7.0 SPECIAL CONSIDERATIONS

7.1 Saline Soils

One of the major problems associated with irrigated agricultural land is accumulation of salt in the soil which results in low productivity if proper water management practices are not adopted. Many arid and semi arid zone soils are rich in soluble salts. It is estimated that about 8.2 mha of land have been affected by salinity in India. The primary sources of soluble salts in agricultural soils are (i) irrigation water (ii) salt deposits present in soil parent materials when the soils were brought into production (iii) agricultural drainage waters draining from upper-lying to lower lying lands, and (iv) shallow water tables. The secondary sources of salts include: (i) fertilizers and (ii) weathering soil minerals.

The concentration of soluble salts in soils increases as the applied water is removed by evaporation and transpiration. Evapotranspiration creates a suction force that may produce an upward flow of water and salt into the root zone from lower soil depth. The main factors responsible for creating salinity problems are (i) salt content of irrigation water (ii) the soil (iii) ground water (iv) water table depth (v) climatic conditions and (vi) water management practices.

In reclamation and subsequent management of saline soils, drainage of the land is of prime importance. If there is no hindorance to vertical water movement in the soil, either by a high ground-water table, a dense indurated pan in the subsoil, or low-water infiltration due to deflocculated or unusually high contents of expanding lattice type of clay, salts will have little chance to accumulate and reclamation will, in consequence be quick and permanent.

The drainage methods used successfully are open drains, tile drains and deep drainage by tubewells.

i) Open drainage method:

This is one of the successful methods used. The open and deep field drains have free outfall. The number and intensity of drains required for effective leaching in a high water -table area depended upon the soil and other factors. The disadvantage in this system is that it occupies a part of land which could have been used for crop production.

ii) Tile drainage:

In saline soils weed growth, however is seldom a serious limitation since such lands are generally barren. The tiles used in drains are actually hollow cylinders, 10-15 cm or more in diameter, 30-60 cm long and made of burnt clay or concrete or polythene. Water drains into the tiles through the open spaces or joints, which are protected by gravel filter to check infiltration of clayey sediments. The placement and spacing of the drains depend upon the soil and its permeability and are most effective in porous strata.

iii) Deep drainage by tubewells:

The tubewells working with a depression can create a lowering of the water-table to a depth, depending upon the infiltration source in the vicinity. It has been observed that the water levels in the vicinity of the augmentation tubewells during the peak pumping periods are lowered. Such waters are not highly saline and are usually fit for leaching more areas of saline soils in the upper reaches; or can be pumped into the canals or the rivers, whichever source of discharge is available. In this manner some of the saline water can even be diluted with freshwater for better utilization.

Thus the drainage problem will have to be diagnosed and essentially of surface or subsurface drainage or both, has to be decided according to the nature of soil, ground water conditions, climate, cropping pattern, etc.

7.2 Coastal Soils

Coastal Saline soils of India occupy an area of approximately 2.3 million hectares in the coastal belt of West Bengal, Orissa, Andhra Pradesh, Tamil Nadu, Kerala, Karanataka, Maharashtra, Gujarat, Goa and the Union territory of Pondicherry. These soils occur in the river deltas and in a narrow belt of 20-25 km. These areas suffer from serious problems of salinity and water logging resulting from the influence of high tides, impeded land drainage and highly saline groundwater.

Reclamation of the salt-affected soils can be carried out according to the local conditions by preventing the tidal water inundation through construction of bunds, leaching of soils from the soil profile and through application of suitable amendments in the case of the acid sulphate soils and sodic soils, and adoption of other suitable soil-water and crop management practices.

The general recognised methods of drainage are surface drainage, subsurface horizontal drainage and vertical drainage. The first one being based on induced surface flow, while the other two on induced ground water flow. Selection of appropriate drainage method depends on the source and amounts of excess water, soil and geohydrological conditions and also on the speed at which excess water is to be removed.

a) **Surface drainage:**

The excess water is coastal saline soils vary from a moderate amount to a very large amounts. Large drainage discharges cannot be attained economically by any system of drainage other than surface drainage.

The surface drainage is affected by one way sluice gates constructed in the protective embankments. The efficiency of sluice gates is improved by construction of peripheral bunds and channelization of the catchment. The catchment has to be channalized to directly route the excess rain water from different zones to the outlet.

b) **Sub-surface drainage:**

Surface drainage cannot meet the requirement of draining excess water in the humid and sub-humid tropic. However, sub-surface drainage can help in controlling salinity by facilitating leaching of salts. It can be done in the form of open drains or tile drains. However, following studies are required before adopting sub-surface drainage

i) Studies on salt and water dynamics to understand the process or salinization-acidification and leaching of excess salts and acids.

ii) The crop response for the improvement in soil salinity and acidity conditions.

iii) Hydrologic and hydraulic performance of various sub-surface drainage systems.

iv) Economic evaluation of such drainage measures.

c) **Leaching of saline soils:**

In the major parts of coastal saline soils, assured irrigation water is not available and the question of desalinisation of soils is to be tackled in slightly different way. As these tracts have generally high rainfall, the rainwater could be stored in the bunded fields to leach the salts from the profile. One seepage drains could serve as storm water drains during rainy season and as horizontal sub-surface drains during the rest of the period. If necessary and possible drainage wells could be installed for keeping the water table well below the critical depths. Thus desalinization of soils could be accomplished during rainy season and the resalinization processes during the rest of the period could be arrested.

d) **Control structure:**

The foremost task in any scheme of rehabitation of agricultural soils in the coastal regions is to construct embankments/barriers for sea water ingress through surface and sub-surface flow. The next step to manage rainwater to avoid congestion and to smooth out the non-availability of irrigation water during dry spells and/or during the rabi seasons.

By proper design of control structures alongwith disposal structure the salt water intrusion can be avoided.

7.3 Heavy Soils

Drainage of heavy soil is largely governed by the fact that the hydraulic conductivity of the subsoil is generally too low to allow percolation of excess rain water to lower depth. Due to these soil properties & under these situations water logging and accumulation of salts generally arises.

Heavy soils occupy that 72.9 mha areas in India. They are distributed in order of extent in the states of Maharashtra, Madhya Pradesh, Gujarat, Andhra Pradesh, Karnataka, Tamil Nadu, Rajasthan, Orissa, Bihar and Uttar Pradesh. Besides high potential productivity of these soils and favourable climatic conditions, the soil remains under utilised due to a number of problems. Most of the problems arises due to their generally low water intake rate and due to poor internal drainage. Heavy land requires proper drainage in the regions with high water table, low infiltrability and poor internal drainage, perched water table and salt affected areas.

There are several techniques available for drainage of heavy soils The solutions depends essentially on the ratio of rate of precipitation to the rate of downward flow through the soil system consisting of poorly pervious layer and the presence or absence of a high pervious subsoil. The techniques may be summarized as follows:

7.3.1 Closed gravity drains (Tile drainage):

This is a pipe system that are installed underground to collect and carry away excess ground water. They consist of pipes, porous material laid horizontally at a depth of 1 to 3 meter. Tile drainage is the most common and effective in heavy soils particularly if a highly pervious layer occurs within a depth that can be reached by drainage machinery, and if the rate of precipitation does not exceed the rate of downward flow through the overlying poorly pervious clay layer. Presence of such layers below the soil surface, say one meter below and adopting tile drainage can lower the ground water table, create more storage in the soil profile and in long run will improve the hydraulic conductivity of the soil thus leading to the better conditions for crop growth.

7.3.2 Mole drainage:

This method can be applied when no highly pervious layer is present within a depth that can be reached by machinery. Mole drainage are unlined underground channels, formed by a mole plough without digging the trench. It is particularly appropriate in dense, poorly pervious clay soils which have a certain general slope. The primary aim of this is to remove excess water from the field surface from topsoil. The water reaches the mole channel mainly through the fissures and cracks that are formed when the moles are being drawn.

7.3.3 Surface drainage:

If irrigation is practised, furrow and ditches can be used to remove excess surface water. Though this method has certain disadvantages as farming becomes more mechanised, it creates problem in doing various agricultural operations in the field. In spite of all this, furrow drainage is a low cost method still has its uses.

7.3.4 Well drainage:

Drainage wells are groundwater wells designed to control an existing high water table. Drainage occurs only within the influence of the cone of depression. Most drainage well installation consist of a group of wells so spaced that their individual cones of depression overlap sufficiently to lower the water table at all points in the well field (Fig. 7.1).

7.3.5 The cultivation techniques which are currently used in various drainage projects in India under heavy soils are summarised below:

7.3.5.1 Raised bed-Sunken bed system:

This system consists of an array of raised and sunken beds running parallel to each other. The runoff from raised beds planted to an upland crop drains into and collected in Sunken beds supporting the crop. The elevation difference between sunken and raised bed is kept 20-30 cm. In high rainfall areas (1500 mm), 3m wide beds with 20cm elevation difference or 6m wide beds with 30-35cm elevation difference have been found to yield good results (Gupta et.al., 1978). However, the specifications can be modified according to the soil depth and rainfall pattern of the region. About 33 percent higher grain yield can be obtained on raised beds than on conventionally prepared flat beds, as shown in Fig. 7.2. The field should be ploughed along with general slope and should be shaped into 20cm high and 20cm long upland strips of about 6m width. The beds

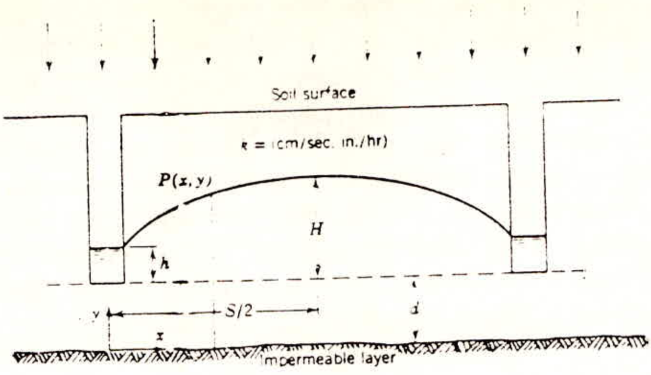

FIG.7·1 WELL DRAINAGE SPACING OF WELLS

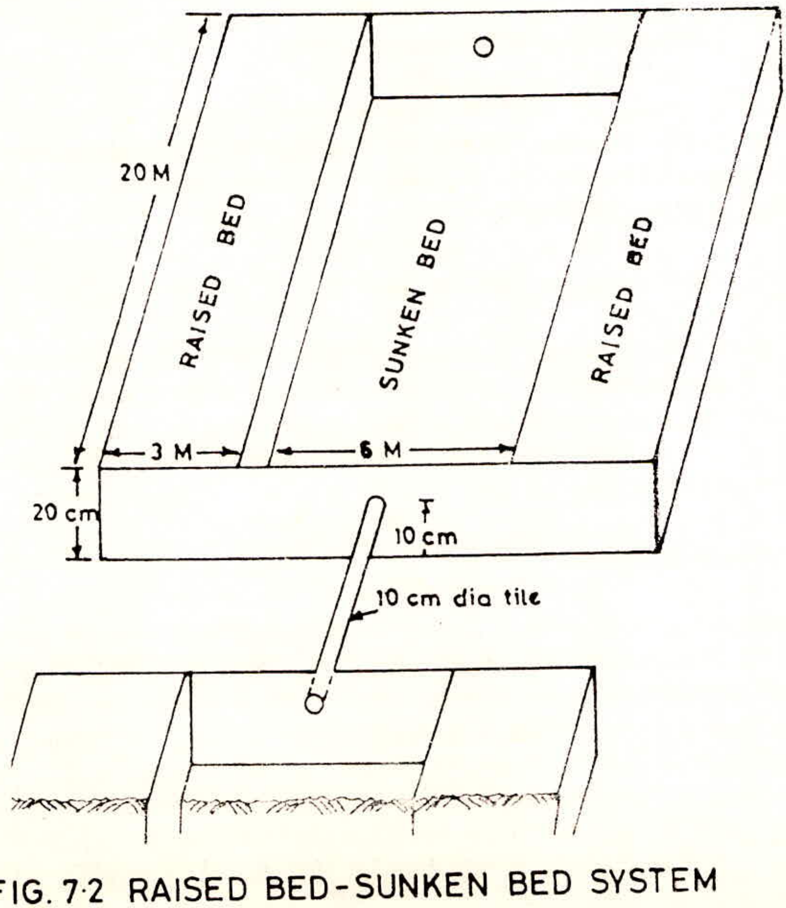

FIG. 7·2 RAISED BED-SUNKEN BED SYSTEM

should be constructed along the general slope. This is done by shifting 10-15 cm surface soil from 6m wide stripes referred to as sunken bed to make raised beds on either side. Each sunken bed serves as a mini water reservoir with two sides formed by raised beds running parallel to each other. Sunken beds are interconnected through 10cm wide tiles placed such that the level of water in sunken beds is always at least 10cm below the surface of raised beds and the excess water can drain into a cross drain provided at the tail end of the field. The land configuration once created is more or less permanent and can be cultivated with bullock drawn implements. The preparation of this type of drainage system involves earth work, costing Rs. 6000/ha approximately.

7.3.5.2 Ridge furrow system:

Furrows provide an effective means of surface drainage and convey excess water into cutoff drains, dug across the slope at about 20m interval. The specifications depend on the spacing of the cropped rows and rainfall. Ridges ave been observed to provide adequate soil aeration during the wet period even under relatively high rainfall (1500 mm) conditions. The orientation of the ridges with reference to the direction of the slopes can be changed depending on rainfall and erodibility of the soil.

7.3.5.3 Broad bed and furrow system:

In this system, 90-150 cm wide beds are created across the contour to a 0.6 percent slope and are separated by furrows that drain into grassed waterways. These beds are stable for 2 to 4 years and permits collection of runoff water in a tank provided down the slope.

7.3.5.4 Parallel open ditch system:

It consist of a series of parallel ditches along with the slope at specified spacing. These ditches take care of excess runoff water and carry it to a collector drain and finally to the outlet. This system is adopted to poorly drained, relatively flat soil in which there are numerous shallow depressions. The size of the ditch varies with drainage area.

7.3.6 Vertical drainage:

Vertical drainage or well drainage is comparatively a recent development as compared to the traditional methods of gravity drainage. The number of projects where well drainage is being used is very limited. Earliest examples are found in California where some projects based on vertical drainage were taken up as early as 1918 (Peterson, 1957) In the Ararat plain in USSR some 2000 hectares were drained by using 25 wells intensive network of shallow multiple systems called by skimming wells have been installed for water table and salinity control. The design and operation criteria for such system have been evolved by Sahar.. (1972, 73). Chandia and Larock (1984). In a drainage research project in Mundlana village of district Sonepat of 5 cavity tubewells of 10 cm diameter installed at 150 meter in spacing in the form of Pantagon with depth varying trom 10 to 20m (Mishra et al., 1986).

The success of vertical drainage system largely depends on the availability of sufficient gradient and clear outfall in the junction of carrier drains and the main drains. If such condition is not existing, the only effective way to lower water table is to pump the water cut.

An extensive review of various drainage schemes in the Maharashtra State has been given in a recent report of Abhange (1986). Some of the worst affected projects are given in Table 7.1.

Table 7.1 Extent of Drainage Problems in Selected Irrigation Projects in Maharashtra State

S.No.	Name of Canal	Irrigated Command Area (ha)	Percentage damaged area (1984-85)
1.	Nira left Bank Canal	60632	6.52
2.	Nira Right Bank Canal	77308	7.44
3.	Krishna Canal	10706	32.35
4.	New Mutha Right Bank Canal	61556	6.37
5.	Ghode Left Bank Canal	24602	11.36
6.	Gode Right Bank Canal	11019	9.80

The data on 34 completed drainage scheme in deep Black Cotton Soils (Abhange, 1986) shows that most of the drains are of open ditch type. The cost of open drains worked out to be Rs. 242,000 per km. In some drainage schemes closed drains are also have been installed and the cost estimated to be Rs. 201,000 per km.

In areas with deep Black Cotton Soils underlain by murum artesian pressures may often to be present. In such soils pumping groundwater from the Murum and other permeable sub-strata may lower the peizometric surface below the water table creating a vertical downward flow from the upper layers. In areas where the water table is quite shallow, lowering of the water table to deeper layers with the help of vertical drainage will help in getting additional induced recharge to groundwater in rainy season.

One of the major limitations of vertical drainage is the additional cost of energy required for operating a multiple well system. Vertical drainage system is also more expensive to construct as compared to pipe drainage system. However, the cost of well drainage can be reduced by constructing radial horizontal pores in deeper and more permeable layers through the vertical wells.

Well drainage offers the following advantages:

i) It can be applied on undulating land, limiting earthmoving and levelling to the installation of pipelines or main drain channels to interconnect the wells.

ii) It diminishes maintenance costs because of the smaller network of canals/drains that are necessary.

iii) The groundwater table can be drawn down to a much greater depth, reducing the risk of salinization of the soils in arid and semi-arid regions.

iv) It diminishes artesian pressure of aquifers underlying the top layers so that downward percolation of irrigation water becomes possible.

v) If the water in the pumped aquifer is of good quality it can be used for irrigation. The drainage water then has an economic value and this fact may contribute considerably to the economic feasibility of the project.

7.3.7 Pipe drainage system:

In this system a series of parallel drains are laid out in the direction of the slope of the land and that feed into the direction of the contour. The key parameter to be selected are the depth and the lateral spacing of the drain. The maximum depth of the drains may be limited by the trenching and pipe laying equipment available. Once the depth of the drains has been selected it is necessary to select the depth of the peak of the curved water table surface midway between the drains. This is usually made equal to the depth of the root zone of the deepest plants in the crop rotation.

A buried rubble drain was constructed near Talgaon in Purna command area of Maharashtra. It was laid at a depth of about 2m below ground, the following procedure were adopted for constructing the buried pipe drains:

i) a contour map of the affected area with a contour interval of 1m was prepared.

ii) number of piezometers were installed at selected location to ascertain the ground water profile.

iii) the alignment of the drain is decided with the depth of murum level and also the outfall level of the drain which would be 0.5 metre above the nalla bed.

iv) after alignment has been decided, a trench was excavated upto 2m depth; where murum was encountered. The main drain is PVC perforated pipe with 5 percent perforated area and covered by 10cm metal. The pipe trench had a gradient of 1 in 500. The trench then backfilled with the excavated stuff.

v) manholes are provided at suitable locations.

vi) the outfall of the buried pipe drain was taken into the nearby Katneshwar distributory.

The above drainage work was completed in May 1986. In the low lying areas of purna command, an experimental scheme was taken for design of buried pipe system. A contour map of the water logged area is prepared with a contour interval of 0.3 meter. Groundwater profile was prepared with the help piezometers. The soil samples were collected, with the help of Auger holes at 100m interval to study the soil profile. The alignment of the drain was decided depending on the groundwater profile. A 2m trench was excavated and the construction of the drain was similar to the Katneshwar drain.

The main advantage of buried pipe drainage system is that it does not involve loss of curtivable land. In the case of an open drain particularly in deep soils a large chunk of area is lost for cultivation and therefore the land owners are reluctant to make the land available for the drainage scheme. Also the maintenance cost of pipe drainage system is much less as compared to the conventional open trench drain.

The cost of drainage scheme can also be described in the form of cost per ha of land protected or cost per ha of land reclaimed. Table 7.2 gives the comparison of the cost of buried pipe drain with the cost of a conventional open type drain and the cost of a closed rubble drain in the state of Maharashtra.

TABLE 7.2 COST OF VARIOUS DRAINAGE SYSTEM IN TERM OF COST PER HECTARE OF LAND RECLAIMED

S.No.	Type of Drain	Cost per ha. of land reclaimed (Rs.)
1.	Conventional open trench drain	2400
2.	Buried rubble drain	3100
3.	Buried pipe drain	1100

7.4 Leaching of Salts

Efficient use of land and water resources is to a greater extent depends on the control of salinization problem. It is a well known phenomenon that when an area is irrigated excessively over an extended period of time, the ground water level rises. This causes soil salinity and sometimes alkalinity which are harmful to plant growth. When a saline water table rises and remains in the root zone longer than 48 hours resulting in an abnormally high saline moisture condition, agriucltural production is usually seriously affected . Therefore, control of salinity is essential for agricultural production.

To prevent harmful accumulation of salts in soils, an additional amount of water, over and above that required to meet crop evapotranspiration needs, must be passed through the root zone while irrigating. This additional amount of water added to the soil to keep a favourable salt balance is termed as Leaching Requirement (L.). It is defined as fraction of the applied water (irrigation + rainfall) leached below the root zone to prevent any loss in crop productivity from an excess accumulation of soluble salts. The concept is most useful when applied to steady state water flow rates or to total depth of water used for irrigation and leaching over a long period of time. Any non-uniformity in water application, in addition, to the Lr must be considered in the design and management of irrigation drainage system to meet the drainage requirement.

An estimation of leaching requirement has been made from a salt balance model approach. The model has been applied to a soil profile, divided into different layers, having some initial salt concentration and soil moisture. When irrigation water having low salt concentration, is applied for leaching, the solute movement from first layer to second layer, second layer to third layer, likewise, have been determined. In the present study, Green and Ampt infiltration equation has been used for estimation of volume of water infiltrated from different layers. The time required to fill the 1st layer, 2nd layer, 3rd layer and 4th layer have been estimated from the initation of the infiltration. The salt concentration at each layers, before and after it is filled with water have been determined.

7.4.1 Problem Definition

Let the top soil of thickness 'D' be divided into number of n layers of thickness D/n. Each layer can be assumed to act as a reservoir. Let and Co represent the initial soil moisture and initial solute concentration in each reservoir. When irrigation water, containing a salt less than that of the soil solution is passed through the soil, the concentration of salts in each reservoir changes gradually depending on the volume of water infiltrated from the beginning of the infiltration. It is aimed to estimate the variation of salt concentration with respect to depth and time due to application of irrigation water of depth 'H' at top of the 1st reservoir and to determine the leaching requirement of given soil, (Fig. 7.3).

7.4.2 Green and Ampt Infiltration Equation

The Green and Ampt infiltration equation has been used for estimation of infiltration rate. The equation is based on the assumption of a sharp wetting front, a constant hydraulic conductivity in the wetted zone and a constant negative water pressure at the wetting front.

Assuming

θ_1	=	initial soil moisture content,
θ_S	=	soil moisture at saturation,
H_f	=	capillary pressure head at the wetting front, m
H	=	depth of water applied at the top surface in the beginning, m
Z_f	=	distance from the surface to wetting front, m and
K	=	hydraulic conductivity in the wetted zone, m/hour

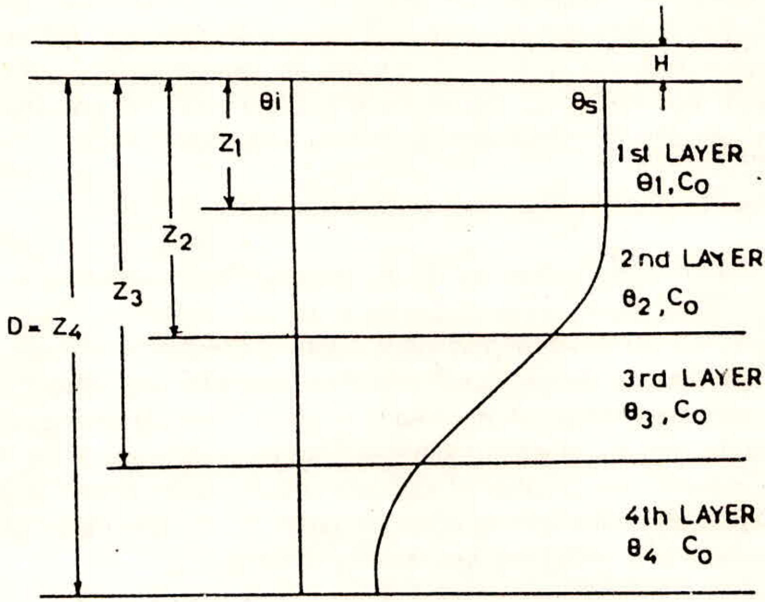

Fig. 7.3: Variation of soil moisture with respect to depth for a typical soil

The rate of infiltration I at time t can be expressed as

$$I = (\theta_S - \theta_i) \frac{dz_f}{dt} \qquad (7.1)$$

Applying Darcy law to the wetted zone, the Green and Ampt equation can be written as

$$\frac{K.(H_f+Z_f+H- \int^{t} I(\tau)\, d\tau)}{Z_f} = (\theta_S - \theta_i)\frac{dZ_f}{dt} \qquad (7.2)$$

upto any time t, $\int_{o}^{t} I(\tau)\, d\tau = w$, Hence

$$\frac{K.(H_f + Z_f + H-w)}{Z_f} = (\theta_S-\theta_i)\frac{dZ_f}{dt} \qquad (7.3)$$

Multiplying and dividing left hand term by $(\theta_S - \theta_i)$

Integrating

$$K (1-\theta_S+\theta_i)t = w - \frac{(H_f+H)(\theta_S-\theta_i)}{(1-\theta_S - \theta_i)} \log [(H_f+H)(\theta_S-\theta_i)+w] + C \qquad (7.4)$$

when t=o, w=o,

Therefore,

$$C = \frac{(H_f+H)(\theta_S-\theta_i)}{(1-\theta_S-\theta_i)} \log (H_f+H)(\theta_S - \theta_i) \qquad (7.5)$$

Substituting value of C in equation (7.4).

$$K(1-\theta_s-\theta_i)t = w - \frac{(H_f+H)(\theta_s-\theta_i)}{(1-\theta_s+\theta_i)} \log \frac{(H_f+H)(\theta_s-\theta_i)+(1-\theta_s-\theta_i)}{(H_f+H)(\theta_s-\theta_i)} \qquad (7.6)$$

From equation (7.6), infiltration rate w can be estimated for any time t for known value of θ_i, H, K, H_f and θ_s.

In situation when again another depth of water H is applied to top surface for further leaching, then the infiltration rate w_1 at time t can be expressed by:

$$\frac{K(H_f+H)(\theta_s-\theta_i)+Z_f(\theta_s-\theta_i)-w_1(\theta_s-\theta_i)}{w_o+w_1} = \frac{dw_1}{dt} \qquad (7.7)$$

$$\frac{K(H_f+H)(\theta_s-\theta_i)+w_o+w_1(\theta_s-\theta_i)}{w_o+w_1} = \frac{dw_1}{dt} \qquad (7.8)$$

$$Kdt = \frac{(w_o+w_1)\,dw_1}{(H_f+H)(\theta_s-\theta_i)+w_o+w_1(1-\theta_s+\theta_i)} \qquad (7.9)$$

Integrating and applying the condition that at $t=t_o$, $w_1=o$

$$K(1-\theta_s+\theta_i)(t-t_o) = w_o \log \frac{(H_f+H)(\theta_s-\theta_i)+w_o+w_1(1-\theta_s+\theta_i)}{(H_f+H)(\theta_s-\theta_i)+w_o}$$

$$+w_1 - \frac{w_o+H_f(\theta_s-\theta_i)}{(1-\theta_s-\theta_i)} \log \frac{(H_f+H)(\theta_s-\theta_i)+w_o+w_1(1-\theta_s-\theta_i)}{(H_f+H)(\theta_s-\theta_i)+w_o} \qquad (7.10)$$

7.4.3 *Solute Movement in Different Layers: Salt Balance Approach*

The irrigation water of concentration C_i applied to the first reservoir, infiltrates to the second, from second to third reservoir and likewise. Due to infiltration, the salt concentration in each reservoir decreases with time. The salt balance approach has been used for estimation of salt concentration in each reservoir when it is partially filled with infiltrated water and when it is fully filled.

7.4.3.1 Salt balance of top reservoir when saturation front has not crossed the reservoir.

For some time after onset of infiltration, the top reservoir receives water only. Since the saturation front has not crossed the depth Z_1, therefore no solute has left the reservoir. Under such situation, the salt concentration at any time t till the reservoir is filled is given by

$$C_{(t)} = \frac{\text{Quantity of salt added + Quantity of salt present}}{\text{Total volume of solute at time t}}$$

$$= \frac{C_i \int_0^t I(\tau)\, d\tau + C_o.Z_1.\theta_i}{\int_0^t I(\tau) d\tau + Z_1.\theta_i}$$

$$= \frac{C_i.w + C_o Z_1 \theta_i}{w + Z_1 \theta_i} \qquad (7.11)$$

where,

$C_{(t)}$ = concentration of solute after t,
t = time reckoned from the onset of infiltration,
C_i = salt concentration of irrigation water,
C_o = initial concentration of the solute,
Z = depth of reservoir from top surface,
w = volume of water infiltrated at time t,
$\int_0^t I(\tau)\, d\tau$

7.4.3.2 **Salt balance of top reservoir when saturation front has crossed the reservoir**

When saturation front has crossed the reservoir, the salt balance is given by

salt in - salt out = change in mass of salt over a period Δt

or $$C_i.I(t)dt = C.I(t)dt + dC.Z_1.\theta_s \tag{7.12}$$

$$C_i\, I(t) = C.I(t) + \frac{dC}{dt}.Z_1\theta_s$$

or $$\frac{dC}{dt} + \frac{I(t)\,C}{Z_1\theta_s} = \frac{C_i\, I(t)}{Z_1\theta_s} \tag{7.13}$$

Change in salt concentration after t+ Δt time will be

$$\frac{C_1(t+\Delta t)-C_1(t)}{\Delta t} + \frac{I}{Z_1\theta_s}\, C_1(t+\Delta t) = \frac{C_i\, I}{Z_1\theta_s} \tag{7.14}$$

$$C_1(t+\nabla t) + \frac{I C_1 (t+\nabla t)\ \nabla t}{Z_1.\theta_s} = \frac{C_1(t)+C_i.\,I.\,\nabla t}{Z_1.\theta_s}$$

or $$C_1(t+\nabla t) = \frac{1}{1+\frac{I.\ \nabla t}{Z_1.\theta_s}}\left[C_1(t) + \frac{C_i.\,I\,\nabla t}{Z_1.\theta_s}\right] \tag{7.15}$$

The time required to fill the top reservoir can be determined by equation (7.6) by substituting for $w = Z_1(\theta_s-\theta_i)$. Similarly the time required to fill the nth reservoir can be determined by replacing w by $Z_n(\theta_s\ \theta_i)$ and variation of salt concentration in different reservoirs have to be solved in succession starting from the top reservoir.

7.4.3.3 Salt balance of second reservoir when it is not filled with water

The equation for salt balance of second reservoir when it is not filled with water is given by:

$$C_2(t+\nabla t) = \frac{C_1(t+\nabla t) \cdot I \nabla t + C_2(t) \cdot [(Z_2-Z_1) \cdot \theta_i + w(t)]}{(Z_2-Z_1) \cdot \theta_i + w(t) + I \cdot \nabla t} \qquad (7.16)$$

7.4.3.4 Salt balance of second reservoir when it is filled

When second reservoir is filled with water, the equation for salt balance is:

$$C_2(t+\nabla t) = \frac{1}{1 + \dfrac{I \cdot \nabla t}{(Z_2-Z_1) \cdot \theta_s}} \left[\frac{C_2(t) + C_1(t+\nabla t)\, I \cdot \nabla t}{(Z_2-Z_1) \cdot \theta_s} \right] \qquad (7.17)$$

7.5 Example Results

The soil data required for estimation of infiltration rate have been obtained from the experimental results of Sonu (1973). The variation of capillary pressure (h_c) with the volumetric soil moisture content (θ) and relation of capillary pressure with relative permeability $k_{rw}(\theta)$ for Touchet Silt loam soil are shown in Fig. 7.4 and 7.5 respectively. The soil system is divided into 4 layers of thickness 50 cm each as shown in Fig. 7.3. The following steps were used for estimation of salt concentration in each layer with respect to depth and time.

1. The initial soil moisture content and concentration of solute in each layer were assumed to be constant. The initial moisture content, θ_i is assumed to be 0.290 for this study.

2. The capillary pressure head (H_f), as suggested by Bouwer was found using the following relationship

$$H_f = \int_0^{h_{ci}} k_{rw}(\theta)\, dh_c \qquad (7.18)$$

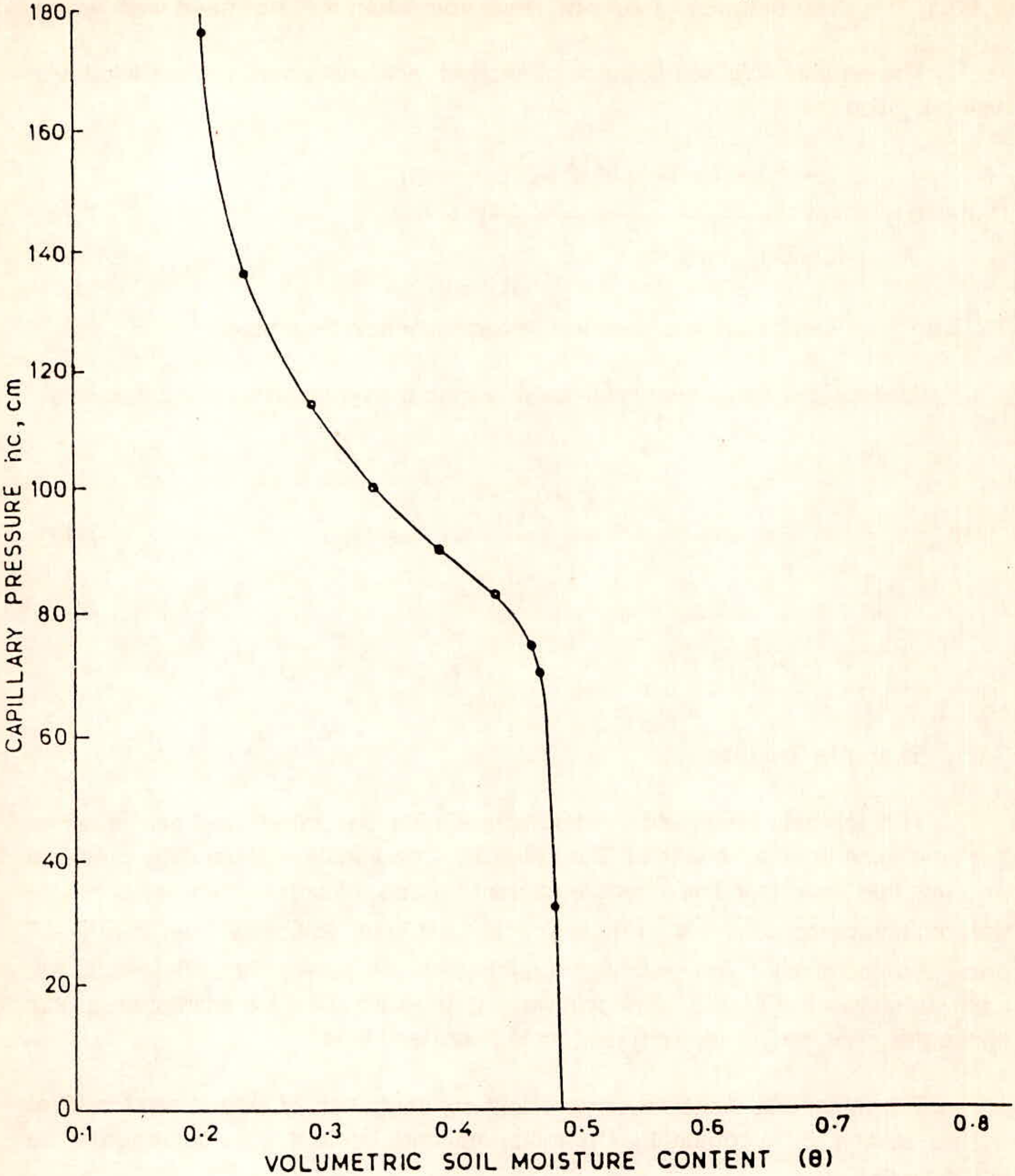

Figure 7.4 Variation of capillary pressure (hc) with volumetric soil moisture content (θ) for touchet silt loam

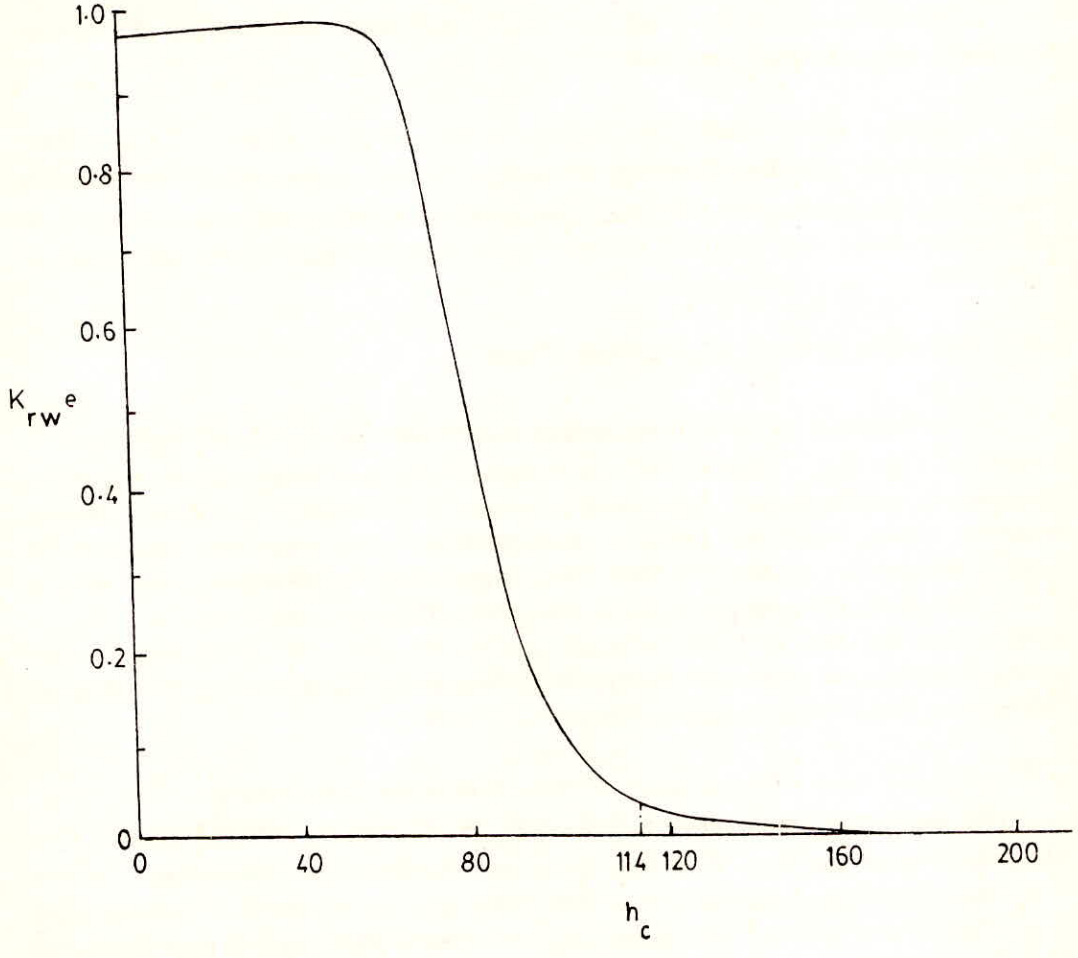

Fig 7.5 Variation of $K_{rw}(e)$ with h_c for toucnet silt loan.

where h_{ci} is the capillary pressure head corresponding to initial soil moisture θ_ι. For θ_i = 0.290, hci is 114 cm. The H_f value was found to be 0.763 m.

3. The values of K and θ_s for Touchet silt loam were taken as 0.0288 m/hour and 0.485 respectively (Sonu, 1973).

4. Irrigation water of depth 'H' (50 cm) having salt concentration (C_i) less than that of solute (C_o) is passed through the soil. The time required to fill the different reservoirs, volume of water infiltrated to reservoir at different times and variation of salt concentration with respect to time have been estimated and presented in Table 7.3.

7.5.1 Variation of $(C-C_i)/(C_o-C_i)$ with Time

The variation of non-dimensional concentration $(C-C_i)/(C_o-C_i)$ with time is shown in Fig. 7.6. When the first reservoir is completely filled, the non-dimensional concentration value is obtained as 0.60 (Table 7.3). When second reservoir is fully filled, the value of concentration in first reservoir decreases to 0.405. When third reservoir is filled, the concentration value further decreases to 0.273. When fourth reservoir is filled, the concentration value is found to be 0.185 and the ime required to fill all the voids upto fourth reservoir is 8.19 hours. The concentration in the first reservoir further decreases to 0.154, and at this stage all the water applied to top surface have been infiltrated.

Fig. 7.7 shows the variation of non-dimensional concentration $(C-C_i)/(C_o-C_i)$ with respect to depth at time = 2, 4, 6 , 8, 12, 14, 18 and 20 hours. It is observed that at the end of 12 hours, the non-dimensional concentration in the first reservoir reduces from 1.0 to 0.155, in the second reservoir it reduces from 1.0 to 0.655 and in the fourth reservoir, non-dimensional concentration reduces from 1.0 to 0.850.

It is observed that at the end of 12-14 hours, the depth of water on the surface is zero.

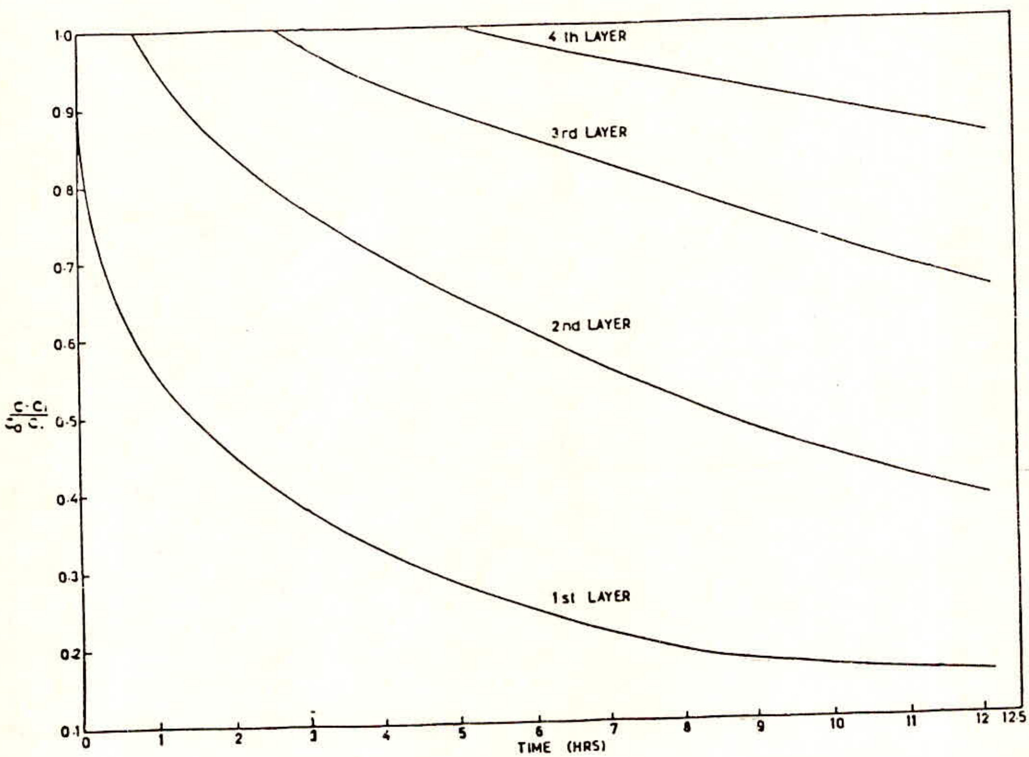

Figure 7.6 Variation of non-dimensional salt concentration with time for different reservoirs (layers)

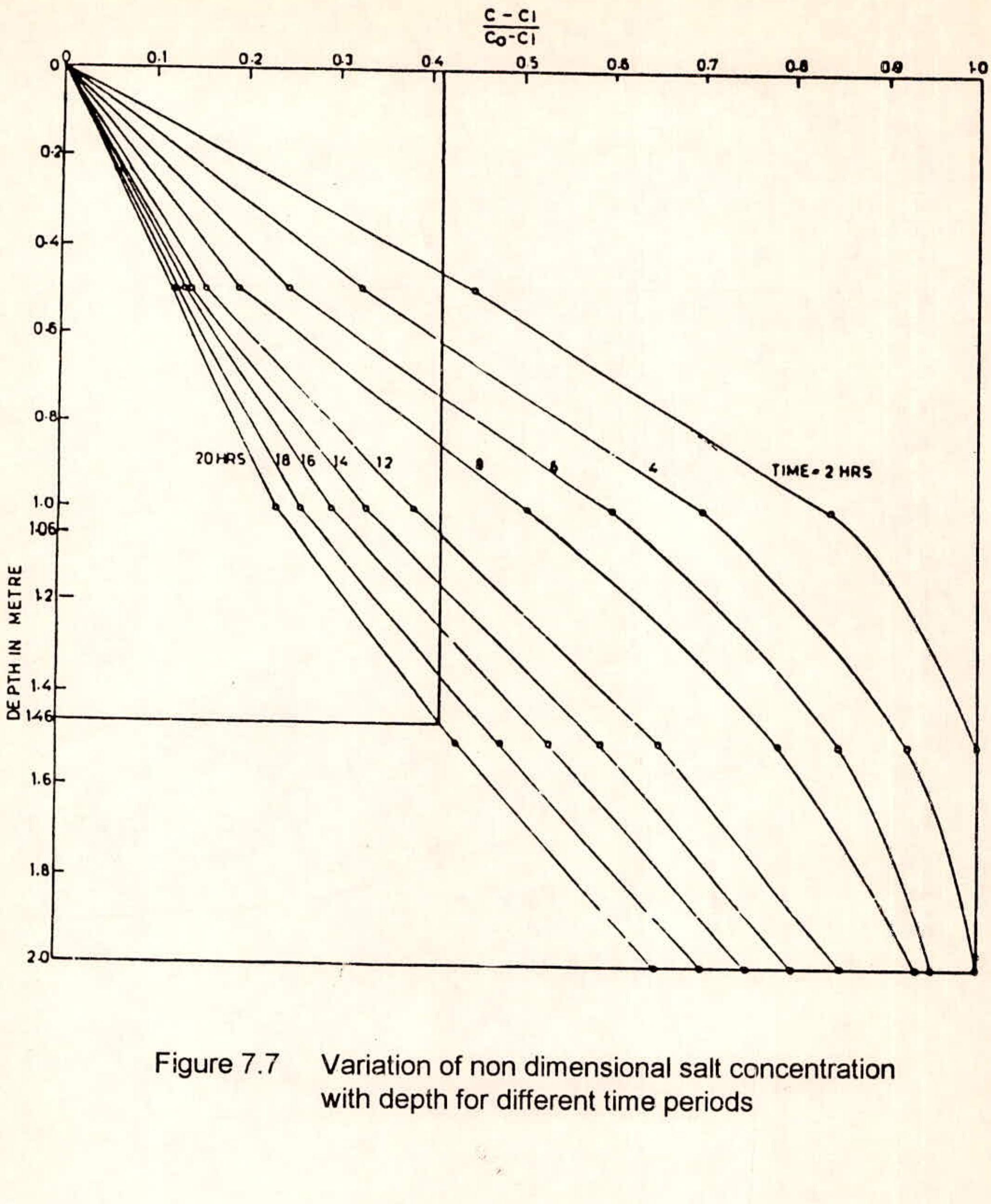

Figure 7.7 Variation of non dimensional salt concentration with depth for different time periods

Table 7.3: Variation of non dimensional salt concentration ($C-C_i/C_o-C_i$) in different reservoirs and volume of water infiltrated with time

1st RESERVOIR	2nd RESERVOIR	3rd RESERVOIR	4th RESERVOIR	INFILTRATION (m/hour)	TIME (hour)
0.93750	1.00000	1.00000	1.00000	0.00970	0.00900
0.88235	1.00000	1.00000	1.00000	0.01940	0.03529
0.83333	1.00000	1.00000	1.00000	0.02910	0.07783
0.78947	1.00000	1.00000	1.00000	0.03880	0.13570
0.75000	1.00000	1.00000	1.00000	0.04850	0.20803
0.71429	1.00000	1.00000	1.00000	0.05820	0.29405
0.68182	1.00000	1.00000	1.00000	0.06790	0.39303
0.65217	1.00000	1.00000	1.00000	0.07760	0.50431
0.62500	1.00000	1.00000	1.00000	0.08730	0.62725
0.60000	1.00000	1.00000	1.00000	0.09700	0.76131
0.57692	0.97356	1.00000	1.00000	0.10670	0.90593
0.55473	0.94892	1.00000	1.00000	0.11640	1.06063
0.53340	0.92584	1.00000	1.00000	0.12610	1.22496
0.51288	0.90410	1.00000	1.00000	0.13580	1.39487
0.49316	0.88355	1.00000	1.00000	0.14550	1.58077
0.47419	0.86406	1.00000	1.00000	0.15520	1.77149
0.45595	0.84551	1.00000	1.00000	0.16490	1.97027
0.43841	0.82781	1.00000	1.00000	0.17460	2.17678
0.42155	0.81088	1.00000	1.00000	0.18430	2.39071
0.40534	0.79466	1.00000	1.00000	0.19400	2.61177
0.38975	0.77909	0.98619	1.00000	0.20370	2.83969
0.37476	0.76354	0.97310	1.00000	0.21340	3.07420
0.36034	0.74803	0.96059	1.00000	0.22310	3.31506
0.34649	0.73259	0.94859	1.00000	0.23280	3.56204
0.33316	0.71722	0.93702	1.00000	0.24250	3.81492
0.32035	0.70196	0.92583	1.00000	0.25220	4.07349
0.30802	0.68681	0.91496	1.00000	0.26190	4.33755
0.29618	0.67178	0.90439	1.00000	0.27160	4.60693
0.28479	0.65690	0.89408	1.00000	0.28130	4.88143
0.27383	0.64217	0.88400	1.00000	0.29100	5.16090

0.26330	0.62759	0.87414	0.99213	0.30070	5.44517
0.25317	0.61319	0.86410	0.98460	0.31040	5.73408
0.24344	0.59897	0.85391	0.97734	0.32010	6.02750
0.23407	0.58494	0.84356	0.97030	0.32980	6.32528
0.22507	0.57110	0.83308	0.96344	0.33950	6.62730
0.21641	0.55745	0.82248	0.95673	0.34920	6.93342
0.20809	0.54402	0.81177	0.95014	0.35890	7.24352
0.20009	0.53079	0.80096	0.94365	0.36860	7.55749
0.19239	0.51777	0.79007	0.93725	0.37830	7.87522
0.18499	0.50497	0.77911	0.93093	0.38800	8.19660
0.18124	0.49069	0.76637	0.92366	0.39920	8.57209
0.17765	0.47686	0.75359	0.91616	0.41040	8.95216
0.17422	0.46350	0.74079	0.90341	0.42160	9.33667
0.17095	0.45059	0.72798	0.90045	0.43280	9.72549
0.16782	0.43810	0.71518	0.89227	0.44400	10.11848
0.16482	0.42604	0.70241	0.88389	0.45520	10.51552
0.16196	0.41438	0.68970	0.87531	0.46640	10.91649
0.15923	0.40312	0.67705	0.86656	0.47760	11.32128
0.15661	0.39223	0.66447	0.85764	0.48880	11.72978
0.15441	0.38172	0.65199	0.84856	0.50000	12.14188
0.15172	0.37157	0.63961	0.83934	0.51000	12.52534
0.14944	0.36176	0.62735	0.82998	0.52000	12.91016
0.14726	0.35229	0.61520	0.82050	0.53000	13.29630
0.14517	0.34315	0.60319	0.81090	0.54000	13.68373
0.14318	0.33432	0.59132	0.80121	0.55000	14.07241
0.14127	0.32580	0.57960	0.79143	0.56000	14.46231
0.13945	0.31757	0.56803	0.78156	0.57000	14.85340
0.13777	0.30963	0.55663	0.77163	0.58000	15.24564
0.13604	0.30197	0.54538	0.76165	0.59000	15.63900
0.13445	0.29457	0.53431	0.75161	0.60000	16.03346
0.13293	0.28744	0.52341	0.74153	0.61000	16.42899
0.13148	0.28055	0.51269	0.73143	0.62000	16.82556
0.13009	0.27391	0.50215	0.72131	0.63000	17.22315
0.12876	0.26750	0.49179	0.71118	0.64000	17.62173
0.12749	0.26132	0.48162	0.70104	0.65000	18.02127
0.12628	0.25536	0.47163	0.69092	0.66000	18.42176
0.12512	0.24961	0.46183	0.68080	0.67000	18.82318
0.12401	0.24406	0.45221	0.67071	0.68000	19.22549
0.12295	0.23872	0.44279	0.66065	0.69000	19.62868
0.12193	0.23356	0.43355	0.65062	0.70000	20.03273

7.5.2 Estimation of Leaching Requirement

The leaching requirement is the fraction of irrigation water above plant consumption which is required to leach the salts through the root zone. Different crops have different salt tolerance levels as given in Table 7.4. It indicates that if salt content is more than the prescribed limits, yield of crop will be reduced significantly. For example for wheat crop when salt content of solute is 6.0 mm ho/cm, yield will not be affected, but when salt content is 13.0 mm ho/cm, yield will be reduced by 50 per cent. When salt content reaches to maximum 20.00 mm ho/cm, 100 per cent yield reduction will be there.

The utility of the present study is shown through the following example. Let the irrigation water applied for leaching have very low salt content (1.0 mm ho/cm). Leaching Requirement (LR) can be estimated by the relationship

$$LR = \frac{EC - EC_i}{EC_o - EC_i} \qquad (7.19)$$

where,

EC_i = salinity of the applied irrigation water,

EC = average soil salinity tolerated by the crop (for 100% yield potential), and

EC_o = solute concentration before leaching.

From table 7.4, for wheat crop when EC_o = 13.0, 50% yield will be affected and when EC_o = 6.0, yield will not be affected by salt present in the soil. Let concentration of solute before leaching is 13.00 mm ho/cm and let the irrigation water has salinity 1.0 mm ho/cm. Let it be intended to reduce the solute concentration from 13.0 to 6.0 mm ho/cm.

Table 7.4: Crop Salt tolerance levels for different crops

Field Crops	100%		90%		75%		50%		Max.	
	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w	EC_e	EC_w
Barley	8.0	5.3	10	6.7	13	8.7	18	12	28	19
Wheat	6.0	4.0	7.4	4.9	9.5	6.3	13	8.7	20	13
Soya bean	5.0	3.3	5.5	3.7	6.3	4.2	7.5	5.0	10	6.7
Corn	1.7	1.1	2.5	1.7	3.8	2.5	5.9	3.9	10	6.7
Ground nut	3.2	2.1	3.5	2.4	4.1	2.7	4.9	3.3	6.6	4.4
Rice	3.0	2.0	3.8	2.6	5.1	3.4	7.2	4.8	11	7.6
Cotton	7.7	5.1	9.6	6.1	10	8.4	17	12	27	18
Sugar cane	1.7	1.1	3.4	2.3	5.9	4.0	10	6.8	19	12

Source: Water quality for agriculture, FAO Irrigation and Drainage Paper 29 Rev.1, 1985.

The non-dimensional concentration at the end of the desired leaching is

$$\frac{EC - EC_i}{EC_o - EC_i} = \frac{6 - 1}{13 - 1} = \frac{5}{12} = 0.416$$

From Fig. 7.7, it is seen that after 12 hours of leaching with 50 cm of water, only soil upto a depth of 106 cm has been leached upto desired level. As the root of wheat crop goes upto 140 - 150 cm depth, further addition of 20 cm of water will be required for leaching so that salts can move further downward beyond root zone depth. Fig. 7.7 shows that by applying 20 cm of water, soil upto a depth of 146 cm has been leached out.

7.5.3 Breakthrough Curve

When irrigation water free from salt flows into the soil, the fraction of solute in the outflowing solution will be C/C_o. The relationship between C/C_o vs volume of the out flowing solution are called Breakthrough Curve. Fig. 7.8 shows the relationship between C/C_o versus volume of outflowing water from different reservoir. In this study, it is found that when soil is near saturation and when one pore volume of water passes through the top soil of 50 cm thickness, the solute concentration predicted by the present model is 0.54. For an ideal Breakthrough curve, 50 per cent displacement of salts takes place at one pore volume. Thus the salt prediction by the present model is satisfactory. It has been said 1.2 to 2.0 times the pore volume replacement of the soil solution should remove about 80 per cent of the original salt content (Ravina, 1982). From this study, it is found that when water twice the pore volume is passed through the 50 cm of the top soil, 76 per cent of salt is removed, as shown in Fig. 7.8.

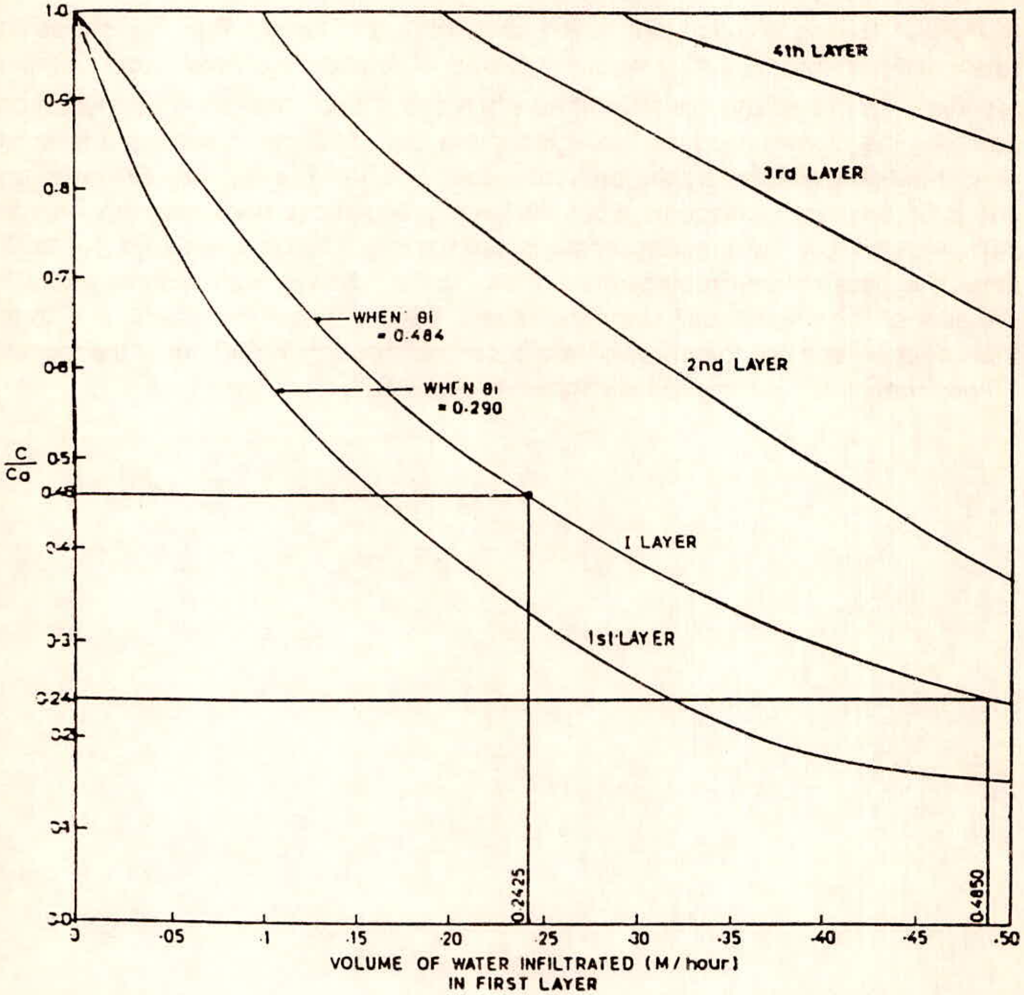

Figure 7.8 Break through curves as a function of relative salt concentration and volume of infiltrated water in a different reservoirs