharge (m^3/sec), R= Hydraulic radius (m), P= Weighted perimeter (m). and V = velocity (m/sec).

Using these relations, the parameters of drainage channel section are computed and summerised in Tables 5.7 through Table 5.9.

The four methods used for drainage coefficient and two method for channel design resulted into following eight combinations. They are abbreviated as follows:

Combination	Abbreviation used
Manning-Rational I	R1
Manning-Rational II	R2
Manning-CN	R3
Manning –Time distribution	R4
Regime-Rational I	R5
Regime-Rational II	R6
Regime-CN	R7
Regime –Time distribution	R8

Table5.7 Design parameters of channel by Manning's Equation

Discharge (m^3/sec)	Assumed Velocity (m/sec)	C.S.Area (m^2)	Depth (m)	Bottom width (m)	Designed Velocity (m/sec)	Designed Discharge (m^3/sec)
R1 Manning-Rational I						
0.03	0.90	0.03	0.14	0.11	0.47	0.02
0.06	0.90	0.07	0.19	0.16	0.59	0.04
0.11	0.90	0.12	0.26	0.21	0.72	0.09
0.17	0.90	0.19	0.32	0.26	0.84	0.16
0.22	0.90	0.24	0.37	0.30	0.91	0.22
0.28	0.90	0.31	0.41	0.34	0.99	0.31
R2 Manning Rational II						
0.02	0.90	0.02	0.11	0.09	0.41	0.01
0.05	0.90	0.06	0.17	0.14	0.56	0.03
0.07	0.90	0.08	0.21	0.17	0.62	0.05
0.14	0.90	0.16	0.29	0.24	0.78	0.12
0.19	0.90	0.21	0.34	0.28	0.87	0.18
0.24	0.90	0.27	0.38	0.31	0.94	0.25
R3 Manning CN						
0.01	0.90	0.01	0.08	0.06	0.33	0.00
0.02	0.90	0.02	0.11	0.09	0.41	0.01
0.03	0.90	0.03	0.14	0.11	0.47	0.02
0.05	0.90	0.06	0.17	0.14	0.56	0.03
0.06	0.90	0.07	0.19	0.16	0.59	0.04
0.08	0.90	0.09	0.22	0.18	0.65	0.06
R4 Manning Time Distribution						
0.02	0.90	0.02	0.11	0.09	0.41	0.01
0.04	0.90	0.04	0.16	0.13	0.52	0.02
0.08	0.90	0.09	0.22	0.18	0.65	0.06
0.12	0.90	0.13	0.27	0.22	0.74	0.10
0.17	0.90	0.19	0.32	0.26	0.84	0.16
0.21	0.90	0.23	0.36	0.29	0.90	0.21

Table 5.8Design parameters of channel by Regime theory

Discharge (m^3/sec)	Bed slope (m/m)	Wetted perimeter (m)	Hydraulic radius (m)	C. S. Area (m^2)	Depth (m)	Bottom width (m)	Designed velocity (m/sec)	Designed Discharge (m^3/sec)
R5 Regime Rational I								
0.03	0.0006	0.69	0.16	0.11	0.24	0.20	0.24	0.03
0.06	0.0006	0.99	0.20	0.19	0.33	0.27	0.28	0.05
0.11	0.0005	1.36	0.24	0.33	0.43	0.35	0.32	0.11
0.17	0.0005	1.70	0.28	0.48	0.51	0.42	0.35	0.17
0.22	0.0004	1.95	0.31	0.60	0.57	0.47	0.37	0.22
0.28	0.0004	2.21	0.33	0.74	0.64	0.52	0.39	0.29
R6 Regime Rational II								
0.02	0.0007	0.56	0.14	0.08	0.20	0.17	0.23	0.02
0.05	0.0006	0.90	0.19	0.17	0.30	0.25	0.27	0.05
0.07	0.0005	1.07	0.21	0.22	0.35	0.29	0.29	0.06
0.14	0.0005	1.54	0.26	0.41	0.47	0.39	0.34	0.14
0.19	0.0005	1.80	0.29	0.53	0.54	0.44	0.36	0.19
0.24	0.0004	2.04	0.32	0.65	0.60	0.49	0.37	0.24
R7 Regime CN								
0.01	0.0007	0.39	0.11	0.04	0.15	0.12	0.20	0.01
0.02	0.0007	0.56	0.14	0.08	0.20	0.17	0.23	0.02
0.03	0.0006	0.69	0.16	0.11	0.24	0.20	0.24	0.03
0.05	0.0006	0.90	0.19	0.17	0.30	0.25	0.27	0.05
0.06	0.0006	0.99	0.20	0.19	0.33	0.27	0.28	0.05
0.08	0.0005	1.15	0.22	0.25	0.37	0.30	0.30	0.07
R8 Regime Time Distribution								
0.02	0.0007	0.56	0.14	0.08	0.20	0.17	0.23	0.02
0.04	0.0006	0.80	0.17	0.14	0.27	0.23	0.26	0.04
0.08	0.0005	1.15	0.22	0.2500	0.3706	0.3039	0.30	0.07
0.12	0.0005	1.42	0.25	0.3548	0.4415	0.3620	0.33	0.12
0.17	0.0005	1.70	0.28	0.4793	0.5132	0.4208	0.35	0.17
0.21	0.0005	1.90	0.30	0.5753	0.5622	0.4610	0.36	0.21

Table 5.9 Design parameters of drainage channel at tail end by different methods.

Parameter	R1	R2	R3	R4	R5	R6	R7	R8
Discharge (m^3/sec)	0.28	0.24	0.08	0.21	0.28	0.24	0.08	0.21
Depth (m)	0.41	0.38	0.22	0.36	0.64	0.6	0.37	0.56
Bottom width (m)	0.34	0.31	0.18	0.29	0.52	0.49	0.3	0.42
C.S.Area (m^2)	0.31	0.27	0.09	0.19	0.74	0.65	0.25	0.48
Assumed velocity (m/sec)	0.9	0.9	0.9	0.9	NA	NA	NA	NA
Designed velocity (m/sec)	0.99	0.94	0.65	0.9	0.35	0.34	0.28	0.34
Designed discharge (m^3/sec)	0.31	0.25	0.06	0.21	0.29	0.24	0.07	0.21

CHAPTER VI

DESIGN OF SUBSURFACE DRAINAGE

6.1 Determination of Drainage Coefficient

Design of drainage coefficient has been discussed in chapter III .In this chapter values of drainage coefficient and subsequently drain spacing and diameter for subsurface drainage are computed for given field conditions by different methods as discussed in Chapter III.

6.1.1 USDA Empirical Relation

USDA (1973) proposed en empirical relation to estimate drainage coefficient for irrigated lands which is:

$$Dc = \frac{(Ds + Lr + Cs)Di}{Ii} \quad \text{....(6.1)}$$

Where, Dc=drainage coefficient (mm/day), Ds = deep seepage expressed as fraction of irrigation water mm), Lr = leaching requirement expressed as fraction of irrigation water (mm), Cs = canal seepage expressed as a irrigation water (cm), Di= depth of irrigation water (mm), Ii= irrigation interval (day).The quantities on the right hand side of equation can be selected for a particular region or on the basis of actual field measurement.

6.1.2 Case Study

i. The irrigation depth per irrigation	7.5 cm
ii. Irrigation interval	7 days
ii. Maximum evapotranspition during crop season	6.9 mm/day
iii. Crop root zone depth	0.9 m
iv. Bulk density of soil	1.26 g/cc
v. Available water	17.93%

$$d = \frac{AWxB.DxZ}{100} \quad \text{...(6.2)}$$

where, AW = Available water (%), B.D. = Bulk Density (g/cc), Z = root zone depth (cm). Substituting the values in equation, water stored in root zone = 20.33 cm.

$$\text{Ideal irrigation interval} = \frac{\text{water stored in root zone(cm) x depletion level(\%)} / 100}{\text{evapotranspiration (cm)}} \quad \text{...(6.3)}$$

Ideal irrigation depth for irrigation scheduled at 50% depletion level with evapotranspiration of 0.8 cm day will yield an ideal irrigation interval as 12.7 days by using the relation:

$$\text{Ideal depth of water to be applied per week} = \frac{\text{Ideal irrigation depth}}{\text{Ideal irrigation int erval}} \text{x } 7 \quad .... \quad \textbf{(6.4)}$$

Bu substitution the value is 5.5 cm and actual water applied is 7.5 cm. Therefore excess water that percolates in root zone is 1.9cm (=7.5 -5.6) and Ds is defined as $\frac{\text{seepage loss}}{\text{irrigationapplied}}$. Thus, Ds = 0.25 cm/day.

6.1.3 Determination of Leaching Requirement

Leaching requirement is given by (Sarkar, 1980)

$$\mathrm{Lr} = \frac{(E - P)Ci}{f(Cfe - ci)} \qquad \ldots\textbf{(6.5)}$$

where, Lr= leaching requirement (cm/week). E= evapotranspiration (cm/week),
Ci = average salt concentration of irrigation water over the period (mmhos/cm),
f= leaching efficiency, Cfe= salt concentration of soil moisture at root zone for field capacity (mmhos/cm)

Cfe=

$$\frac{\textit{saturated soil moisture on volume basis}}{\textit{soil moisture at field capacity}} \textit{xpermissible salt concemtration(mmhos / cm)} \qquad \textbf{6.6}$$

For saturated soil moisture on volume basis = 48.8 %, soil moisture at field capacity = 0.38%, and permissible salt concentration for crops to be grown = 4 mmhos/cm, the vale of Cfe s 5.14 mmhos/cm. Ci = 0.4 mmhos/cm (canal water from reservoir). Therefore Lr for f = o.6 and P = 0 from equation 6.2, Cfe is computed as 0.11 cm/week.

Assume canal seepage factor as 0.20, Dc by equation is 0.6 cm/day

6.1.4 Equation used in Netherlands

The water balance of field drainage system in most part of The Netherlands is given as

$\mathrm{Dr} = qd \triangleleft t = P - E - \triangleleft W$

where Dr=drainage (mm), qd=drainage rate (mm/day), ⊲t= Period (day), P=Precipitation (mm), E= evapotranspiration (mm) and ⊲W= water storage (mm).

Here since the precipitation during the period is considered as nil. Therefore, precipitation will be replaced by irrigation depth. ⊲W can be set to zero as the period considered for water balance is only a week. E @ rate of 0.69 cm/day (Table 6.6) for a period of week is 5.6 cm. After substitution, Dr = 1.9 cm/week i.e 0.28 cm/day.

Table 6.1 Designed values of Dc by different methods

Method	Dc (cm/day)
USDA Equation	0.6
Netherlands Equation	0.28

6.2 Design of drain spacing

In this chapter the subsurface drainage is designed using the data of study area (Chapter III) and different subsurface design methods. Here steady state condition is assumed.

6.2.1 Hougoudt Equation

In steady-state flow, the spacing between drains can be calculated using Hooghoudt equation:

$$L^2 = \frac{8Kdeh + 4Kh}{R^2} \quad \text{.... (6.7)}$$

where, L = spacing between drain laterals (m), K = saturated hydraulic conductivity (m/day), R = drainage coefficient (m/day), de = water depth in a fictitious ditch that would be just as effective in removing soil water as a tube drain of radius r at a distance D above the impervious boundary. It is also called as equivalent depth or effective flow depth below drains and h = water table height above the drain centre at mid-spacing (m): h = DD – DWD, where DD = drain depth (m) and DWD = desirable water table depth (m) depending on type the of crop and rooting depth (Table 6.3).

6.2.2 Case study for R = 0.60 cm/day

For given value of K = 0.62 m/day (Chapter III) and the data shown in Figure 6.1,

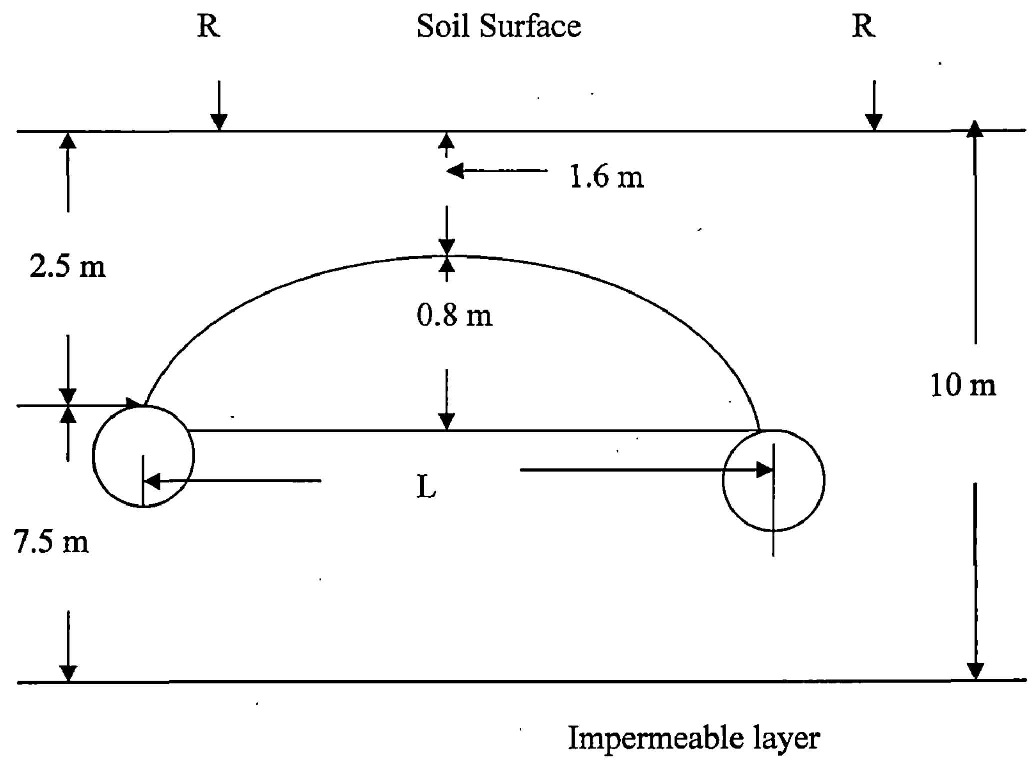

Figure 6.1 Ground water table in study area.

Maximum permissible (h) = 0.80 m, depth of impervious layer from soil surface= 10m L= 60 m (assumed) and radius of pipe (r_o) = 10 cm.

The table value (Table 6.3) de for d= 7.5 m and (r_o) = 10 cm is 3.824 m. Substitution of these values in equation 6.1 resulted into 52.85 m. Since it is less than assumed, next table value is taken as 50 .Iterations are made till assumed and computed value are same or nearly same. The designed values are shown in Table 6.2.

6.2.3 Kirkham Equation

Kirkham equation neglected the flow above the drain and it is common in areas where the impervious strata is far below the drain. He introduced the constant F_k as influenced by radius of pipe drain; drain spacing and depth of impervious strata below the drain can be read from Kirkham's F_k (Table 6.3):

$$L = \frac{Kh(1-\frac{R}{K})}{RF_k} \quad \text{... (6.8)}$$

where the terms represents the same as equation 6.1 above. The design value of L is computed as explained in para 6.2.2 and shown in Table 6.2.

6.2.4 Dagan Equation

Similar to Kirkham equation, Dagan (1964) considered a combination of radial and horizontal sub-surface flow towards the drain in a homogeneous soil and neglected the flow from above the drain. The Dagan equation is expressed as:

$$L = \frac{Kh}{RF_D} \quad \text{... (6.9)}$$

where all the terms are as per equation 6.1. The F_D values as given in Table 6.3 are interpolated for different L, h and drain radius in combination are used to compute the designed value of L by iterations and are shown in Table 6.2.

Table 6.2 Drain spacing (L) by different methods

Dc (cm/day)	Spacing (m) by different Methods		
	Hoogoudt	Kirkham	Dagan
0.60 cm/day	51	41	45
0.28 cm/day	82	77	77

Table 6.3 Equivalent depths (de) , Fk and FD values for drain radius (r0) of 10 cm

h (m)	Hooghoudt's Equivalent depths (de)							
	Drain Spacing L (m)							
	10	20	30	40	50	60	80	100
	Equivalent depth(m)							
6	1.156	1.905	2.477	2.911	3.252	3.525	3.937	4.232
8	1.156	1.920	2.579	3.114	3.555	3.924	4.507	4.944

h (m)	Kirkham's Fk values				
	Drain Spacing L (m)				
	20	40	60	80	100
6	1.351	1.771	2.188	2.604	3.019
8	1.330	1.654	1.967	2.279	2.591

h (m)	Dagan's FD values						
	Drain Spacing L (m)						
	20	30	40	50	60	80	100
6	1.576	1.784	1.992	2.201	2.409	2.826	3.242
8	1.563	1.719	1.876	2.032	2.188	2.501	2.813

6.3 Design of pipe diameter

Diameter of pipe is a function of discharge and velocity of flow and it is given as:

$$Q = AxV \qquad \text{... (6.10)}$$

where, Q = flow rate (m^3/sec), A = Cross sectional area of conduit (m^2).Recommended velocities of flow through pipe drain under different soil conditions are shown in Table 6.4. For given velocity, cross section of pipe can be computed and subsequently diameter can be commuted by the following relation,

$$D = \frac{4xA}{\Pi} \qquad \text{...(6.11)}$$

where, D = diameter of pipe (m) and A = cross sectional area of pipe (m^2).

6.3.1 Velocity

The minimum velocity that should be used in all subsurface drains is 0.75 m/sec. Lower velocities will allow sediment to accumulate in the drain. Maximum allowable velocities based on soil texture are listed in Table 6.4 below,

Table 6.4 Maximum allowable velocities for tile drains for different soils

Soil texture	Maximum allowable velocity (m/sec)
Sandy and sandy loam (non colloidal)	0.75
Silt loam (also high lime clay)	0.90
Sandy clay loam	1.00
Clay loam	1.20
Stiff clay, fine gravel, graded loam to gravel	1.50
Graded silt cobbles	1.60
Shade, hardpan and coarse gravel	1.80

(Ref: Schwab et al (1966).

While computing the area contributing to a lateral drain, the field is divided as shown in Figure 6.1. Since laterals cannot be taken into fraction, the drain spacing is adjusted to round the laterals to an integer value. The designed diameter of laterals under different combination is shown in Table 6.5.

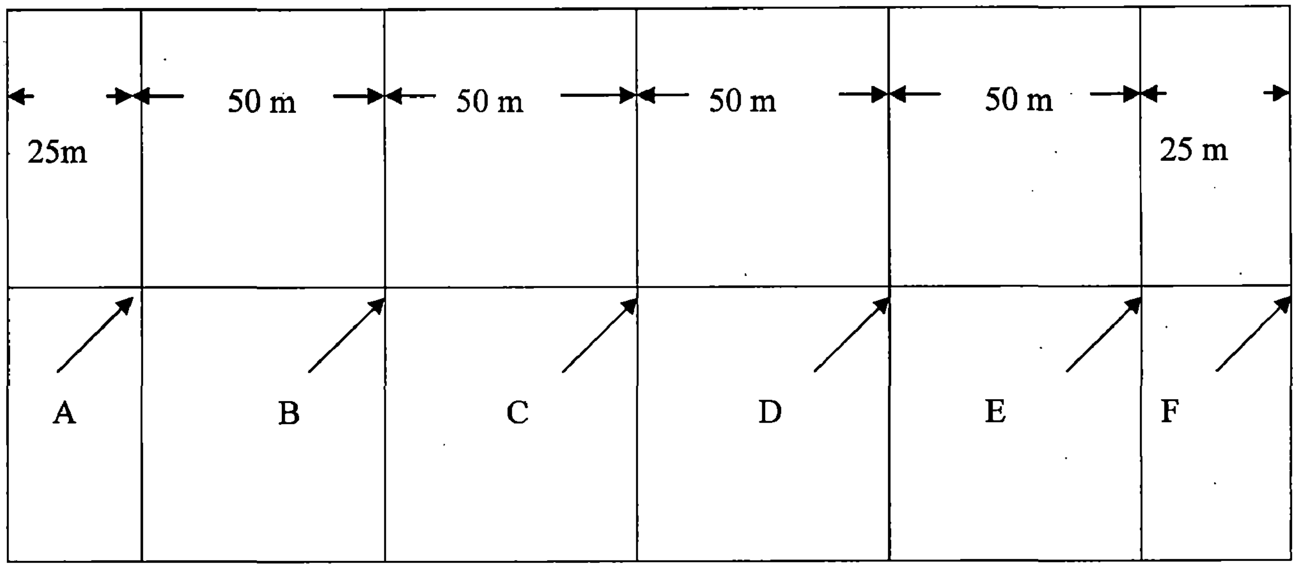

Figure 6.1 Typical layout of pipe drain.

Table 6.5 Computation of Diameter of lateral drainage pipe using different methods.

Method	Ds (cm/day)	Width (m)	Actual No of laterals	Rounded to	Rounded Width (m)	Length of lateral (m)	Area covered by lateral (m^2)	Discharge of lateral (m^3/sec)	Velocity (m/sec)	Cross section area (m^2)	Diameter of pipe (m)	Diameter of pipe (mm)
Hooghoudt	0.6	51	19.61	20	50.00	250	12500.00	0.0009	0.75	0.0012	0.0388	38.76
Kirkham	0.6	41	24.39	24	41.67	250	10416.67	0.0007	0.75	0.0009	0.0348	34.75
Dagan	0.6	45	22.22	22	45.45	250	11363.64	0.0008	0.75	0.0010	0.0364	36.41
Hooghoudt	0.28	82	12.20	12	83.33	250	20833.33	0.0007	0.75	0.0009	0.0336	34.75
Kirkham	0.28	77	12.99	13	76.92	250	19230.77	0.0006	0.75	0.0008	0.0325	32.54
Dagan	0.28	77	12.99	13	76.92	250	19230.77	0.0006	0.75	0.0008	0.0325	32.54

Table 6.6 Month wise daily Evapotranspiration (ETo) at Mangaon, Distt: Raigarh.

Variable	Jan	Feb	March	April	May	Jun	July	August	Sept	Oct	Nov	Dec
Minimum temp (^{0}c)	19.30	20.00	22.60	25.00	27.00	26.30	25.30	24.90	24.90	24.80	23.00	20.90
Maximum temp (^{0}C)	29.60	29.60	31.10	32.30	33.40	32.00	30.10	29.60	30.50	32.50	32.90	31.60
Average	24.45	24.80	26.85	28.65	30.20	29.15	27.70	27.25	27.70	28.65	27.95	26.25
RH mean (%)	40.00	38.00	27.00	26.00	29.00	78.00	91.00	79.00	79.00	81.00	62.00	49.00
Ea from Table IX	30.66	31.32	35.39	39.30	42.90	40.45	37.17	36.23	37.17	39.30	37.70	34.13
Rh/100	0.35	0.38	0.27	0.26	0.29	0.78	0.91	0.79	0.79	0.81	0.62	0.49
Ed =ea x Rh/100	10.73	11.90	9.56	10.22	12.44	31.55	33.82	28.62	29.36	31.83	23.37	16.72
ea-ed	19.93	19.42	25.83	29.08	30.46	8.90	3.35	7.61	7.81	7.47	14.33	17.41
Wind speed (U) (Km/day)	2.32	2.25	2.65	3.01	3.31	3.45	4.20	2.98	2.78	3.00	2.77	2.52
f(U)=(0.27(1+U2/100)	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28	0.28
(1-W) from Table VIII	0.27	0.26	0.24	0.24	0.20	0.22	0.24	0.24	0.23	0.15	0.23	0.25
(1-W)*f (u)*(ea-ed)	1.46	1.40	1.73	1.97	1.68	0.56	0.22	0.50	0.50	0.31	0.92	1.19
N Observed	12.20	11.98	12.16	11.25	11.05	10.54	9.64	10.05	10.83	11.09	11.04	12.04
N from Table III	13.09	12.73	12.26	11.74	11.27	11.01	11.11	11.54	12.00	12.56	12.99	13.19
(0.25+0.50n/N)	0.72	0.72	0.75	0.73	0.74	0.73	0.68	0.69	0.70	0.69	0.67	0.71
Ra from Table II	17.13	16.50	15.08	13.17	11.33	10.33	10.73	12.25	14.07	15.80	16.83	17.15
Rs=(0.25+0.50n/N)*Ra	12.26	11.89	11.25	9.60	8.39	7.53	7.34	8.40	9.86	10.92	11.36	12.11
Rns=((1-α)*Rs and α =0.25 For agriculture	9.20	8.92	8.44	7.20	6.29	5.65	5.51	6.30	7.40	8.19	8.52	9.08
f(T) from Table V	15.51	15.60	16.07	16.43	16.86	16.53	16.15	16.15	16.15	16.43	16.09	15.95
f(ed)=0.34-0.044*(ed)^0.5	0.20	0.19	0.20	0.20	0.18	0.09	0.08	0.10	0.10	0.09	0.13	0.16
f(n/N) = 0.1+0.9n/N	0.94	0.95	0.99	0.96	0.98	0.96	0.88	0.88	0.91	0.89	0.86	0.92
Rnl=F(t)*f(n/N)*f(ed)	2.85	2.78	3.25	3.15	3.06	1.48	1.20	1.49	1.50	1.35	1.77	2.35
Rn=(Rns-Rnl)	6.35	6.14	5.18	4.05	3.23	4.17	4.31	4.81	5.90	6.84	6.75	6.73
W from Table VIII	0.73	0.74	0.76	0.76	0.80	0.78	0.76	0.76	0.77	0.85	0.77	0.75
W*Rn	4.66	4.53	3.93	3.06	2.59	3.24	3.29	3.66	4.53	5.81	5.19	5.07
c from Table IV	1.10	1.10	1.11	1.12	1.14	1.15	1.02	1.13	1.12	1.11	1.11	1.10
Eto=c[W*Rn+(1-W)f(u)(ea-ed)	6.74	6.55	6.27	5.65	4.87	4.38	3.57	4.72	5.62	6.79	6.75	6.88

CHAPTER VII

RESULTS AND DISCUSSION

This part of dissertation deals with the analysis of results obtained by adopting various methods used to derive the parameters of surface as well as subsurface drainage system for given conditions of soil, crop and rainfall at Mangaon, Distt: Ratnagiri falling in west coast Konkan region of Maharashtra (India). The surface drainage system is designed on a hypothetical field of 50 hectares to take care of torrential rain of southwest monsoon from mid-June to mid-October. Attempts are made to drain out water to keep the field conditions suitable for seasonal crop as well as avoid waterlogging in case of deep-rooted plantation crops. The study area comes under command of **Kal** project and is experiencing waterlogging conditions due to flood irrigation system used for summer rice. The plain topography and uncontrolled irrigation method resulted into rise in groundwater table. This actually does not restrict from the possibility of growing cash crops like vegetables during nonmonsoon season also. Further, the shallow water table has adversely affected the growth and yield of established plantation crop like mango, cashew and coconut in command of this project. Attempts are made to compare the different methods used to determine parameters like drainage coefficient required for design of subsurface drainage system using an appropriate method.

7.1 Rainfall

The study area comes under lateritic heavy rainfall zone of Western Ghats that receives rainfall through southwest monsoon commencing from mid-June and continued up to mid-October. This study is categorized based on the assured rainfall zones and dominated by kharif rice cropping pattern. The district of Raigarh is particularly known as the basket of rice supply for the state of Maharashtra. The previous ten years average annual rainfall of Mangaon is 3422.50 mm (Table 4.2). The data indicated that June to October contributed the major share of annual rainfall while remaining period of year i.e November through May have very little contribution. Month wise distribution of rainfall revealed that July recorded maximum rainfall (1222.31 mm), followed by August (858.77 mm), June (770.98 mm) and September (418.05 mm) and October (1140.18 mm). Further analysis of ten years rainfall data indicated that one day maximum rainfall varied from 198 mm (1995) to 357 mm (2005). Since, the state of Maharashtra has experienced abnormal rainfall during 2005, the one-day maximum of this year is not considered for design. Instead, next one-day maximum rainfall of 268 mm (2004) is considered for design.

7.2 Soils

The soils of the study area are known as Mangaon series and are clayey in texture and acidic in reaction. These soils are derived from Deccan basalt having keolonite clay. As per universal soil classification triangle, these soils are classified as clayey on account of proportion of clay, silt and sand. But their hydrological behavior in not exactly as normal clayey soils due to the presence of keolonite clay. Saturated hydraulic conductivity of these soils was measured to be 0.62 m/day. Despite prevailing water logging, the soils are free from salinity. It could be attributed to flushing of salts during monsoon season due to heavy rainfall and good quality water of **Kal** project. The physiochemical properties of soil are shown in Table 4.5.

7.3 Topography

The Konkan, a hilly area is located in Sahyadri ranges. But the part of study area constitutes a long strip of plain lands encompassing between foot of Sahyadri Mountain and West Coast of Arabian Sea. It is only because of this peculiarity, the **Kal** irrigation project could become feasible. Otherwise, despite assured rain and good location for reservoirs, there are no such projects in this part of Maharashtra. The area is plain with slopes in the range of 2 to 5%. Almost all command area is terraced and can be described as typical rice fields representing typical kharif rice belts of India. Since the study area follows double rice cropping pattern, there has been a tendency to encroach natural drain, which adds to the problem of drainage. The industrial and urban development around the command area as well as a rail track of Konkan railway trace passing through the command have adversely affected the natural drainage pattern. This further aggravates the drainage problem in this area.

7.4 Groundwater Table

The data on groundwater table for last four years is given in Table 4.6, which revealed that the depth of water table from ground was maximum in the month of May (1.70 m) while it was minimum in the month of July (0.48 m). The data implies that the area is waterlogged throughout the year, as consistent with the definition of Tanwar B. S. (1998) as well as FAO norms.

7.5 Surface Drainage

7.5.1 Runoff

Amongst the available methods, Rational method with $Tc = 0.0195 \quad L^{0.77} S^{-0.038}$ Rational with $I = \frac{3.974T^{0.1647}}{(t+0.75)^{0.7327}}$, CN method and Time Distribution Methods were used to predict runoff through study area and results are shown in Table 5.3.The data indicated that there is a significant difference in the values of runoff resulting from the application of different methods. Runoff was computed as maximum the by Rational method with $Tc = 0.0195 \quad L^{0.77} S^{-0.038}$ (4.37 m^3/sec), followed by Rational Method with $I = \frac{3.974T^{0.1647}}{(t+0.75)^{0.7327}}$ (3.70 m^3/sec), Time Distribution Method (3.24 m^3/sec) and minimum by CN method (1.26 m^3/sec). The relatively high runoff by both the approaches of Rational method could be attributed to the genesis of this method itself. This method amongst other methods, predicts peak rate of runoff at the outlet of watershed resulted due to an isolated storm. Secondly, it is based on the hypothesis that a storm which could continue for period of time of concentration and distributed uniformly all over the watershed, can only result into accumulation of runoff water from all points from watershed to the outlet at a time and this situation will lead to peak runoff and not the average runoff rate which would be lower than the peak flow, at the outlet. Further, this method is based on isolated storm rather than total daily rainfall. Runoff is basically a function of rainfall, slope, vegetation and soil type. This method duly takes into account these factors. Intensity for time of concentration takes into account rainfall and slope while runoff coefficient takes into account the soil type and cover. As against this, other two methods predict average runoff rate on the basis of daily rainfall. Therefore, runoff by both approaches of Rational methods resulted into higher runoff as compared to other two methods. Within the rational Method, the runoff by Rational method with $Tc = 0.0195 \quad L^{0.77} S^{-0.038}$ (4.37 m^3/sec) was more than the runoff by Rational Method with $I = \frac{3.974T^{0.1647}}{(t+0.75)^{0.7327}}$ (3.70 m^3/sec). The former method is more location specific and considers geomorphologic parameters of watershed as well as one-hour maximum intensity for the given return period. The one-hour maximum intensity for given return period can accurately be read from the monograms available for India while geomorphologic characters like maximum length of run and slope can be found from toposheet or actual survey. Further, the one-hour rainfall intensity is very well convertible to design time of concentration from the monograms. On the other hand, in latter method, the intensity is computed from out by empirical relations on the basis of five zones of India. It is possible that the field conditions of study area cannot be properly represented by the zone under consideration. In the present case, the empirical relation viz $I = \frac{3.974T^{0.1647}}{(t+0.75)^{0.7327}}$ given for Southern Zone was used to determine intensity. It is pertinent that Southern Zone covers Maharashtra, Tamil-Nadu, Karnataka and Kerala. Within the State like Maharashtra, there is a marked difference in pattern of rainfall. West Coast of Maharashtra where study area is located is known for its heavy rainfall while Western part of Maharashtra falls under scarcity zone. Southern Zone receives rainfall due to South West monsoon which originats from Kerala. Intensities of South West monsoon are torrential at originating location and go on fading as it advances towards North. These geographic variations are also not taken into account by the latter method. Since the relation takes into account a wide range of rainfall pattern, it would be diluting the effect of heavy rainfall zone of study area and therefore, resulted into lower value of runoff.

As compared to above two methods, the Time Distribution Method is based on a different hypothesis. It takes into account one-day rainfall as against the isolated storm intensity. One-day rainfall is assumed to be precipitating over a period of six hours only by introducing a reduction factor in the range of 0.5 to 0.7. This 6 hours period can be correlated to threshold tolerance period of any sensitive crop for submergence (0.2 to 0.5 days Gupta et al, 1972).Further, with in the 6 hour period of precipitation, the distribution is given according to Table 3.4. i.e. it goes on increasing up to 2.5 hours from the start of rainfall i.e nearly mid of storm period and then recedes further. It is analogous to the pattern of isolated rainstorm wherein the intensity of storm goes on increasing upto certain period and then recedes. Runoff is computed independently for every time incremental rainfall using CN method. The runoff so computed is considered to be contributing to outlet runoff sequentially over a period of 5 hours as given in Table 5.2 i.e runoff due the to first time increment will start contributing after 0.25 hours from the start of rainfall at the rate of 11 % and runoff by the next time incremental rainfall will contribute at 11 % in the next time interval i.e 0.5 hour. A stage is reached when all the incremental runoff contributes to the outlet at the same time, resulting into peak rate of runoff. This value is considered as designed runoff. It implies that attempts are made to simulate runoff resulting from daily rainfall on the lines of one that results from an isolated storm. Only because of storm period being 6 hours (a large period), it is segmented into small fractions. This method simulates the field condition very appropriately from crop submergence view point. It computes runoff by using CN method which is considered to be one of the most reliable and practiced runoff predicting methods. Therefore, it forms to be superior to other methods and can be recommended for computing runoff as design parameter for design of surface drainage system in the study area.

Naturally the CN method also predicts runoff from daily rainfall taking into account the four major watershed characteristics viz, soil type, land use, hydrologic conditions and antecedent moisture conditions. However, it assumes that the rainfall precipitates in 24 hours. It is one of the reasons for reduced runoff by this method. Further, except for preceding 5 days rainfall, all other field conditions are congenial to low CN values and subsequently result into lower runoff. Since this method gives significantly lower runoff and do not match the requirements of flood control measure (surface drainage in present case), it cannot be recommended for use in the study area.

7.5.2 Drainage Coefficient for Surface Drainage

Drainage coefficient is the quantity of water to be removed from the drainage affected area over a period of 24 hours and it is expressed in terms of depth. The unit generally used is cm/day or mm/day. In case of city drainage, peak rate of runoff and drainage coefficient are the same except for the units are different.. In design of city drainage, runoff accumulating at the peak rate in the drainage area has to be disposed off at the same rate. However, in case of agricultural drainage, the runoff accumulating in watershed can be safely evacuated over a period of threshold tolerance index of crop under consideration. This index is the expression of maximum time of submergence for which the crop under consideration does not have any adverse effect on its yield. It implies that the peak rate of runoff can be distributed over period equal to threshold tolerance index for evacuation or disposal from the filed. Therefore, runoff value is divided by the threshold tolerance limit of crop under consideration to obtain drainage coefficient. In present case, surface drainage system is designed for vegetable crops and therefore, average value of 0.65 day (0.8 days for Cowpea and 0.5 for Pegionpea) as recommended by Gupta et al.(1992), is considered . The data on drainage coefficient is reported in Table 5.2. Since, the value of drainage coefficient the variation of runoff derived by dividing a common value of threshold tolerance index (0.65 day), it showed the similar trend in runoff computation similar to other methods as explained in section 7.5. Introduction of threshold tolerance index substantially reduced the values of design discharge, and thereby, subsequent reduction in channel section, irrespective of the method. Installation of drainage is a costly affair. To reduce the cost and depending on cropping pattern, the D_{50} tolerance index is also used in design of agriculture drainage systems. This index gives the time of submergence in days for which the given crop is likely to loose 50 % of normal yield. In present case, the main objective of introducing the surface drainage is to facilitate use of rice field for vegetable crop during kharif season. Vegetable crops are sensitive to submergence and therefore, threshold tolerance index is considered for design .

7.5.3 Block wise runoff

The layout of subsurface drainage system was planned as shown in Figure 5.2. The block size was kept equal to 2.5 hectares. A lateral drain divided the block of 2.5 hectares into 1.25 hectares each on both the sides, which is sufficient by large size of a farm unit for uninterrupted farm operations either by bullock or tractor. This is a vital point in layout of surface drainage. The layout is also necessary to make the system economically feasible. It divides the field into different compartments which facilitates distribution of runoff proportionately. In turn, it helps in reducing the channel section. Since, area contributing to lateral drain in all the blocks is same, the design parameters of lateral drainage channel will also be same for each block for a given method. However, the runoff passing through the collector drain would increase from head reaches to tail reaches and therefore, would have varying sections. The 20:40 rule recommended by Bhattacharya et al. (2003) is applied to compute block wise runoff as shown in Table 5.4.

The data revealed that the discharge computed significantly differs for lateral and blocks from one method to other. It is in accordance with the principle of summation of runoff from first order stream to second order stream. Here lateral drain is synonymous to first order stream while Junction A to E are synonymous to 2^{nd} to 5^{th} order stream. This resulted into sequential summation of runoff following 20:40 rule, and therefore, exhibited increase in runoff from lateral to sequential blocks. However, lateral and block wise runoff showed the same trend as influenced by different methods as explained in section 7.5. It is because total runoff determined using different methods, as discussed in section 7.5 is distributed in respective blocks. Therefore, there is no reason for change in trend so far as block wise distribution is concerned.

7.5.4 Design of Drainage Channel

Two methods namely Manning's Equation and Regime Theory are used for design of drainage channel and the results are given in Table 5.9. Manning's theory is based on the regosity coefficient of channel bed material and predicts velocity of flow for given channel section. While regime theory gives empirical relations to compute parameters like wetted perimeter, hydraulic radius, bed slope etc. of channel section. All the empirical relations of regime theory are based on discharge and silt factor. Thus, selection of appropriate value of 'n' in Manning's equation and silt factor 's' in regime theory decides the accuracy of these methods. The different design parameters of drainage channel at lateral and block levels are reported in Table 5.8. As discussed in section 7.7. The runoff increased from lateral to sequential blocks and subsequently, the channel section also increased proportionately. Therefore, the comparison of design parameters of channel at any one location will suffice for evaluating the effect of design methods. In view of this, channel section at tail end junction E was selected and compatibility of the two methods was assessed on the basis of channel parameters at this junction.

The four methods of runoff and two methods of channel design resulted into eight combinations abbreviated as R1, R2 etc. (Table 5.9). The critical analysis of data revealed that irrespective of the method, all design parameters are influenced by discharge. The parameters increase in proportion of discharge. It could be attributed to the fact that in case of Manning's equation, the velocity of flow was assumed to be 0.90 m/sec for all the combinations, and therefore, for this velocity, channel section increased with increase in discharge. Similarly, in case of regime theory, since silt factor was assumed to be 1 in all the combination and all parameters like wetted perimeter, hydraulic radius, bed slope are a function of discharge and silt factor only, the channel parameters increased with increase in discharge for given value of silt factor. However, interactive effect of methods of design revealed that in all the combination of discharges, design parameters like depth, bottom width and cross sectional area were higher in case of regime theory than due to Manning's equation. It could be attributed to the fact that in case of Manning's equation, velocity is a controlling parameter for design. The velocity assumed is non-silting and non erosive velocity which would have resulted into optimal section of channel. In case of both the methods, best economical section approach was used for computing depth and bed width. It is observed that cross section of channel in regime theory is derived from two parameters viz. wetted perimeter ($P = 4.30\ Q^{0.5231}$) and hydraulic radius ($R = 0.515\ Q^{0.3406}$). While velocity is given by $V = (\frac{Qf^2}{140})^{1/6}$ which again is a function of discharge and silt factor. Thus, there is no control on velocity in regime theory. It is important to note that the design velocities by regime theory in all combinations of discharges are very low (0.3 to 0.39 m/sec), and therefore, cannot be adopted for drainage channel under consideration. This range of velocities will result into early silting of channel and the drainage system may become non-functional in a very short period of time. As against this the assumed design velocities in Manning's equation are almost at par. In case of drainage channel, it is more important to have non-silting and non-erosive velocities, which are easily obtained by Manning's equation. For given situation, Manning's equation gives superior results to those due to regime theory and, therefore, this method is recommended for design of surface drainage channel for study area.

7.6 Subsurface Drainage System

Attempts were made to select proper design technique for subsurface drainage for given field conditions. The purpose of subsurface drainage is to reduce water table which has encroached the root zone due to percolation of irrigation water from **Kal** project. The drainage conditions have posed a serious threat to the existence of orchards like mango, cashew and coconut in the command area of this project. There are two approaches viz steady state and unsteady state conditions of water table in root zone used for design of subsurface drainage. In the present study, steady state conditions are assumed for design of subsurface drainage system. FAO Manual 38 (Table 4.8) recommends a water table depth of 1.6 m for fine textured soil with tree crops, and therefore, this value was considered for design. The design conditions are depicted in Figure 6.1. Hooghoudt equation is one of the popular and widely used methods for design of subsurface drainage. In addition to this, Kirkham and Dagan equations are used and design parameters are copmpared. While design drainage coefficient was computed using USDA and Netherlands equations.

7.6.1 Drainage Coefficient

The designed values of drainage coefficient determined by USDA and Netherlands equations are shown in Table 6.1. The data revealed that drainage coefficient by USDA equation (0.60 cm/day) was 2.14 of that due to Netherlands Equation (0.28 cm/day). The Netherlands equation ($Dr = qd \triangleleft t = P - E - \triangleleft W$) takes into account only evapotranspiration and root zone storage as utilizable part of irrigation depth, and remaining as deep percolation. Thus, the contributing factor to seepage is only excess part of irrigation depth. It is only possible in the command areas of irrigation projects where either canal network is lined up to field channel or water course or where irrigation water is delivered to the field by network of pipes through lift irrigation method. Furthermore,the USDA equation ($Dc = \frac{(Ds + Lr + Cs)Di}{Ii}$) takes into account the leaching requirement and canal seepage, in addition to excess irrigation water. Therefore, these two additional parameters viz. canal seepage and leaching requirement lead to a higher value of drainage coefficient by USDA equation than that due to Netherlands equation. Notably the canal of **Kal** irrigation project passes along the foothills and all the command area lies on the right side of canal. The entire network of canal system is unlined. Further, at the outlet end, irrigation is carried out from field to field. There is no provision of field channels. The industrialization coupled with urbanization, network of highways and railways in the command have further blocked the surface and subsurface flow of seepage water. Even localized ponding of water along the borders of railway and highway is a common feature of **Kal** command and can be witnessed all along the railway and highway. This situation leads to very heavy seepage losses from canal system, which is one of the major causes of waterlogging. The USDA equation very well represents the field situation of the study area and, therefore, it is recommended for determination of drainage coefficient for design of subsurface drainage system, but with some modifications. Water quality of **Kal** project is good from irrigation view point and there is no problem of soil salinity in the command of this project (Table 4.5). So leaching parameter used in the equation can be eliminated while applying this method to determine drainage coefficient for the study area. In USDA equation, canal seepage is taken as a fraction of irrigation depth. This however can not be properly justified as there is hardly any data available to link irrigation depths applied with canal seepage in the command. It is, therefore, suggested that field data on seepage needs to be generated at different locations like canal outlet, minor and field out let. On the basis of this data, an independent parameter based on seepage as fraction of discharges at these locations be developed and introduced appropriately in USDA equation.

7.6.2 Drain Spacing

Drain spacing is a function of hydraulic conductivity of soil strata and recharge i.e drainage coefficient. Three methods used for drain spacing viz. Hooghoudt, Kirkham and Dagan equations and two methods viz. USDA and Netherlans equations used for drainage coefficient resulted into six combinations. The design drain spacing by above combinations is reported in Table 6.2. In all these three equations, drain pipe diameter is assumed to be 0.10 m and necessary constant values like equivalent depth in Hooghoudt, and values of F_k and F_D in Kirkham and Dagan equations are taken against 0.10m pipe diameter. These constant values are indicators of frictional head loss of flow while entering from soil profile to drain pipe. The data revealed that drain spacing was higher in Hoogoudt followed by Dagan and Kirkham equation, irrespective of drainage coefficient. It could be attributed to the fact that Hooghoudt equation takes into consideration flow from above as well as below the drain pipe. In addition to this, a hydraulic head of 0.8 m above centre of drain pipe made available due to 2.5 m depth of drain would result in relatively large share of drainage discharge contributed from upper strata as compared to lower strata. In general flow of water in drain pipe is convergence of vertical, horizontal and radial flow lines towards the pipe. Except for Hooghoudt equation, the vertical flow lines are not considered while computing drain discharge. Hypothetically, it is possible to neglect vertical flow lines, if h<< H, as shown in Figure 6.1. In the present case, h =0.11 H and therefore, possibility of vertical flow lines cannot be overlooked. The overall effect would be reflected in more drainage discharge per unit length of drain pipe and, therefore, increase in spacing in Hooghoudt equation as compared to remaining two methods. Kirkham and Dagan take into consideration only horizontal and vertical flow lines with difference in frictional factors F_k and F_D. It is, perhaps the reason that spacing of drain by both these methods are same in one case (Dc = 0.60 cm/day) and similar in other one (Dc = 0.28 cm/day), when Kirkham and Dagan equations were used.

The data further reveled that drain spacing increased with decrease in drainage coefficient in all the methods. Drainage discharge is a function of area contributing to drain pipe, drainage coefficient, hydraulic conductivity and head over mid way of drain pipe. Therefore, for all other factors remaining the same, the drain spacing will change with change in drainage coefficient. Further, spacing is inversely proportional to drainage coefficient as seen from the three equations. Therefore, spacing increased with decrease in drainage coefficient in all the methods.

It is explained in section 7.6.1 that drainage coefficient for study area is properly represented by USDA equation. Drain spacing against drainage coefficient by USDA equation (0.60 cm/day) was maximum in Hooghoudt equation (51m). It is, therefore, recommended that drain spacing of 51 m be adopted for subsurface drainage for orchard crops in the study area.

CHAPTER VII

SUMMARY AND CONCLUSIONS

A drainage condition in agriculture poses serious problems to soil health. It has immediate effects on yield of crops. The drainage affected area is most vulnerable to pest and diseases to crops as well as to human being. Drainage conditions can be posed either naturally or induced due to faulty land development and improper irrigation practices. Drainage is an inherent problem of heavy rainfall area during monsoon. Most of the command areas of major and minor irrigation projects in India are subjected to serious drainage problem. Command area of **Kal** irrigation project located in Konkan region of Maharashtra is characterized for dual drainage problems i.e. drainage problem during monsoon due to heavy rainfall coupled with rice fields and flood irrigation to summer rice. The rice based agriculture is in loss and farmers are inclined to go for vegetable crops. While due to increased water table the horticulture orchards are in danger. This situation has compelled to adopt drainage systems in command area as a preventive measure. In view of this, to select an appropriate drainage design method, the available techniques suitable for the Kal command project were analysed. Both surface and subsurface drainages were considered. The designed parameters were compared to identify a suitable method for the study area.

It is observed that farmers in command area of **Kal** irrigation project are reluctant to grow rice during kharif, as it is not very remunerative. The command is close to Mumbai where vegetable and fruit crops fetch comparatively good prices and these are required thought the year. It is however not possible to grow these crops in rice fields for reasons of submergence during monsoon. If appropriate surface drainage is provided, it will be possible to grow the vegetable crops.

Surface Drainage Design

For runoff being an important parameter for design of surface drainage, the Rational Formula, Time Distribution Method and CN method were used for its computation. The first method using time of concentration yielded the highest runoff magnitude (4.37 m^3/sec) followed by the same formula using rainfall intensity (3.70 m^3/sec), then Time Distribution Method (3.24 m^3/sec) and the lowest by CN method (1.26 m^3/sec). The relatively higher runoff by both the approaches of Rational method could be attributed to its predicting the peak rate of runoff among others. However, Time

Distribution Method takes into account one-day rainfall as against isolated storm intensity with precipitation occurring in six hours and, therefore, employing a reduction factor (0.5 to 0.7) to daily rainfall. This 6 hours period can be correlated to threshold tolerance period of any sensitive crop for submergence. The distribution of rainfall in 6 hours increases up to 2.5 hours from the start of rainfall and then recedes. Thus it simulates the condition of an isolated storm, which for from crop submergence view-point is quite appropriate. Since it computes runoff using CN method, one of the most widely used runoff predicting method, it is can be recommended for computing runoff for surface drainage design. However, the CN method predicts runoff from the rainfall precipitated over a period of 24 hours, leading to reduced runoff. Proper laying out of the drainage system is key to surface drainage. The block size of 2.5 ha was divided into 1.25 hectares each on both the sides of lateral, sufficient size for farm operations. The runoff computation by different methods, through laterals and blocks, varied significantly.

Manning's Equation and Regime Theory were used for design of drainage channel. Selection of appropriate value of 'n' in Manning's equation and silt factor 's' in regime theory decides the accuracy of the runoff computed. The four methods of runoff and two methods of channel design resulted into eight combinations. It was found that, irrespective of the method used, all design parameters are influenced by discharge. The parameters increased with increase in discharge. In Manning equation, the assumption of flow velocity as 0.90 m/sec for all combinations, the channel section increased with increase in discharge. Similarly, in regime theory, the constant silt factor (1.00) in all the combination affected all parameters like wetted perimeter, hydraulic radius, bed slope, which are a function of discharge and silt factor. Therefore, the channel parameters increased with increase in discharge for given silt factor. Interactive effect of methods of design revealed that in all the combination of discharges, design parameters were higher in regime theory than those due to Manning largely because velocity in the latter was a controlling parameter for design. In regime theory, velocities were very low (0.3 to 0.39 m/sec) in all the combinations of discharges, and therefore, were not recommended for drainage design. These velocities would result into silting of channel, making the drainage system non functional in a very short period of time.

Subsurface Drainage System:

The purpose of subsurface drainage is to reduce water table, which has encroached in root zone due to percolation of irrigation water from **Kal** project. Steady state condition was assumed for design, and water table depth at 1.6 m for fine textured soil with tree crops as recommended by FAO. Three methods namely Hooghoudt, Kirkham and Dagan equations were used for design of spacing while USDA and Netherlands equations were used to compute drainage coefficient.

The drainage coefficient by USDA equation (= 0.60 cm/day) was 2.14 times of that from Netherlands Equation (0.28 cm/day). Notably, the latter accounts for evapotranspiration only. The root zone storage is taken as utilizable part of irrigation depth, and remaining as deep percolation. Thus, the contributing factor to seepage is only excess part of irrigation depth. It is only possible in a irrigation commands where either canal network is lined up to field channel or water course or where irrigation water is delivered to the field by network of pipes through lift irrigation method. On the other hand, the USDA equation, which accounts for leaching requirement and canal seepage, resulted into high drainage coefficient. The canal of. **Kal** irrigation project is passing along the foothills and all the command area is on right side of canal. The entire network of canal system is unlined, field to field irrigation method is considered at the outlet end, and there is no provision of field channels. The USDA equation appropriately represented the study area and, therefore, is recommended. Since water quality of **Kal** project is good from irrigation view-point, the leaching parameter can be done away with. Instead of taking canal seepage as fraction of irrigation as in USDA equation, data on seepage could be generated at canal outlet, minor, or field outlet for introducing an independent parameter.

The Hoogoudt equation yielded drain spacing higher than that due to Dagan and Kirkham equation because the accounted for the flow from above as well as below the drainpipe. In addition, a hydraulic head of 0.8 m above center of drainpipe made available due to 2.5 m depth of drain might have resulted in relatively larger share of drainage discharge from upper strata than that from lower strata, resulting in more drainage discharge per unit length of drain pipe and, therefore, increase in spacing in Hooghoudt equation than the others. The drain spacing, inversely proportional to drainage coefficient, increased with decrease in drainage coefficient in all the methods Drainage discharge is a function of area contributing to drain pipe, drainage coefficient, hydraulic conductivity and head over mid way of drain pipe. Thus, for all other factors remaining same, the drain spacing will change with change in drainage coefficient. The highest drain spacing (= 51m) from Hooghoudt equation was recommended for design. In brief, the following can be concluded from the **KAL** study:

1. Time Distribution Method is appropriate for runoff computation.

2. Manning's equation providing non-erosive and non-silting velocities through channel is useful for surface drain design.
3. USDA empirical relation is appropriate for computation of drainage coefficient by considering actual seepage losses at canal outlets, minor outlet and within field.
4. Drain spacing of 51 m with pipe diameter of 10 cm is sufficient for subsurface drainage.

REFERENCES

1. Anonymous. 1984. Extension Bulletin no 871-98.Web www.oholine.ag_state.edu.accesed on 12-3-2005.
2. Anonymous. 2001. International Commission on Irrigation Drainage. Irrigation and Food production information about ICID network countries. Web www.icid.org.in.accessed on 25-7-2005.
3. Anonymous. 2005. Manual on Design of Drainage: FAO Publication. 11.1-3.
4. Babu Ram, Tejwani, K.G., Agrawal, M.C. and Bhushan, L.S. 1979. Rainfall Intensity –Duration- Return Period equations and Nomographs of India. Bulletin No.3. Central Soil and Water Conservation Research and Training Institute (ICAR) Dheradun. pp70.
5. Balam, J.J. and Corbin, William. 1962. Effect of water table depth variation and soil type on yield of peaches. Drainage Principles and Applications. Publication 16. pp 435.
6. Bhattacharya A.K. and A.M. Michael.2003. Land Drainage: Principles, Methods and Applications. Karmic Publications, New Delhi. 301-319.
7. Boonstra, M. N., Bhutta, M.N. and Sultan A Rizvi.1997. Drainable Surplus Assessment in Irrigated Agriculture: Field Application of the Groundwater Approach. J. Irrigation and Drainage Systems. 11. 41-60.
8. Christen E.W. and J.W.Hornbuckle.1990. Subsurface Drainage Design and Management Practices in Irrigated Areas of Australia. Web www.irrigationinsight. org accessed on 23-10-2005.
9. Christen E.W. and Skehan D. 1999. Design and Management of Subsurface Drainage for Improved Water Quality: A field investigations. Report No 5, School of Agriculture, University of Sydney. 98-106.
10. Dirk van Zyl and A. Macg Robertson.1980. Subsurface Drainage of Tile Impoundment: Some Design and Management Considerations. Proc. of Symposium Uranium Hill Tailfings, Collarado University. 57-65.
11. Eilert Waskow, Rienk R and van dr Ploeg. 2003. Calculation of Drain Spacing for Optimal Rainstorm Flood Control. Journal of Hydrology. 163-174.
12. Eng. Hussein El Atfyl.1999. Modified Drainage System For Rice Growing Areas: web www.irrigationinsight.org accessed on 15-11-2005.
13. Farmer Ranch.1999. Subsurface Drainage Plan. A publication of British Columbia, Ministry of Agriculture, Fisheries and Food. 3-9.

14. Gafni A.M.1994. Concept of bio -drainage. Plant and Soils. 44. 23-27.
15. Gupta S.K., Singh, R.K. and R.S.Pandey.1992. Surface Drainage Requirement of Crops. Journal of Irrigation and Drainage Systems. 6. 249-261.
16. Heupermark, T.T. 1992. Eucalyptus as a bio- pump. Irrigation and Drainage. 14. 105-109.
17. Johnston William R.1976.. Drainage installation problem in San Joaquin Valley, California, USA. Proc. Of the International drainage Workshop, Paper No. 4.01. Publication 25.
18. Kirkham, D. 1957. The Theory of Land Drainage of Agriculture Lands, American Society of Agronomy, Madison, WI. 139-141.
19. Leasaffre, B. and Zimmer, D. 1988. Subsurface Drainage Peak Flow in Shallow Soil. J. Irrigation Drainage Division ASCE 114 (IR 3). 387-406.
20. Masland H.T and Haskew, H.1958. Design criteria for subsurface drainage in MIA. Symposium for land drainage for salinity control. Vol.3. 425-424.
21. Michael A.M.1978. Irrigation: Theory and Practices. Vikas Publishing House, New Delhi. 257-402.
22. Minessy, F.A., M.A. Barkat and E.M., El Azab.1977. Effect of soil properties on root top of tapioca. Plant and Soils, 34. 1-15.
23. Naraine, D.S. 1990. The development of drainage criteria and their application to sugarcane cultivation in Guyana. M. Sc thesis, International Institute of Hydraulic Engineering/ IHE Delft, The Netherlands. 56-74.
24. Oosterbaan, R.J. and Abu Senna.1990. Using saltmode to predict drainage and salinity in Nile Delta. In II RI Annual report, Wagneningen. 63-75.
25. Oosterban.R.J.1991. Agriculture Land Drainage: A Wider Application Through Caution And Restraint. Lecture delivered at the Symposium to mark the occasion of the 30 th International Course on land drainage, ILRI, Wageningen, The Netherlands, 27 November 1991. 21-36.
26. Penman, F.1938. Soil conditions at Bamawan and Ballendella in relation to citrus growth. Journal of the Department of Agriculture, Victoria, Vol 1.31-34.
27. Polkinhorne, C. 1992. Tile Drainage in the MIA, Farmers Journal. 41-45.
28. Ritzema, H. P. and Sfwat Abdel – Dayem.1994. Drainage Principles and Applications, Chapter 17: Agricultural Drainage Criteria. 9-12.
29. Salem H.E and R.W. Skaggs.1998. Predicting Drainage Rates Under Varying Water Table Conditions. Proc. of 17th International Drainage Symposium, ASAE, St. Joseph, MI. 168-175.

30. Sarkar, Tarun Kumar.1980.Mannual on Drainage Design. Water Technology Centre, Indian Agriculture research Institute, New Delhi. 57-58.
31. Sharma S.K. 1984. Textbook of Irrigation Engineering. Oxford, New Delhi. 401-455.
32. Singh Bharat.1988. Fundamentals of Irrigation Engineering. Nemchand and Brothers, Roorkee. 305-401.
33. Talsma, T and Flint, S.E.1958. Some Factors Determining the Hydraulic Conductivity of Subsoils with Special Reference to Tile Drainage Problems. Journal of Soil Science Vol. 22. 198-206.
34. Taslm, T and Haskew, H .1959. Investigation of Water Table Response to Tile Drain in Comparison with Theory. Journal of Geophysical Research. Vol. 64. pp11.
35. Tiedmen E.M.1996. Watershed Management. Omega Publishing, New Delhi. 102-143.
36. Van der Lely, A.1972. Winter Water Table Surveys in MIA. Water Commission and Irrigation Report. 12-17.
37. Van der Lely, A.1978. Artificial Subsurface Drainage in the MIA. Hydrology of Ravine Plains of South East Australia. 101-114.
38. Van der Ploeg, Horton R.R. and Kirkham, D.1999. Steady flows to drains and wells. Agriculture Drainage, Agronomy Monograph No. 38, ASA/CSSA/SSSA, Madison, WI. 213-263.
39. Van der Ploeg, R.R.Kirkham and M.B.Marquardt.1999. The Colding Equations for Soil Drainage: its origin, evolution and use. Journal of Soil Science Soc. Am. 63, 33-39.
40. Van Schilfgaarde.1974. Nonsteady flow to drain. J Drainage for Agriculture lands, Monographs No 17, American Society of Agronomy, Madison, WI. 245-270.

SYMBOLS USED

Symbol	Unit	Meaning	Definition
Q	m^3/sec	Discharge	Rate of flow of water
I	mm/hr	Intensity of rainfall	Rate of precipitation
A	Hectare	Area	Measure of area
Tc	Minute	Time of concentration	Time taken by runoff water to travel from peak to outlet of watershed
L	Meter	Length of stream	Measure of length
T	Year	Return period	Time of recurrence of event expressed in years
P	mm	Precipitation	Measure of amount of rainfall
R	mm	Runoff	Part of rainfall resulted as channel or overland flow
S	mm	Maximum possible abstraction	Capacity of soil to absorb maximum possible quantity of rain water
Ia	mm	Initial abstraction	Quantity of rain water that can be absorbed by soil profile before initiation of runoff
AMC	-	Antecedent Moisture Conditions	Moisture status of soil at time of occurrence of storm
CN	-	Curve Number	A representative measure of runoff
Dc	cm/day	Drainage Coefficient	Depth of water removed from root zone over a period of day
Qp	m^3/sec	Peak rate of Runoff	Maximum rate of runoff resulted under given storm conditions
Tp	Hour	Time to peak rate of runoff	Time from onset of runoff till it attains its peak
C	-	Coefficient of Runoff	Constant in Rational Formula
ECe	mmhos/cm	Electric conductivity	Indicator of salt content in water and a measure of salinity
pH	-	pH value	Logarithm of H ion concentration in solution
Z	m	Root zone depth	Depth of soil profile upto which roots of crop can penetrate
F.C.	%	Field Capacity	Measure of water content in soil when gravitational water is drained or water held by soil at 1/3 rd bar
P.W.P.	%	Permanent Wilting Point	Water content in soil when plant shows permanent sign of wilting or water content at 33 bar
T.W.P	%	Temporary Wilting Point	Water content in soil when plants show temporary wilting symptoms or water content at 15 bar
z	-	Side Slope of Channel	A measure of channel slope made with horizontal

DS_{50}	Days	Tolerance limit of crop for submergence	Period for which if crop is subjected to submergence will loose 50 % normal yield
θ	Degree	Theta	Measure of angle
P	Meter	Wetted Perimeter	Perimeter of channel at level of given discharge
R	Meter	Hydraulic Radius	Ratio of area to wetted perimeter
V	m/sec	Velocity	Rate of flow of water
f	-	Silt Factor	Measure of silt content in flow
K	cm/day	Hydraulic Conductivity	Rate of low of water through unit section of soil mass under unit head
L	Meter	Drain Spacing	Measure of distance between two consecutive drains
de	Meter	Equivalent Depth	Water depth in a fictitious ditch that would be just as effective in removing soil water as a tube drain of radius r at a distance D above the impervious boundary
d	Meter	Depth of impervious layer below drain	Measure of distance between soil surface and impervious layer
Fk	-	Constant in Kirkham Equation	$Fk = \frac{1}{\Pi} [A + \sum_{n=1}^{\infty}\{(\frac{1}{n})(B)(C)\}]$ Where $A = \ln [\frac{L}{(\Pi)(r0)}]$ $B = \{\cos(\frac{2\Pi r0}{L}) - \cos(n\Pi)\}$ and $C = \{\coth(\frac{2n\Pi h}{L}) - 1\}$ where, r0 = radius of drain pipe (m), n = series of flow lines, h = depth of water mid way between drain pipe(m) L = drain spacing (m)
FD	-	Constant in Dagan Equation	Where $FD = (\frac{1}{4}) \{(\frac{S}{2h}) - \beta\}$ and $\beta = (\frac{2}{\Pi}) [\ln \{2\cosh(\Pi r0/h) - 2\}]$ Where r0 = radius of drain pipe (m), n = series of flow lines, h = depth of water mid way between

			drain pipe(m)
h	Meter	Hydraulic head mid way between two drain pipe	Head of water measured from mid way between drains to water table elevation
H	Meter	Depth of impervious layer below soil surface	Depth of impervious layer measured from top of soil profile
Ds	-	Deep seepage expressed as fraction of irrigation water	Part of irrigation water that result as deep percolation
Lr	-	Leaching requirement	Water required to leach out salts from active root zone of crop
Cs	-	Canal seepage expressed as fraction of irrigation water	Contribution of seepage from canal and expressed in terms of fraction of depth of irrigation water
Di	cm	Depth of irrigation water	Quantity of water applied per rotation of irrigation and expressed in terms of depth
Ii	Days	Irrigation Interval	Time interval in between two successive irrigation cycles
Cfe	mmhos/ cm	Salt concentration of soil moisture at root zone at F. C.	Expression of salt concentration in soil water at root zone depth
Ci	mmhos/ cm	Salt concentration of irrigation water	Expression of salt concentration in irrigation water
E	mm/day	Evapotranspiration	Cumulative depth of water which is evaporated from surrounding and transpired by crop

APPENDIX

Table I Maximum active incoming shortwave radiation (Rse) (cal/cm2/day

North	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
South	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
0	343	360	369	364	349	337	343	357	368	365	349	337
10	299	332	359	375	377	374	375	377	369	345	311	291
20	249	293	337	375	394	400	399	386	357	313	264	238
30	191	245	303	363	400	417	411	384	333	270	210	179
40	131	190	260	339	396	422	413	369	298	220	151	118

Table II Extra-terrestrial radiation for Northern hemisphere (Ra) (mm/day).

Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
20	11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7
18	11.6	13	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12	11.1

Table III Daily duration of Maximum Possible Sunshine Hours (N) in Northern hemisphere.

Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
20	11	11.5	12	12.7	13.3	13.7	13.5	13	12.3	11.7	11.2	10.9
15	11.3	11.6	12	12.5	12.8	13	12.9	12.6	12.2	11.8	11.4	11.2

Table IV Values of adjustment factor c.

	RHmax 60%				RHmax 90%			
Rs (mm/day)	3	6	9	12	3	6	9	12
U day (m/sec) 0	0.96	0.98	1.05	1.05	1.02	1.06	1.1	1.1
3	0.92	1	1.11	1.19	0.99	1.1	1.27	1.32
6	0.85	0.96	1.11	1.19	0.94	1.1	1.26	1.33
9	0.76	0.88	1.02	1.14	0.88	1.01	1.16	1.27

Table V Effect of temperature f (T) on longwave radiation (Rnl)

T° C	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	36
f(T)	11	11.4	11.7	12	12.4	12.7	13.1	13.5	13.8	14.2	14.6	15	15.4	15.9	16.3	16.7	17.7	18.1

Table VI Effect of vapour pressure f(ed) on Longwave radiation (Rnl)

ed (m bar)	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
F(ed)	0.23	0.22	0.2	0.19	0.18	0.16	0.15	0.14	0.13	0.12	0.11	0.1	0.09	0.08	0.08	0.07	0.06	

Table VII Effect of ratio of actual and maximum bright sunshine hours f(n/N) on longwave radiation (Rnl)

n/N	0	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4	0.45	0.5	0.55	0.6	0.65	0.7	0.75	0.8	0.85	0.9	0.95	1
f(n/N)	0.1	0.15	0.19	0.24	0.28	0.33	0.37	0.42	0.46	0.51	0.55	0.6	0.64	0.69	0.73	0.78	0.82	0.87	0.91	0.96	1

Table VIII Values of weighted factor W

T°C/Lat	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
0	0.43	0.46	0.49	0.52	0.55	0.58	0.61	0.64	0.66	0.69	0.71	0.73	0.75	0.77	0.78	0.8	0.82	0.83	0.84	0.85
500	0.45	0.48	0.51	0.54	0.57	0.6	0.62	0.65	0.67	0.7	0.72	0.74	0.76	0.78	0.79	0.81	0.82	0.84	0.85	0.86

Table IX Saturated vapour pressure (ea) (mbar)

Temp ° C	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ea (mbar)	6.1	6.6	7.1	7.6	8.1	8.7	9.3	10	10.7	11.5	12.3	13.1	14	15	16.1	17	18.2	19.4	20.6	22.6
Temp ° C	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
ea (mbar)	23.4	24.9	26.4	28.1	29.8	31.7	33.6	35.7	37.8	40.1	42.4	44.9	47.6	50.3	53.2	56.2	59.4	62.8	66.3	69.9