3.0 DESIGN CONSIDERATIONS

3.1 General

A drainage problem is caused by an excess of water either on the surface of the soil or in the root zone beneath the surface of the soil. If the water stands on the surface of the soil the problem, is one of surface drainage. The other type of drainage problem is due to high water table. In many instances the soil surface may appear to be dry, although water logged soil at depth of 0.5 to 1 m beneath the surface may cause serious damage to the grown crops.

Surface drainage is the evacuation of excess water over the ground surface through improved natural channels or constructed ditches and through, shaping of the level surface. Surface drainage systems when properly planned, eliminate ponding, prevent prolonged saturation and accelerate flow to an outlet. Surface drainage system includes both collection and disposal ditches. Where the system or parts of the system, primarily collect and remove surface water from a field, the cross section, slope, pattern and spacing of ditches are essential factors to be considered for design of the system. Ditches for surface drainage are usually designed to remove the runoff produced by normal rainfall in time to prevent damage to the crops growing in the drainage area: The parameters required for design of drainage system such as conversion of annual maximum series to partial duration series, conversion of point rainfall values to areal average values, runoff coefficient, depth area duration relationship, time of concentration etc.

As all drainage is to be let off into river (lake or sea) the drain design has to take into consideration an outfall level to avoid leakage and consequent disfunction of the drain system. In this context, estimating a ruling 75% dependable level in the oufall available over the submergence tolerance period of the crop, in the (particular 120 day life span of a) kharif or rabi crop is important and is a primary consideration in the drain design/layout.

Sub surface drainage is defined as the removal of excess ground water below the ground surface. This system lowers the high water tables caused by rainfall, irrigation leaching water, seepage from higher lands or irrigation canals etc. The various parameters essential for design of subsurface drainage system are soil permeability, depth to impermeable layers, depth of water table, drainage coefficient, percolation rate and drainable porosity. The values of these parameters will help in determining depth and spacing of drains.

3.2 *Indian Standards*

Drains are constructed with the object of relieving excess water from agricultural and other areas and disposing of surplus water not required for normal agricultural operations. The proper disposal of surplus rain water is also essential to avoid its percolation down to the water table which may otherwise lead to rise in the water table thereby aggravating or creating the problem of waterlogging.

3.2.1 Classification of drains:

The drains are broadly classified into the following categories according to the purpose for which these are constructed:

a) **Outfall drains** - These are the main drains outfalling into a nallah or a river from a particular catchment.

b) **Link drains** - These are branch drains draining subcatchment into the outfall drain. These are aligned along subsidiary valley lines.

c) **Field drains** - These are small drains draining individual or a group of fields into the link drains.

d) **Ditch drains** - These are constructed to drain the water by connecting borrow pits along roads, railway lines, etc.

e) **Cunnette** - This is a small drain constructed in the bed of main drain at a level lower than the normal bed levels of the maind rain for carrying non-monsoon/seepage discharge without allowing it to spread across the entire section of the main drain.

f) **Seepage drains** - These are constructed along the canals to collect the seepage water from the canal embankments and to drain it either directly into a natural outfall or into a carrier drain.

3.2.2 Capacity/Design discharge of drains:

Normally the cut sections of the drains are provided to accommodate the design discharge where drains follow natural valley lines. In such cases, no embankments should be provided along the drain so as to allow free flow of water from the surrounding areas. Wherever embankments are necessary for accommodating a portion of the design discharge or where disposal of excavated soil will be very costly, large gaps should be provided in the embankments on either side so as to allow unrestricted inflow, and in case of incidence of discharges higher than the channel capacity, the water should spill over the area and return to the channel freely when the discharge in it recedes. In the forced or diversion reaches, embankments on both sides are, however, provided as the design discharge cannot be accommodate within the cut section of the drain. However, even in such cases attempts should be made by selecting a proper alignment to keep the height of the embankments to the minimum. In such cases, inlets of adequate size should be provided in the embankments to admit the water from surrounding areas.

3.2.3 Intensity of rainfall

Analysis of the storm rainfall throughout the country indicates that generally the duration of the storm is about 3 days. Therefore, for design of the drains, a storm rainfall of 3 day duration should be taken.

3.2.4 Design frequency of rainfall:

In fixing the design capacity of the drain the following factors have to be taken into account:

a) **Economics** - Drains of a bigger size or catering for a rainfall of infrequent occurrence prove to be costly compared to the benefits. Drains are never designed to cater for the worst conditions. In other words, in any drainage project, occurrence of damage at periodical intervals is to be accepted.

b) **Performance** - The experience indicates that drains of a bigger size tend to deteriorate fast, as these are not required to carry the design discharge frequently. Consequently in carrying smaller discharge, drains tend to get silted soon. On the other hand, drains of a smaller size remain in a better condition and can occasionally carry higher discharges with marginal scour of bed and sides and encroachment on free board.

c) **Land Requirement** - On account of small land holdings, bigger drains involve larger land acquisition resulting in a permanent loss of the cultivated land.

d) **Design Frequency** - Generally the drains should be designed for three day rainfall of 5 year frequency. Studies carried out indicate that 5 year frequency gives optimum benefit cost ratio.

3.2.5 Period of Disposal

The period of disposal of the excess rainfall is entirely dependent on the tolerance of individual crops. Crops like paddy can generally stand submersion for a period of 7 to 10 days without suffering any significant damage. Therefore, in paddy growing areas, the drainage should aim at disposing of the rain water in a period varying from 7 to 10 days. Based on experience the following periods of disposals are recommended:

a)	Paddy	7 to 10 days
b)	Maize, bajra and other similar crops	3 days
c)	Sugarcane and bananas	7 days
d)	Cotton	3 days
e)	Vegetables	1 day (in the case of vegetables, 24 hour rainfall will have to be drained in 24 hours)

3.2.6 Runoff

Runoff coefficient depends on the type of soil, crops, general topographical conditions like land slopes, etc. In plain areas, the runoff percentage is generally of the order of 15 to 20. In semi-hilly areas the percentage may be higher. Until precise data becomes available, the following runoff coefficients for different soils are recommended for plain areas:

a)	Loam, lightly cultivated or covered	0.40
b)	Loam, largely cultivated and suburbs with gardens, lawns, macademized roads	0.30
c)	Sandy soils, light growth	0.20
d)	Parks, lawns, meadows, gardens, cultivated area	0.05-0.20
e)	Plateaus lightly covered	0.70
f)	Clayey soils stiff and bare and clayey soils lightly covered	0.55

3.2.7 Runoff for composite crops

In large areas, there are often different types of crops grown. In such cases, the field and link drains can be designed on the basis of the crops grown in a particular area. For the outfall drain, either a composite discharge can be worked out or the total discharge can be worked out by taking into account the discharges from individual link drains. As the area grows larger, the chances of synchronization of discharge from the entire area become less. As such, working out a composite discharge may also serve the purpose. However, individual cases will have to be studied on their own merit.

3.3 Parameters for Surface Drainage

The various parameters required for design of surface drainage system are described in the following paragraphs.

3.3.1 Factors for Converting Annual Maximum Series to Partial Duration Series

For design of surface drainage system the quantitites of water that have to be discharged as also time in which to be evacuated must be known. If possible, these amounts should be assessed by direct measurements. If not, indirect method such as calculation of discharge from rainfall data will have to be used. As rainfall is extremely variable in time and space, the rainfall data covering long period and recorded at various stations are needed from which a design rainfall is selected. The design rainfall is then transformed to a design discharge. The parameters which are required for finding the design discharge from rainfall data are presented here.

Drainage systems are usually designed based on a precipitation event which has a certain statistical frequency of occurrence. However, proposed systems are usually evaluated for their performance during a range of other events depending upon the importance of a system. While selecting a rainfall event with certain duration and frequency an assumption is inherent that a given frequency rainfall of a critical duration will lead to same frequency runoff flood. Different rainfall events can lead to runoff events which do not have the same frequency of occurrence. Experience indicates that very intense storms are of short duration and are rare. Storms of long duration tend to be less intense. Extremely long storms supplying large amounts of rain are also rare. Drainage design needs quantification of the inverse relationship between intensity, duration and frequency.

There are two methods for selecting data for analysis of extreme values. The first method considers the annual sereis in which the largest single event that occurred within each year of record is selected. In the annual series, year may be calender year, water year, or any other consecutive 12 month period. The limiting factor is that one and only one piece of event is accepted for each year. Use of the annual maximum series ignores the second and third highest events of a year, even though they may be larger than the ***maxima*** of other years. The second method recognizes that the large events are not calendar bound and that more than one large event may occur in the time unit used as a year. In a partial duration series, the largest N events are used regardless of how many may occur in the same year. The only restriction is that independence of individual events be maintained. The number of events used is at least equal to the number of years of record. The partial duration series does not fit the extreme-value distribution and therefore can not be extrapolated by extreme value distribution function (Dunne and Leopolod, 1978). Instead, the return period and magnitude of the partial duration series can be plotted on semi-logarithmic paper using the relation

$$T = \frac{N + 1}{M}$$

in which,

T is recurrence interval,
M is the ranking, the events being arranged in descending order the highest event having the first ranking, and
N is number of events.

The magnitude of the N year event can be determined from this plotting. This technique is particularly useful for estimating events of low recurrence interval from a short record.

For return periods greater than 10 years there is almost no difference between the partial duration series and annual maximum series. There is a difference, however, between the probabilities calculated from the two series for small events.

Table 3.1 gives empirical factors for converting the magnitude of the partial duration series from that of the annual maximum series.

Table 3.1 : Empirical factors for converting rainfall magnitude calculated from the annual maximum series to the partial-duration-series for the same recurrence interval.

Recurrence Interval (Year)	Converting Factor
2	1.13
5	1.04
10	1.01
20	1.00

3.3.2 Factors for Converting Point Rainfall Values to Areal Average Values

Averaging point-rainfall values of a given frequency does not yield an areal average of the same frequency. It is not permissible to average the 10 year, 1 hour storm at five stations in a 100-square-miles basin to obtain the 10 year, 1 hour storm over the whole 100 square miles. The U.S. weather Bureau based on field study, has found the relationship as shown in Fig. 3.1 between point rainfall of a specified duration (regardless of its frequency) and the average rainfall over areas upto 400 square miles. Once the magnitude of the rainfall of some frequency has been evaluated for one station located in an area of interest the average rainfall for the area of interest can be obtained by multiplying it with appropriate value taken from the ordinate of Fig. 3.1 (Vide Sheaffer et al, 1982).

3.3.3 Depth-Area-Duration Relationship

The depth-area-duration (DAD) relationship provides the designer with important information on temporal and spatial variation of rainfall for a given area. To obtain this knowledge a series of storms with continuous records at a number of stations in the area are required. The basin is subdivided into zones by isohyetss and the mean cumulative precipitation for each zone is determined. Next the maximum average depths of rainfall for different durations are determined for cumulative area of the basin. For each duration the maximum average depths are plotted against the logarithms of the areas (De Wiest, 1965). A typical depth area duration curve is shown in Fig. 3.2 (Raudkivi, 1979).

3.3.4 Runoff Coefficient

The storm runoff peak, volume and timing provide the basis for planning, design and construction of drainage facilities. Four basic approaches can be utilized for determining the character of storm runoff. They are:

a) The Rational Method
b) Synthetic Unit Hydrograph Procedure,
c) Computer Simulation Modelling, and
d) Hydrologic Modelling

The rational method is adequate for approximating the peak rate of runoff from a rainstorm in a given basin and it provides only this one point on the runoff hydrograph. In spite of the criticism because of its simplicity the rational method has been widely used (Bartlett, 1981). The Rational Method which can be applied only for basins upto 100 acres or less is based on the rational formula:

$$Q = 0.275\, C\, I\, A$$

in which,

Q = maximum rate of runoff in cubic meter per second,
A = catchment area in squarre kilometers,
I = rainfall intensity in mm per hour for the period of maximum rainfall of a given frequency of occurrence having duration equal to the time of concentration, and

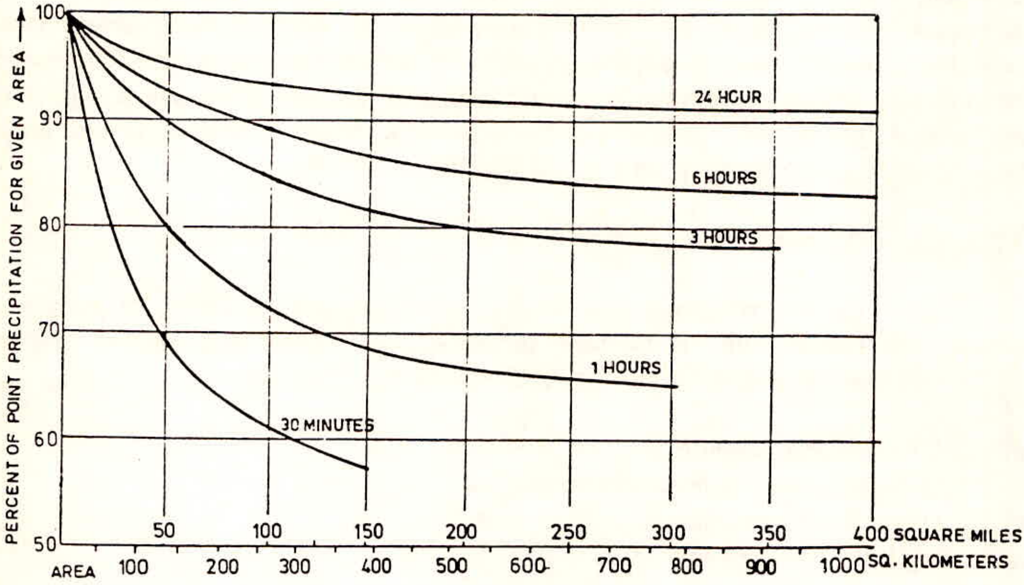

Figure 3.1 Areal Analysis Graph

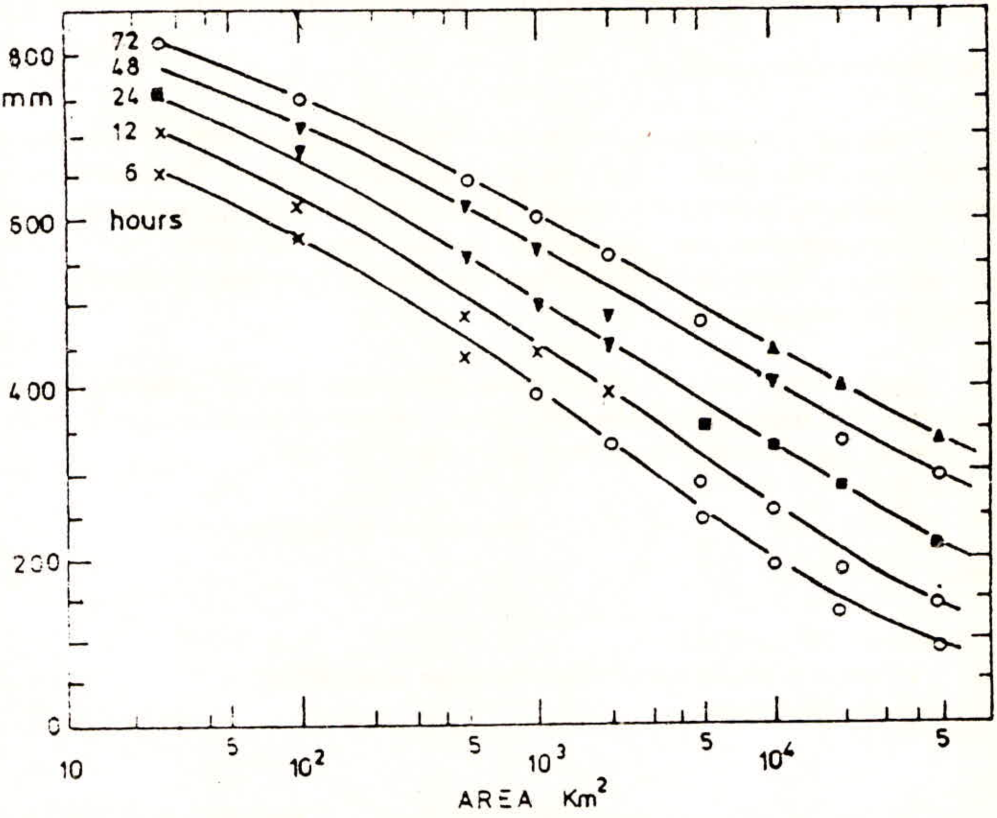

Figure 3.2 Diagrammatic presentation of maximum depth area duration curves for a catchment

C = impermeability factor which accounts for the abstraction such as interception by vegetation, infiltration etc. C is also known as the runoff coefficient and its determination is a difficult task. The coefficient represents the integrated effects of infiltration, detention, evaporation, retention, flow routing and interception which all affect the time distribution and peak rate of runoff. The run-off coefficient to be used in the rational formula are given in Table 3.2.

3.3.5 Time of Concentration

In rational formula the duration of the design storm is taken as the time of concentration of the basin. The time of concentration is the time required for a particle of water to reach the outlet from the most remote part of the basin. The time of concentration can either be derived from correlation with basin characteristics or it can be computed from the times of flow in successive bankful reaches of the main channel.

Based on the study on seven small agricultural basins extending in size from 1.25 to 112 acres, it has been found that the time of concentration is related to a factor L/ S in the following manner (ILRI, 16 16 (II), 1973:

$Tc = a(L/\sqrt{S})^n$ (T_c units have to be specified)

where,

a and n are constants,
L is length of travel, and (units have to be specified for L)
S is channel slope.

The channel slope is derived from the stream profile which is a plotting of elevation versus the horizontal distance along the main stream. If the stream profile is curved, the equivalent uniform slope is found by drawing a straight line through the down stream end so as to have the same area under the line as is under the profile (Fig. 3.3).

The U.S. Soil Conservation Service has developed the following formula for determination of the time of concentration:

$t_c = (L/\sqrt{S})^{0.38} /4902.5$

where,

t_c is the time of concentration in hours,

L is the length of the catchment along the mainstream from the basin outlet to the most distance ridge in meters.

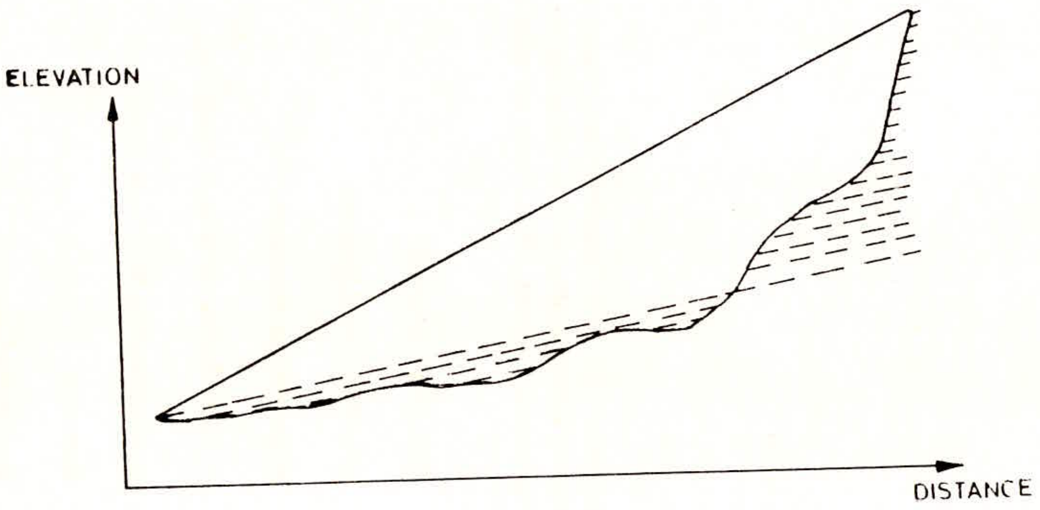

Figure 3.3 Equivalent slope for a curved stream profile

TABLE 3.2 VALUES OF THE RATIONAL RUNOFF COEFFICIENT C. (FROM AMERICAN SOCIETY OF CIVIL ENGINEERS 1969, RANTZ, 1971,AND ELSEWHERE)

Urban Areas	
Streets: asphalt	0.70-0.95
concrete	0.80-0.95
brick	0.70-0.85
Drives and walks	0.75-0.85
Roofs	0.75-0.95
Lawns; sandy soil, gradient ≤2%	0.05-0.10
sandy soil, gradient ≥7%	0.15–0.20
heavy soil, gradient ≤2%	0.13–0.17
heavy soil, gradient ≤7%	0.25–0.35

The values listed above can be used, together with areas of each type of surface measured from a map or aerial photograph, to compute weighted average values of C. The following overall values have been applied to most North American urban areas:

Business areas	: high-value districts	0.75-0.95
	neighbourhood districts	0.50-0.70
Residential areas	: single-family dwellings	0.30-0.50
	multiple-family dwellings, detached	0.40-0.60
	multiple-family dwellings, attached	0.60-0.75
	suburban	0.25-0.40
	apartment buildings	0.50-0.70
Industrial areas	: light	0.50-0.80
	heavy	0.60-0.90

Parks and cemeteries	0.10-0.25
Playgrounds	0.20-0.35
Unimproved land	0.10-0.30
Rural Areas	
Sandy and gravelly soils: cultivated	0.20
pasture	0.15
woodland	0.10
Loams and similar soils without impeding horizons: cultivated	0.40
pastured	0.35
woodland	0.30

Heavy clay soils or those with a shallow impeding horizon:

shallow soils over bedrock:

cultivated - 0.50, pasture - 0.45, woodland - 0.40.

The following runoff coefficients for different soils have been recommended by ISI for plain areas in India till precise data become available:

Loam, lightly cultivated or covered	0.40
Loam, largely cultivated and suburbs with gardens, lawns, macadamized	0.30
Sandy soils, light growth	0.20
Parks, lawns, meadows, gardens, cultivated area	0.05-0.20
Plateaus lightly covered	0.70
Clayey soils stiff and bare clayey soils lightly covered	0.55

As an independent check it is wise to assess the time of concentration from estimates of the velocities of overland flow and channel flow. If the overland flow transverses more than one kind of surface the travel times across them should be added up. Rantz (1971) (Vide Dunne and Leopold, 1978) has represented Fig. 3.4 for deriving overland travel time as a function of hillslope length and gradient and the C value for the catchment.

The channel velocities can be computed by using the Manning's Equation, but regardless of the computed value one should not accept values greater than 2.4m/sec for small artificial channels and 1.8 m per sec for natural channels of the kind likely to be encountered in planning problems.

Ramser (vide ILRI, 16(IV), 1974) has defined the time of concentration as the time required for the water in the channel at the gauging station to rise from the low to the maximum stage. The most accurate estimate of the time of concentration according to Ramser's definition can be from the direct water level recordings on the basin itself provided natural drainage conditions above the point of outlet remains unchanged.

3.3.6 Synthetic Unit Hydrograph Parameters

The Synthetic Unit Hydrograph Procedure begins with the derivation of a unit hydrograph for the basin of interest. This unit hydrograph is then used to estimate the runoff hydrograph according to the design rainfall.

Snyder proposed two basic equations to be used in defining the synthetic unit hydrograph. The first equation defines the lag time of the basin in terms of time to peak tp which, for the synthetic unit hydrograph procedure, is defined as the time from the centre of the unit storm duration to the peak of the unit hydrograph:

$$T_p = C_t (0.3861\ L\ L_{c\,a}\ )\ 0.3$$

where,

T_p = time to peak hydrograph from midpoint of unit rainfall in hour

L = length along stream from study point to upstream limits of the basin in km,

$L_{c\,a}$ = distance from study point along stream to the centroid of the basin in km,

ct = a coefficient reflecting time to peak.

The second equation defines the unit hydrograph peak

$$qp = 7.0\ Cp/Tp$$

where,

qp = peak rate of runoff in m^3 per sec per km^2

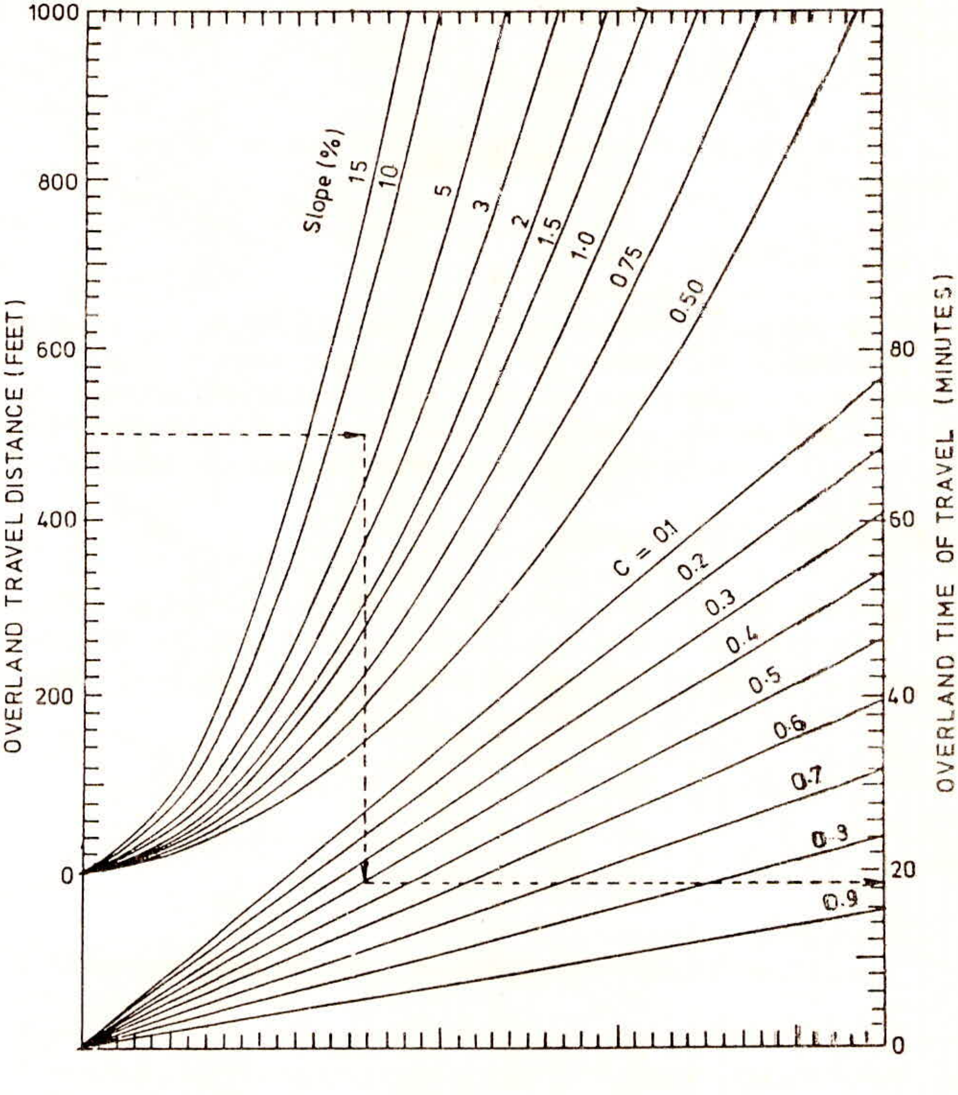

Figure 3.4 Relation of overland time of travel to overland travel distance, average overland slope and the rational runoff coefficient SUH Procedure

C_p = a coefficient related to peak rate of runoff.

Further a relationship is derived to define the recommended unit rainfall duration for the unit hydrograph as:

where,

T_c = time of concentration

The average relationship between the lag time tp and the time of concentration is:

$$T_p = 0.6\, t_c$$

Final determination of a synthetic unit hydrograph for a given watershed requires additional information about the two parameters Ct and Cp. Many hydrologists have analysed data of various types of catchment and have arrived at coefficients and variation of and additions to the basic unit hydrograph equation. Any of these relationships has potential application to the basin being studied.

3.3.6.1 Time Coefficient Ct

The expression for Tp given by the Tulsa District Army Corps of Engineers, U.S.A. for rural areas which has been derived based upon the data of natural watershed in the central and north eastern Oklahoma area is (Shaeffer et al, 1982):

$$T_p = 0.1842\,(L\,L_{c\,a}/\sqrt{S})^{0.39}$$

in which

S is watershed slope,
L and Lca are stream length and length along stream to centroid of basin in km.

For a mountain and foot hill regions the expression of tp is as follows:

Mountain region:

$$T_p = 0.1642\,(L\,L_{c\,a}/\sqrt{S})^{0.38}$$

where,

L and Lca are measured in km.

Foot hills:

$T_p = 0.0985 (L L_{ca} / \sqrt{S}) 0.38$

Relationship between Tp and L Lca/√S for synthetic unit hydrograph procedure for various types of catchments are shown in Fig. 3.5 from which an estimation of ct could be made.

For urbanised areas the expressions for tp as recommended by Tulsa District Army Corps, U.S.A. for different percentage of urbanisation are as follows:

For 50 and 100 percent urbanisation the respective expressions are:

$$T_p = 0.1193 (L L ca/ \sqrt{S})$$
$$T_p = 0.07653 (L Lca/\sqrt{S})$$

Snyder has given the following relationship between the time coefficient, ct, and the percent of watershed, Ia, which is impervious:

$$c_t = 7.81/(I_a)^{0.78}$$

The relationship between ct and Ia as given by Snyder is shown in Fig. 3.6 which also includes data of other experimental study. It is not advisable to use this curve for impervious areas les than 10 percent.

Surface runoff problem is left hanging here. Two of the four methods listed at 3.3.4 have not been discussed. No guidance as to how the given methods will be applied.

3.3.7 For all drainage design the disposal point is very important. If that is a river, lake or reservoir, a ruling outfall level on which the drain system hydraulics are to be worked out has to be determined as per procedure given in the IS code.

If such an outfall level does not permit natural, gravity flow, pumping needs to be envisaged if economically justifiable.

Pumping plant sizing is an important consideration and needs to be planned in such a way that plant operates for some time, year round and is likely to be operable when needed. As in the case of canal sizing a slight undersizing the capacity is more appropriate than over sizing.

3.4 Parameters for Subsurface Drainage

The design calculation for any water table problem requires knowledge of

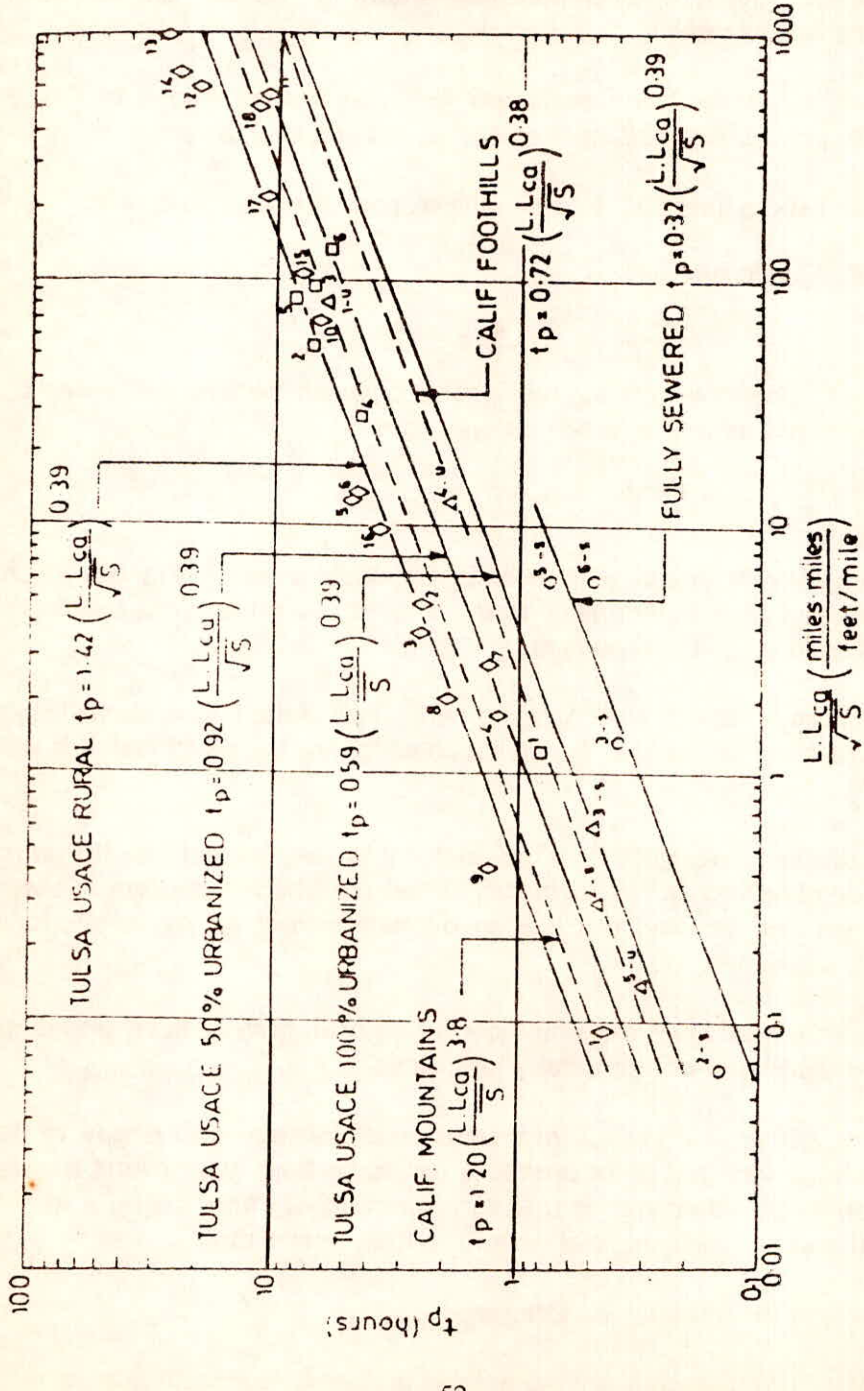

Figure 3.5 SUH Procedure

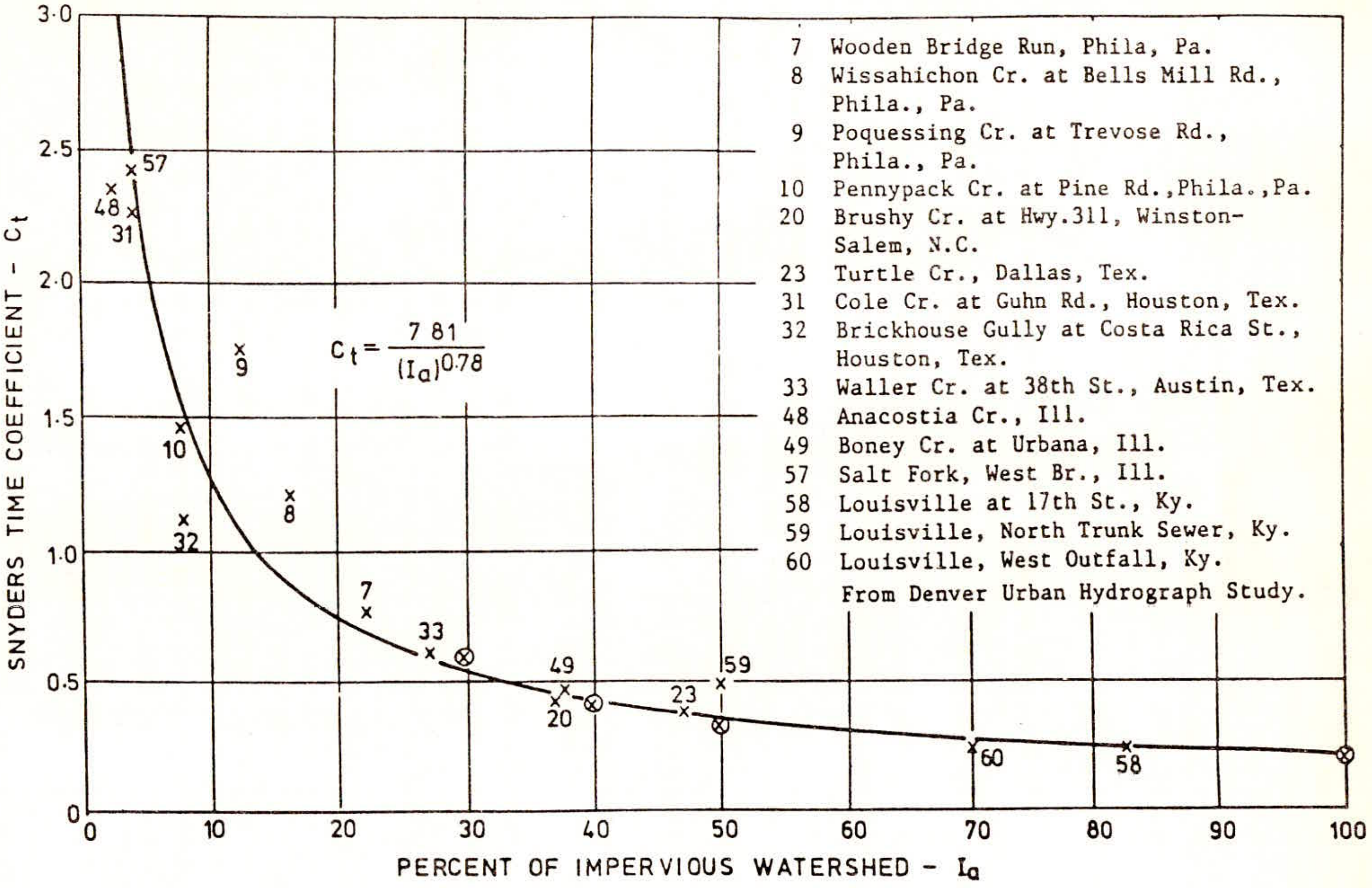

Figure 3.6 Relationship between C_t and Imperviousness

a) Soil permeability (if there is more than one layer, the permeability of each layer must be found),
b) The thickness of each layer of soil and the depth to impermeable layer,
c) The minimum depth at which the water table is to be controlled,
d) The design drainage coefficient which is the amount of water that must be removed in a given period (usually 1 day).

3.4.1 Soil Permeability

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

A number of tests for determining the insitu hydraulic conductivity below a water table have been developed. The two tests that have been found to be most adaptable in use are auger hole and piezometer test procedure (Drainage Manual, 1978). Both procedures measure the rate of change of water level in a hole or the difference of water level elevation with time. Hydraulic conductivity and transmissivity of aquifer comprising of gravel and gravelly materials are determined by pumping test. The well pumping method is an expensive test and is used mainly for determining the suitability of an area to be drained by pumping rather than by drains.

3.4.2 Depth to Impermeable Layer

The effect of depth to impermeable layer below drain on required spacing of drains has been studied by Galvin (1979). The results have been presented in Table 3.3 for value of drainage coefficient = 0.1 m/day, permeability = .9 m/day, and required maximum height of water level midway between drains = 0.5 m.

These results show that while the size of drain has very little effect, the depth of the impermeable layer below the drain depth has a major efect on the spacing. Infact the drain spacing can be doubled if the impermeable layer is 1 meter below the drain level and still further increased as the depth to the impermeable layer increase. Thus it is quite obvious that substantial savings can be achieved where one knows of the existence of a deep impermeable layer. The information about the existence of impermeable layer is a prerequisite for rational design.

TABLE 3.3: EFFECT OF DEPTH TO IMPERMEABLE LAYER ON DRAIN SPACING

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

3.4.3 Desirable Depth of the Water Table

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

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

The water table depths suggested by FAO (1980) for steady state and transient drainage design are given in Tables 3.4 and 3.5.

TABLE 3.4: SUGGESTED IRRIGATED SEASON WATER TABLE DEPTHS FOR DRAIN SPACING DESIGN USING STEADYSTATE FORMULA

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

TABLE 3.5 : SUGGESTED IRRIGATION SEASON WATER TABLE DEPTHS FOR DRAIN SPACING DESIGN USING TRANSIENT FORMULA

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

3.4.4 Drainage Coefficient

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

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

An empirical way of adjusting the design requirement to the natural drainage intensity of a field has been suggested (Table 3.6:) by Van Someren for Dutch condition (Vide Schifgaarde, 1974). The high water table conditions prior to artificial drainage is taken as the basis for adjusting the drainage coefficient.

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

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

where,

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

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

S_c = Seepage from canals,

S_i =Groundwater flow into the area including artesian inflow,

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

Table 3.6: EXAMPLE OF ADOPTION OF DRAINAGE COEFFICIENT TO NATURAL DRAINAGE CONDITION OF FIELD

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

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

3.4.5 Deep Percolation

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

In the planning stage of new project's or on the operating projects where the measured build up is not available, the amount of deep percolation must be estimated from each irrigation application. The build-up is computed by dividing the amount of deep percolation by the specific yield of the material in the zone where the water table is expected to fluctuate. Table 3.7 shows deep percolation as a percentage of the irrigation net input of water into the soil. These percentages are based on various soil textures and infiltration rates of the upper root zone soils. By knowing the infiltration rate, hydraulic conductivity of the soil in the root zone, the percolation rate can be known. Making use of the relationship between the hydraulic conductivity and specific yield given in Fig. 3.5, build up is calculated.

TABLE 3.7 : APPROXIMAT DEEP PERCOLATION FROM SURFACE IRRIGATION (PERCENT OF NET INPUT)

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

By infiltration rate

Inf.rate, in/h	Deep percolation percent	Inf. rate, in/h	Deep percolation percent
0.05	3	1.00	20
0 .10	5	1.25	22
0.20	8	1.50	24
0 .30	10	2.00	28
0.40	12	2.50	31
0.50	14	3.00	33
0.60	16	3.00	37
0.80	18	-	

3.4.6 Drainable Porosity

Representative drainable porosity values for use in transient state equations are difficult to be measured accurately. Whenever possible and practical, the drainable porosity should be determined from measurement of drain discharge and drawdown of existing drains or pilot drains. Where field drain tests can not be made the following procedure has been recommended (FAO, 198).

A limited number of representative undisturbed soil samples for laboratory determination of drainable porosity should be collected. The drainable porosity may be estimated from soil moisture release characteristics of each particular soil. The values determined should be correlated with soil structure and texture obtained from the soil profile. The value arrived at should be compared with empirical curves developed else where relating drainable porosity with such factors as hydraulic conductivity, soil texture and soil structure and provisional value of drainable porosity for the various soil types in the area should be established. The values of drainable porosity of soils having different structure and texture and presented in Table 3.8 which can be used where first approximation of drainable porosity is needed.

Table 3.8: *DRAINABLE POROSITY VALUES AS RELATED TO SOIL TEXTURE AND STRUCTURE

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

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

3.5 Tolerance Limit

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

3.5.1 Plant Tolerance to Waterlogging

Not much work in India has been done on the relative tolerance of crop plants to waterlogging. A list of tolerance to 0_2 deficit is given in Table 3.9. (Cannon 1925). This will be supplemented by data on tolerance to excess CO_2, tolerance to permanent high water table and tolerance to waterlogging (VanHoorn, 1958; Butijn, 1961; Dhawan 1958).

The tolerance of plants are grouped in three category:

i) High resistant plants:

Rice is the most typical crop in this group. Perennial grain can easily tolerate floodings of several days without much harm. Sugarcane comes close to the same tolerance. Potatoes, Beans can tolerate without much harm high water tables of 40-50 Cm under soil surface.

ii) Medium tolerant plants:

The cereals crops, cotton, citrus and sugar beets belong to this group. The cereals crops can tolerate high water table and flooding even during period of low temperature. With increasing temperature however yields are affected considerably with high ground water tables.

Table 3.9: Relative tolerance of plants under 0_2deficit, high ground water levels based on laboratory experiment and field tests.

	to 0_2 deficit (lab.expt.)	to excess CO_2(lab.)	to high ground water levels *(field tests)*	to waterlogging (practical experience)
Highly tolerant	rice willow sugar cane	citrus	sugar cane potato broad beans	plum strawberry several grasses
Medium tolerant	oats barley onion cotton citrus soya apple	apple tomato sunflower	sugar beet wheat barley oats peas cotton	citrus banana apple pear blackberry
Sensitive	maize peas beans tobacco	tobacco	maize	peach cherry respberry date palm olive

The limiting values for the different groups are about as follows:

	0_2 deficit	excess $C0_2$	groundwater depth of 0.50m
Highly tolerant	0_2 concentration 0-1%	$C0_2$ concentration > 20%	80-100%
Medium tolerant	0_2 concentration 2-5%	$C0_2$ concentration 10-20%	60-80%
Sensitive	0_2 concentration abt. 10% affects root growth	$C0_2$ concentration <10% of normal yield	<60%

iii) Sensitive plants:

Plants like peas and beans are particularly sensitive to 02 deficit. In practice this means that their tolerance to flooding is low, the same plants however are more tolerant to high groundwater levels. Maize and tobacco on the other hand are found to be sensitive both to flooding and to high groundwater levels.

Apart from selecting the suitable crops for an particular area the possibilities of preventing the harmful effects of waterlogging on crop yields are limited. The solution is to improve the existing drainage conditions. Land levelling may also contribute to the reduction of unfavourable effects. Where no improvements is possible in near future the following practices can be used under conditions of waterlogging.

i) The crops growing under excess water conditions can be helped by applying large amounts of nitrozen preferably in the form of nitrate.

ii) Tillage practice should be handled carefully. Under wet conditions tillage practices may leads to soil deterioration thus increasing the harmful effects on crop growth. Germination of seed for most of the plants is the most sensitive stage to oxygen deficit.

3.6 Land levelling and smoothing

Most of the agricultural & cultivated fields are in irregular shape having elevated and depressed areas. This results in pondage of irrigated or rain water (in depressions) and accelerates soil erosion, creates difficulties in field operation (in elevated area). Also it results in nonuniformity of crop yield & quality. Thus it is advisable to reform the land surface so as to provide continuous gentle slopes which regulates water flow. This is expensive therefore it must be well designed, carefully executed & well maintained.

The following three main types (land levelling, and smoothing & land grading of land forming are used. Land levelling is a precise operation of modifying the land surface to planned grades planning of the land surface without changing its general topography. The smoothing operation eliminates small difference in elevation including shallow depressions. Land smoothing on irregular topography improves surface drainage. It is the cheapest and yet one of the most productive surface drainage practices. The work can be done with an old type of wooden drag behind a farm tractor as well as with more sophisticated equipment like land levellers and land planes.

Land grading for drainage consists of shaping the land surface by cutting, filling and smoothing. The purpose of establishing continuous surface grades is to make sure that runoff water does not pond. It is a one time operation, carried out by bulldozer and scrapers and involving the transport of earth, according to specified cuts and fills based on the predetermined grades. Slopes cuts and fills are influenced by the soil, topography, climate, crops to be grown and methods of irrigation and drainage. The major problem in land grading is the effect of removing the top soil and its influence on plant growth. Reduced growth may occur on the fill area. Several methods of computing cuts and fills for land grading are available. Field data are normally obtained from an instrument survey with ground elevation taken to the nearest 1 cm on a 30 m square grid for horizontal control. Elevations are taken at other critical points such as highs and lows between grid stakes and the water surface at the supply ditch. After obtaining the desired balance between cuts and fills, the cut volume and fill volume are computed. With the introduction of laser technology for controlling the operation of land grading/smoothing equipment it is now possible to achieve high degree of precision.

There are several methods of computing cut and fills for obtaining the designed slopes.

i) Plane method
ii) Profile method
iii) Plane inspection method
iv) Contour adjustment method

i) Plane method:

One of the most efficient and widely used methods for land grading is the plane method. The average elevation of the field is determined and measured elevation is assigned to the centroid of the area. The centroid is located by taking moments about two perpendicular reference lines for an irregular shaped area. Using this method a plane is designed such that the sum of the squares of its deviations from the original surface would be minimum and the volumes of cut will be equal to fill The general equation for a plane surface is

$$E = a + S_xX + S_yY$$

where

E = elevation at any point
a = elevation at the origin
S_x&S_y = slope in the x and y directions respectively.

ii) Profile method:

In this method, the average profile of the plot in x and y direction and the average slopes in these directions are determined such that the sum of squares of deviations of the average slope line from the average profile will be minimum.

iii) Plan inspection method:

In this method, the grid point elevations are recorded on the plan and designed elevations are calculated, taking into account the topography, by careful inspection.

iv) Contour adjustment method:

A contour map of the area is drawn and the proposed ground surface is shown on the same map by drawing a new contour line. The contours should be properly spaced for obtaining the uniform slope. The proper balance between cuts and fills is estimated graphically at the grid points.