AGRICULTURAL HYDROLOGY & DRAINAGE

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INTRODUCTION

Out of the 329 m ha geographical area of the country, about 140 m ha is only under cultivation. Moreover an area of around 144 m ha is suffering from water and wind erosion and about 29 m ha from special problems of water logging, excessive salt concentration, gullied and ravinous soils and area subject to shifting cultivation, riverine and torrents (Abrol 1990).

The history of irrigation development in the country can be traced back to pre historic times. Vedas and ancient indian scriptures made reference to wells, canals, tanks and dams which were useful to the community. The entire land scape in the central and southern india is studied with numerous irrigation tanks which have been traced back to many centuries before the beginning of the christian era. Reh committee was the first in India to recommend proper attention to drainage in saline, alkaline and waterlogged areas. The committee suggested deep drainage, introduction of lift irrigation, instead of surface flow canal irrigation straightening and opening of the natural drainage outlets in the country side and provision of culverts on embankment where needed.

India made great strides in her irrigation development during the post independent era. The irrigation potential which stood at 22.6 m ha at the beginning of the First Five Year Plan (1950-51) around double (44.20 m ha) at the close of the 4th plan (1973-74), treble (67.5 m ha) by the end of Sixth Plan period (1984-85) and is estimated to have attained the level of around 77 m ha till the 7th Plan (1989-90) against the feasibie target of 113.5 m ha (Agarwal & Dinkar, 1990).

As the development in the irrigation potential is increasing, the problem of Water logging and salinity is also increasing. The increase in water logging and salinity problem is also due to the change in hydrological behaviour of a region. The country net cropped area has increased from 118.75 m ha in 1950-51 to 140 m ha in 1970-71 and has not increased significantly since then.

Among the soil groups, Black soils occupying about 70 m ha in the states of Maharashtra, Madhya Pradesh, Gujarat and Northern parts of Karnataka and Andhra Pradesh are highly erosion prone. Red soils covering about 72 m ha are another major group of soils that pose serious soil and water management problems.

On the review of the irrigation resource development vis-a-vis agricultural production in irrigated areas, it was noted that the expected productivity per unit of space, water and

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time has not been achieved because of the inefficient water management. This lead to the twin maladies of water logging and salinisation in many of the medium and major irrigation commands project.

Water Logging and Salinity

One of the major problem associated with irrigated agriculture land is the accumulation of salts in the soil which results in low productivity if proper water management practices are not adopted. In India, about 7 m ha of land have been affected by salinity/alkalinity. In Haryana & Punjab about 1.2 m ha of salt affected land occurs which are called Reh or Thur. The district were the problem is more serious are Karnal, Sonepat, Rohtak, Jind, Hissar, Gurgaon, Kurukshetra and Patiala, Sangrur, Kapurthala, Amritsar, Gurdaspur, Faridkot, Ferozpur and Bhatinda in Punjab. In U.P. the total area under saline soil is 1.295 m ha and the major district affected are Aligarh, Mathura, Agra, Allahabad, Etah, Etawah, Hardoi, Kanpur, Lucknow, Meerut, Pratapgarh and Sultanpur. The statewise statistics of area affected by salts is shown in Table 1.

Table 1: Area affected by salts in different states

State	Affected area M ha	State	Affected area M ha
U.P	1.295	Maharashtra	0.534
Gujarat	1.214	Orissa	0.404
West Bengal	0.850	Karnataka	0.410
Rajasthan	0.728	Madhra Pradesh	0.224
Punjab	0.688	Andhra Pradesh	0.042
Haryana	0.526	Other States	0.040

The data collected by Command Area Development indicates that about 8.53 m ha area is affected by water logging. Thus proper planning and design of improved drainage system both surface and subsurface including vertical drainage depending upon the site characteristics are required for controlling waterlogging and salinity. The premier institution/organisations working in the solution of this twin problem are Central Soil Salinity Research Institute, Karnal; Hissar Agri. Univ., Punjab Agri. University. States irrigation and Agricultural Department, and Command Area Development Agency. Recently, water and land management institution have been established indifferent states with the objective to train officers/village level workers for efficient use of irrigation and adopt proper water management practices and to minimis the effect of salinity/water logging in agricultural production. The CAD authorities/WALMI are also engaged in training of personnel at all levels including participation of farmer community for getting maximum return per unit land. The details of waterlogged and salinized area under various project are shown in Table 2 and drainage characteristics of some pilot projects sites are shown in Table 3.

Table 2: Waterlogged and Salinized area (in thousand ha)

Name of the Project	Cultural command Area	Area waterlogged	Area salinised
Sree Ram Sagar Project	252	30.00	-
Nagarjunasagar Left Canal	352	33.15	30
Nagarjunasagar Right Canal	475	114.00	Not assessed
Tungbhadra Project (including salinity)	149	33.00	
Jaimena	25.80	-	
Gondak (Bihar)	1062.00	562	400
Sone	85.60	Negligible	-
Kul-Badna-Chandase	128.64	Negligible	-
Shatranji Irrigation Project	35.70	0.43	9.95
Kadana	212.00	1.72	60.72
Ukai-Kakrapar-Commaed (including salinity)	356.00	8.294	
M.R.B.C.	312.00	9.835	35.763
Rewari L.I.Command	46.19	-	0.11
J.L,N.Canal command	23.60	-	0.06
Ravi-Tawi-Command	76.48	-	0.2
Tawa Command	236.70	.461	-
Chambal (M.P.)	234.00	20.029	-
Krishna Command	74.00	3.142	0.059
Mula	75.12	0.021	0.771
Girna	68.65	0.33	0.15
Ghod	42.75	0.012	0.087
Purna	58.00	3.1	0.32
Jayakwadi	170.00	2.1	0.49
Nira	137.94	0.197	4.28
Pravara	63.74	Negligible	0.267
Godavari	88.819	Negligible	0.179
Hirakund	152.00	3.00	nil
Salandi	41.96	0.117	0.92
Mahanadi (Old)	167.00	58.30	-
Mahanadi (St. II)	136.00	55.90	-
Malaprabha	213.00	0.98	0.14
Ghataprabha	317.00	3.52	nil
Tungabhadra	363.00	37.67	20.00
I.G.N.P.	114.00	50.00	17.00
Chambal(Rajasthan)	229.00	44.50	6.39
Cauvery	378.00	Neglible	Neglible
Periyarvaigai	163.00	Neglible	Neglible
Lower Bhawani	105.00	Neglible	Neglible
Farambikulami Abvar	-	nil	1.76
Gandak Command Gorakhpur U.P.	443.00	Neglible	Neglible
Sarada Sahayak	1658.00	326.00	6.20
Ramganga Command	2000,00	195.00	352.00

Table 3: Drainage characterstics of study sites

Drainage Characteristics	Mundlana	Uzhana	Bhana	Drainage pilot project sites Bhana I	 Dabhou II
Project Area (Acres)	25	80	152	110	125
Soil Texture	Clay Loam	Clay Loam	Clay Loam Loam	Clay Loam	Clayto Clay
Annual Fluctuation of Water Table (m)	0.0-2.0	0.0-1.5	0.0-2.0	0.0-1.8	
Hydraulic Conductivity (m/day)	0.8	0.61	0.88	0.86	0.48
Drainable Porosity	0.1	0.09	0.09	0.08	0.07
Presence of ground water aquifer	Poor	Poor	Poor	Poor	Poor
Soil pH_2 (initial)	9.2	8.5	8.2	8.4	8.4
Soil Ec_2 (initial) (dS/m)	7.3	6.8	7.1	9.2	1.7
Depth of lateral drain (m)	1.6	1.4	1.5	1.5	1.5
Spacing of Lateral Drains(m)	50	50	67	67	50
Material Used					
(a) Collector Drains	Rigid PVC pipe	Rigid PVC pipe	Rigid PVC pipe	Rigid PVC pipe	S.W. pipe
(b) Lateral Drains	Corrug. PVC	Corrug. PVC	Corrug. PVC	Corrug. PVC	Corrug PVC
(c)Enveloping	Gravel Netting	Gravel Netting	Synthetic &	Synthetic	Gravel geotextile
Disposal of Drainage Water	Surface Drain	Canal Drain	Surface Drain	Surface Drain	Surface
Annual Rainfall(mm)	530	465	465	465	600

2.0 Review of the Work

2.1 Salinity & Alkaline Soils

Considerable attention has been made since Independence for the solution of salinity control in irrigated agriculture, reclamation and management of saline and alkaline soils and provision of adequate drainage system (Abrol 1971, Abrol and Bhumbla 1971, Bhumbla 1972, Gupta & Dhruv Narayana 1972, Yadav 1972, Abrol & Bhumbla 1973, Abrol et al 1975, J S Kanwar, 1961, 62).

Tyagi , N K and Narayana V V Dhruva (1982) have done work on Ground Water Recharge in alkali soils during Reclamation for Jundla command area in Haryana. The groundwater balance of the Jundla command area has been estimated by the following expression:

$$(CWR+STR+CPR+IGW+CCR) - (ST+DT+OGW+EVG) = +MGW \quad \ldots (1)$$

where

CWR	=	recharge from canal conveyance and distribution system
STR	=	recharge from shallow tubewell conveyance system
CPR	=	recharge from crop land
IGW	=	ground water inflow from adjoining areas
CCR	=	recharge from carrier channels and drains
ST	=	withdrawal by deep tubewells
OGW	=	ground water outflow to adjoining area
CVG	=	evaporation from ground water storage
MGW	=	mining or addition to ground water storage

The water balance in alkali soils under reclamation becomes modified and remains in a transient stage for a long period of time until the alkali soils attain the hydrological status of normal soils. The increase in ground water availability due to recharge from crop land makes it possible to meet part of the irrigation demands and thus helps in stabilisation of the ground water which usually declines in the initial years due to heavy ground water pumping.

Tyagi and Dhruva Narayana (1982) have also developed a procedure to estimate the rate of change in recharge from crop land and applied to a typical alkali conditions in the Jundla command area of the Western Jamuna canal. The soil texture varies from silty alkali in nature. The soil are characterized by mgh pH (9.5 to 10.5) and low infiltration rate (0.5-1.0 cm/day). These soil were uncultivated for several decades. These soils were reclaimed by the technology developed at CSSRI Karnal. In order to meet the irrigation demand of the newly reclaimed land a large number of shallow cavity tubewell has been installed. The density varies from 0.10 to 0.35 per ha. Besides these shallow tubewells, there are deep tubewells installed by the Haryana Govt. for augmenting the water supplies of the Western Jamuna Canal. The value of ground water recharge from the composite watershed having normal and alkali soils in the ratio of 70 to 30 respectively shows an increase of about 17.5% of the recharge value before reclamation for the optimal cropping patterns over a period of 20 years.

Tyagi and Dhruva Narayana (1983) developed a chance constrained linear programming model with rainfall as stochastic input to plan optimal land and water use in alkali soils under reclamation. The model is based on the water balance of a typical alkali catchment in the command area of the Western Jamuna Canal in Haryana. Available water supplies at low rainfall probabilities were found to be inadequate to sustain the high cost reclamation technology. The model also indicates that the great risks are taken if reclamation programmes are undertaken on the basis of mean rainfall data.

S K Gupta (1986) analysed the subsurface drainage problem in Rohtak and Sonepat districts of Haryana. These two district in the state of Haryana suffer badly due to lack of proper drainage facilities. The author has made attempt to highlight the subsurface drainage problem and suggested a suitable strategy for the area. The districts covers a total area of 604700 ha. A bowl shaped depression is formed with its lowest portion located somewhere near Jhajjar town in Rohtak district. Nearly 75 percent of the average annual rainfall occurs during monsoon. The area has extreme drainage congestion almost once in five years thereby emphasizing the need to improve the existing drainage system. With an estimated recharge of 20.6 cm of water annually, the existing draft as on March, 1983 could take care of only 53.7 percent of the total recharge. Therefore it is necessary to increase the draft by installing more shallow and deep tubewells and suggested that whereas farmers can be encourages to install shallow tubewells in fresh and marginal water quality zones. Government may concentrate on saline water zone. It has been shown that marginal water upto 6 ds/m can be used for crops grown in these districts. In severely salt affected soils and where tubewell installation is not feasible, horizontal tile drains should be installed. The drains can be spaced at 60 m so as to fall on 'killa lines'. The author suggested that a combination of horizontal and vertical drainage systems can effectively be used to solve the menacing waterlogging problem of these districts. Preventive measures such as lining of canals, improvements in existing surface drainage system and improvement in on-farm water management can assist in ameliorating the situation at a faster rate.

A large area in the country is suffering with waterlogging and salinity problem. The cause of the problem is the hydrological imbalance in the region. Reclamation of these land requires the installation of the sub-surface drainage system to lower down the water table and leaching plan to reclaim the soil. To achieve these objective the hydrological investigation is the first essential requirement. Pandey & Singh (1986) have discussed the hydrological investigation needed with reference to a projects site in the central Haryana.

The hydrological investigation revealed that the salinity problems are found at low lying areas and there surface drainage problem also exists. Water table fluctuates from surface in monsoon season to 1.40 meter in summer season. The underground water is saline and the evaporation of saline ground water is the cause of the salinization of the soil. The hydraulic conductivity of the soil is very good and for subsurface drains large drain spacing is possible. Infiltration rate in the area is poor which is expected to rise after the land treatment as deep ploughing and sub-soiling. Critical water table depth was found to be 80 cm which determine the lowering of the water table to 1.75 m depth.

Drainage coefficient for the area can be taken as 8 mm/day when the water table is at 15 cm. below the soil surface. Drainable porosity varies with the depth and it ranges in between 0.03 to 0.13 when the water table depth changes from surface to one meter depth. This will affect the design of the sub-surface drainage systems.

The reclamation of saline soils depends upon the efficiency of the leaching of salts from the upper soil layers to lower layers and subsequently their removal along the sub soil water. For the reclamation of these soils the provision of subsurface drainage either in the form of horizontal or vertical subsurface drainage system is a pre-requisite. The leaching effiuency in also inflnaed by method of water application water lose due to evaporation and soil factors. Singh and Pandey (1986) described the advantage of vertical sub-surface drainage system for the reclamation of saline soils and a history of well drilling and failures indicating the poor aquifer characteristics and their frame work for the successful installation and operation of the vertical drainage system. Based upon a pilot research project study in a representative saline soil region, the low values of hydraulic conductivity and transmissivity were observed. The residual draw downs after pumping and recovery period for the individual wells as well as for the combined battery of tubewells were observed to be very low. Practically no change in ground water quality was observed during operation of vertical drainage system. The radius of influence was also estimated to be in low range indicating the need for the large number of tubewells per unit area. All these observations did not favour the success of vertical sub-surface drainage for the reclamation of saline soils.

Singh and Pandey (1985) have studied the hydrological aspect of reclamation of saline soils due to sub-surface drainage. After the installation of sub-surface drainage system the behaviour of the water-flow pattern was observed. More amount of water-flow took place through the root zone instead of surface flow making the leaching of the soil effective. The salinity of the under ground water was reduced which can help in overall reclamation of the area. Sub-surface drainage system lower down the water table in lesser time resulting in the reduction in the evaporation from the soil surface and thus secondary salinization. During a period of 4 years the salinity (ECG) was reduced from 3.0 mmhos/cm to 0.68 mmhos/cm. The heterogenity of the salt leaching was found if the leaching operation was conducted by uniform flooding the area between the tile drains. The effect of drain spacing on the salt leaching if also analysed. The cultivation was possible within one year of reclamation and the yield increased with the elapse of time after installation of sub-surface drainage system.

Tyagi et al (1987) carried out ground water simulation studies for salinity management in parts of Sirsa & Hissar Distt. of Haryana. They have developed a simulation model based on Tyson & Weber model.

The area was divided into asymmetric grid by using Thiessin polygon method. The number of sides in each polygon was six and the area of each polygon ranged between 4.2.5-6.2.5 sq. km. The most important and difficult problem is the definition of boundaries at the external nodes. There may be three types of this simulation study the ground water basin is not an isolated one and its boundaries extend well beyond the study area. Based on the ground water simulation studies conducted by HSMITC for the whole of Haryana State (Anonymous, 1984) the boundaries at the external nodes of the study area were identified at flow controlled. The model input include specific yield, recharge/

discharge, ground surface & base of the unconfined aquifer above m.s.l., aquifer thickness & hydraulic head. The calibrated model was used for forecasting the water table behaviour on monthly basis from 1984-2000 A.D. The water table levels during June and Oct. were used to compute extend of area under different water table ranges. The estimates of probable losses in production and farm income were made from the extent of area affected by waterlogging and salinity.

Ground water simulation studies conducted in part of Sirsa and Hissar districts in Haryana have shown that nearly 70 percent of the area would have water table in the critical zone (0-3 m) and about 57% would be completely waterlogged with water table within 1.0 m. Studies have also shown that rate of rise in watertable was faster in some area as compared to the others. This information on differential rate of rise in waterlogging may be used with advantage in planning anti water logging and salinity control measures.

Tyagi (1988) has developed management model and applied to a typical waterlogged command area of Western Yamuna Canal in Haryana. The study objective was to plan management strategies that would control water logging and salinity and would generate additional water resources to mitigate the perennial water scarcity. The model consist an objective function and a set of linear constraint. The formulated model is based on salt and water balance in the crop root zone where most of the action for production takes place. Change in salinity in aquifer & change in the downstream river quality are also described. The developed model is quite general in nature and can be used to find solutions to a variety of problem in waterlogged saline areas. Some of the problem that can be solved with the aid of this model include optimal level of ground water development for irrigation and drainage to maintain salinity below critical level.

Soni and Mishra (1987) have formulated a model for salt and water movement using Green and Ampt infiltration equation. The soil system was divided into different layers. The solute movement from 1st layer to 2nd layer, 2nd to 3rd layer likewise have been determined using salt balance approach. The time required to fill the different layers have been estimated from the initiation of the infiltration. The variation of salt concentration with time and depth have been determined. Break through curves have been presented for different layers. From the study it was found that when twice the poor volume is passed through the 50 cm of the top soil, 76 percent of salt is removed.

D Rai (1990) suggested the measures for reclamation of water logged and usar soils in Sharda Canal Command area. This command covers blocks of districts Pilibhit, Shahjahanpur, Hardoi, Unnao, Lucknow, Bareilly, Barabanki, Pratapgarh, Raibareli, Sitapur, Lakhimpur Kheri and Nainital. Water logging and soil alkalinisation are much serious in central and eastern command, such as in Hardoi, Unnao and Lucknow due to low surface gradient (< 0.3m/km) and predominance of impervious thick clay layers upto the depth range of 10m to 30m with thin sandy strata. Soil alkalinisation is the consequent effect of water logging due to capillary rise of ground water to the surface and alkali precipitation because of high evaporation rate in hot weather. In this area the critical water table is at the depth range of 1.50 m to 2.0 m in varying lithological setup above which complete soil profile is saturated and water logged. The prerequisites for prevention and reclamation of water logging and usar is to lower down water level below the critical water table in the safe zone. With this aim judicious ground water management with conjunctive use planning and effective drainage systems are much helpful. Surface drainage is not well suited for this area, whereas sub surface drainage and ground water pumping from shallow aquifers are effective methods to lower down water level. The author have studied the hydrogeology of the area, causes of water logging, usar and deals with effective methodology for its prevention and reclamation.

Reclamation of saline soils in semi-arid regions often involves ponding the soil surface with good quality irrigation water in order to leach salts from the upper layers of the soil. Such reclamation relies on subsurface drainage which allows the removal of leaching water. Recent field studies in India where large areas of irrigated land have had to be taken out of production because of waterlogging and salinity have shown that severely affected soils can be brought back to production in a short period of time using these methods (Rao et.al., 1986).

KVGK Rao et al (1991) have done field experiment at Sampla, India to study in detail the leaching phenomena. The soil in this region is a two-layered light-textured alluvium, having a sandy loam 1.75 m depth with a hydraulic conductivity of about 1.0 m/day and from 1.75 to 4m depth a loamy sand with a hydraulic conductivity of 7.5 m/day. At 4.0 m depth there is fine- textured layer of low hydraulic conductivity which may be taken as the impermeable boundary. The soil is highly saline with an average EC (electrical conductivity of the saturation extract) of 42.5 dS/m in the top 0.15 m layer, 30.3 dS/m in the 0.15-0.3 m layer and with an almost uniform value of 21.0 dS/m below 0.3 m. The water table is shallow and fluctuates between the soil surface during the monsoon to 1.5 m below the soil surface in summer. Drains at 75m spacing and 1.75m depth allow desalinization with surface irrigation water. In this study the over-relaxation method. was used to obtain a finite-difference solution to the two-dimensional Laplace equation for potential and stream functions for given boundary conditions assumed for the flow. The mass flow equation was used for computing the leached volume in each stream tube. The equation has the form:

$$C(t) = C + (Ci - C)\, e^{-fQt/w}$$

where

C(t)	=	the average salt concentration of the soil at any time t;
C	=	the average initial salt concentration of the soil;
Ci	=	the salt concentration of the in-flowing water;
f	=	leaching efficiency;
t	=	duration of ponding
w	=	total amount of soil water in the soil layer; and
Q	=	flow rate per unit area in a stream tube.

The computer simulations has been done for the analysis of various leaching strategies for a two layered soil at Sampla, Haryana, India. Zones in the soil profile above the drain already leached in a partial ponding strategy would require mulching to reduce capillary rise and the upward transport of salts to the soil surface and re-salinization of the upper soil layers. It is expected that crop residue mulches and/or cultivation techniques could successfully control capillary rise in this situation. Reversing the strategy starting with 20% ponding and increasing it to complete ponding would remove this problem and may lead to an even greater economy of water use. In the case of ponding of the entire area between the drains the rapid desalinization of the soil zone above the drain leads to an inefficient use of water but does allow a rapid improvement in the quality of the drain effluent. Partial ponding improves desalinization away from the drain and allows a more efficient use of water. However, an inevitable consequence of this is that the quality of the drainage effluent remains poor for a longer time compared to the completely ponded case.

The author has expressed that the work reported will act as a rationale for future leaching experiments in drained saline soils in Haryana, India.

2.2 Surface & Subsurface Drainage

Basic approach for planning of surface drainage for an agricultural area has been discussed by B Das (1985). Selection of design storm, fixation of loss rate (due to evaporation as well as deep percolation) and other parameters required for assessment of runoff have been described. Problem of water logging generally arises in tidal tracts where field elevation is below tide level of Creeks due to premature reclamation. In tracts lying outside tidal influence such problem may occur during floods when water level in adjoining rivers/channels rises high above level of crop fields. For achieving desired crop yield, the surface drainage system should be so planned as to convey the runoff at fast rate in order to prevent harmful accumulation. Method of estimating the period for drainage and the volume of water to be drained has been outlined both for tidal and non tidal tracts.

Mishra and Soni (1988) have discussed the suitability of surface drainage system, the hydrological parameters needed for design of surface drainage system, updating of SCS curve number and computation of design discharge by SCS method during successive rainy days. A method for computation of peak discharge for which the surface drainage channel should be designed has been suggested.

A large extent of agricultural land gets flooded in Western U.P during the monsoon period and a portion of it is not drained till mid-November thus rendering the land unfit for the timely rabi sowing. This adversely affects the local community and the associated agro-based industry in the region. Expeditious removal of the seasonal flood water to facilitate timely rabi sowing can provide a reasonable solution to the problem. Patna-Jalesar area in Etah district (Western U.P) had been facing similar problem prior to 1978. Subhash Chander & Kapoor (1985) analyses the problem and develops a design to meet the specific objective on a probabilistic basis. The analysis brings out that in such situations the problem can be reviewed on a seasonal basis. The average rise in ground water table over a number of years and climatological data have been used in computing the runoff volumes for various return periods. Due consideration has been given to the variability in evaporation for different return rainfalls becauses of varying submergence. The runoff computations has also been carried out using Khosla's method for estimating losses. It emerges from the study the Khosla's method and the proposed method yield the same runoff volume for 25 years return period while for lower return periods, estimates of runoff using Khosla's method are lower than those realised using the alternative method.

Depth and spacing are two important parameters for the design of sub surface drainage system. Drain depth is determined on the basis of crop characteristics, critical water levels and soil layers condition, the spacing of drains is estimated using empirical, steady or unsteady state formulae. Gupta (1985) has compared the glover equation, Terzidis, Vanschilfgaarde, Hammad equation in general as well as by taking data from a specific case study. The study suggests that experimental design spacing for a particular local should be selected on the basis of equations that yield minimum and maximum values. If need be an intermediate spacing and a spacing based on economic consideration may be included. This study concludes that the experimental design spacings thus selected will be superior to those derived from the present practice which is most arbitrary. It consists of selecting one of the arbitrarily and then increasing and decreasing the spacing by some arbitrary value to arrive at the design spacing. In general the present practice allows some undesirable and theoretically unjustified spacings in the experimental design which can be avoided. The suggested practice will also allow better theoretical interpretation of results which ultimately will be more meaningful in understanding the theory of drainage design.

The Introduction of Canal Irrigation at Haryana Agricultural University farm has led to the rise in water table from 16 m during 1969 to less than 1 m to 4 m during 1985 depending upon the deep percolation losses from Irrigation conveyance and application systems. The excessive recharge of good quality canal water has resulted in the development of groundwater mound and improvement of upper groundwater quality in the vicinity of Farm Minor. Ranvir Kumar and Joginder Singh (1985) have discussed the management of saline groundwater through skimming wells. The coarse strata of 30-60 cm thickness exists at a depth of 4 to 5 m from ground surface. Two skimming wells each are sunk within and outside ground water mound for subsequent testing with regard to quantum and quality of pumped water. The drained water is being revised for irrigation either directly or in conjunction with canal water. The quality of pumped water is three to four times better (600-800 Us $^{-1}$ Cm) from the skimming wells within the groundwater mound same as compared to the ones outside the mound (2500-4000 Us Cm $^{-1}$).

The ayacut under Nagarjunasagar Right Canal lies in upland taluks of Contour & Prakasam districts. The entire ayacut is divided in 22 blocks seperated by well defined valleys formed by major drainage courses, the branch canal & distributaries. To determine the degree and extent of drainage required in the ayacut area, the entire area was surveyed and salinity index map & pre monsoon and post monsoon groundwater table maps were prepared & pre monsoon and post monsoon groundwater table maps were prepared (Rao 1985). Drains in the Nagarjunasagar Project Right Canal ayacut area receive drainage either entirely from wet cultivation or from irrigated dry lands or from a combination of both. It is considered sufficient if the existing drainage courses are improved to carry the ordinary floods together with the irrigation water from the ayacut lands, by evicting encroachments on the drainage courses, removing shoals and other obstructions and widening the courses wherever necessary. However, ordinary floods are considered for excavation of drainage courses and maximum floods for acquisition of land for future widening and for design of cross masonry works on the drains.

Engineers concerned with the design of small and medium hydraulic structures and drainage works are constantly faced with the problem of suitable design criteria. Economic considerations are important and choice of a suitable design flood has a major bearing on the cost of projects. Informations about maximum rainfall of different probabilities is an essential pre-requisite for the planning and design of such hydraulic structures. Keeping this in view, Puri et al (1985) have made attempt to study the maximum one-day rainfall for different return periods for 80 stations in and around Haryana State. Using the annual maximum point rainfall data of these stations, generalised charts of one-day maximum rainfall for the return periods of 2-yr., 5 yr., 10-yr., 25-yr., 50-yr., and 100-year have been prepared for Haryana State. The generalised charts are presented in this paper and important aspects of one-day extreme rainfall distribution over Haryana state have been discussed.

The engineering designs of all hydraulic structures require reliable information on runoff due to storms whose probabilities of occurrence can be fixed based on the importance of the structures. The inadequacies of some of the empirical formulae developed earlier have been pointed out by several field workers and researchers who personally preferred some other formulae instead under the conditions prevailing in their respective regions. Satyanarayana et al (1985) made an attempt to apply the

Snyder's synthetic unitgraph approach to a few small agricultural watersheds selected in the black soil region of Karnataka. They derive three parameters namely the basin lag, peak rate and total time base of hydrographs from the observed rainfall and runoff data of five years. The exact values of the coefficients associated with these parameters can be again ascertained from any additional data and modified if necessary from time to time depending upon the changes in watershed conditions either natural or man made.

Singh and Soni (1990) have discussed the application of unit hydrograph techniques for estimation of design flood for drainage systems. Various methods of unit hydrograph derivation for gauged as well as ungauged catchment have been reviewed and step by step procedure for estimating the design flood for given design rainfall using unit hydrograph approach has been described.

For efficient design of soil and water conservation structures estimation of peak discharge from watershed is necessary. Almost all the watersheds in Doon Valley are ungauged. To have the hydraulic information needed for design of structures it is essential to transfer the information from a nearby gauged watershed to site where no data is available. Five small watersheds were selected for developing flood frequency curve (Ram Babu & Dhruva Narayana, 1985) for small watersheds (area less than one square km) in Doon Valley. Three probability distribution functions were compared with the observed values obtained from probability paper, and the log pearson's type III distribution was selected to develop frequency curve.

Based on the 24 years maximum peak discharge data from 5 small watersheds of varying sizes (4.4 to 83.4 ha) under agriculture, forest and mixed land use in Doon Valley, peak discharge-frequency relationships for individual watershed and the generalised peak discharge-area-frequency relationship was developed. Estimated peak discharge with various return periods obtained from generalised equations were compared with the results obtained from individual watershed equation and the log pearson's type III distribution. Comparative values showed that the generalised equation could be considered very satisfactory. A nomograph of the generalised equation was also developed for easiness in calculation.

CWPRS (1987) has developed mathematical model for the water movement in Mahanadi Delta Mahanadi-Kathjuri-Devi, River System and Hansua, Singarpur-Nagpur-Alka, Drainage System, Orissa. The Mahanadi delta consists of eight segments. Each segment is called as DOAB, which is land area between two rivers. The modelling of delta region has been done by simulation of flow through river channels and drainage channels.

a) River System

The river system in the delta has flat topography and loop formation, sometimes with flood plain. As such the assumptions of bed slope equal to energy gradient in kinematic wave routing may not be applicable. Therefore, a hydraulic method using full dynamic wave equations was selected for routing the flows. The routing model needs data on upstream boundary, in the form of observed stage/discharge hydrograph; a downstream boundary with observed stage/discharge hydrograph, single/loop rating curve or normal flow conditions governed by Manning's equation; initial conditions and data for calibration. The main calibration parameters the roughness coefficient represented by Manning's n.

b) Drainage System

For simulation of flow through drainage system, a two tier modelling scheme was adopted. A widely accepted comprehensive parametric model viz., CWPRS version of OPSET, was considered for calibration of the catchment area of each drain upto the first gauging site. The model needs hydrometeorological data on rainfall, evaporation and discharges, and other catchment characteristics like time area histogram, recession constants and land phase parameters. The calibration is achieved through matching of observed and synthesised stage/discharge hydrograph(s).

For the purpose of calibration of models for river and drainage systems, boundary data and hydrometeorological data were made available by the Drainage Master Plan Circle, Bhubaneshwar, Orissa. These were scanned and then corrected, wherever found necessary, through the pre-processing software developed at CWPRS. The initial conditions were derived from execution of the steady state backwater routine.

CWPRS has made attempts to calibrate the river system comprising Mahanadi Kathjuri-Devi and the drainage system comprising Hansua and Singarpur-Nagpur-Alka using acceptable hydrologic and routine models. The data collected from the various Govt./ Authorities have been duly screened and corrected wherever necessary. The necessity of improving observation technique using sophisticated instrumentation is brought out for updating the calibration and for using the models for flood plain mapping.

Due to the introduction of canal irrigation, the groundwater table has been rising in certain parts of the country. The problem of waterlogging and salinity also exists in South Western part of Punjab, the main reasons for this is the seepage from canals and poor drainage conditions. The quality of groundwater in this area is saline and unsuitable for irrigation. The usual due to the inter-mixing of saline groundwater with the good quality seepage water.

G S Dhillon et.al (1986) developed a technique to skim off and reclaim the useful canal seepage water without mixing with the unfit saline water in deeper zones. A coupled tubewell consisting of four shallow tubewells of 11.5 metre depth and 15.0 cm diameter, having a bamboo cage double coir strainer has been developed. The tubewell can be operated with a diesel or electric pump of 7.5 H.P. capacity. The system has been found quite efficient and has yielded 175 percent additional discharge as compared to the discharge of single tubewell. The technique of using solar photovoltaic pumps has also been studied for skimming off the shallow sweet groundwater. These techniques are being usefully employed in Faridkot area of Punjab where there is a serious problem of waterlogging and salinity in the vicinity of Rajasthan canal and Sirhind Feeder.

2.3 Soil & Water Erosion

Out of total geographical area of 329 m ha of India, about 167 m ha (about 51% of total) are affected by serious water and wind erosion, erosion due to shifting cultivation and erosion of area includes about 127 m ha subject to serious soil erosion and 40 m ha degraded through gully and ravines (3.98 m ha), shifting cultivation (4.36 m ha), waterlogging (8.53 m ha), alkali soils (3.58 m ha), saline soils including coastal saline sandy area (5.5 m ha), riverain lands (2.73 m ha) and desert area (11.79 m ha) (Gurmel Singh, 1990). Out of 127 m ha subject to soil erosion includes rainfed nonpaddy areas (77.88 m ha), other cultivable land including permanent postures and cultivable wastelands (21.32 m ha), forest lands including protected and unclassified forest (19.49 m ha) and area not available for cultivation (7.93 m ha).

Till 1987-88 both under State (29.34 m ha) and Central (2.74 m ha) sectors about 32.08 m ha of agricultural and non- agricultural lands have been treated by various soil and water conservation measures and under special programmes at an expenditure of about Rs. 1,739 crores (Anonymous, 1989).

The most serious soil erosion problem is sheet and rill erosion which has a serious effect on agricultural production on red soils, covering an area of 72,000,000 ha. The depth of these soils is about 200 mm (8 in.) in most areas. The lateritic soils, associated with rolling or undulating topography, also suffer from this form of erosion because they are located in the regions of relatively high rainfall. These soils are estimated to lose annually about 40 ton/ha of valuable top soil, particularly in the absence of soil conservation measures. The black soils, occupying nearly 64,000,000 ha, are usually unlized for crop production under rainfed conditions. Surprisingly, these lands are normally cultivated and kept fallow during the intense rainy season making them susceptible to serious erosion (V.V.D.Narayana & Ram Babu 1983).

The area of most spectacular erosion is the severly eroded gullied lands along the banks of Yamuna, Chambal, Mahi and other West-flowing rivers in Gujarat, Nearly, 4,000,000 ha of such lands are covered by shallow, medium and deep gullies (Tejwani & Dhruva Narayana, 1961). The Himalayan and lower Himalayan regions have greatly deteriorated from intensive deforestation large-scale road construction, mining, and cultivation on steep slopes. Approximately, 3,000,000 ha are seriously eroded in the northeastern Himalayas from shifting cultivation. Due to these practices, major river basins experience recurring floods of high magnitude with very high sediment loads.

The soil loss was estimated for each of the 20 land resource regions of India (Gupta et.al, 1970) as shown in Table 4.

TABLE 4 Annual Soil Loss Estimates from Water Erosion in India
(V V D Narayana and Ram Babu, 1983)

Detailsof land resource regions (Ref.10)	Area,in square kilo-meters	Percent	Agriculture, in square kilometers	Forest, in square kilometers	Soil loss, in tons per square kilometer	Type of forest or rotation followed	Source of informa-tion	Soil loss in millions of tons
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
A. North Himalaya, snow clad region	116,000	3.56	-	116,000	Negligible	-	-	-
B. North Himalaya, Alpine grass and meadow region	98,250	3.02	-	98,250	15.93	Sal forest	Rajpur (Dehradun)	1.6
C. North Himalaya, forst region	131,750	4.08	-	131,750	Nil			-
				25%-32,940- No erosion				
				75%-98,810- Medium erosion	287	Forest (Sal)	Dehradun	28.4
D. Punjab Haryana alluvial plain region	101,250	3.10	101,250	-	330	Maize (un-bundled)	Chandigarh	33.4
E. Upper Gangetic alluvial plain region	200,000	6.15	172,120	-	1,410	Jowar-2.2% (Up and down cultivation)	Kanpur	242.7
				8,750	50	Forest	Estimation	0.4
				19,130 (ravine)	3,320	Ravine lands	Vasad	63.5

F.	Lower Gangetic alluvial plain	145,500	4.41	140,750	-	940	Jowar-1.5% (Up and down cultivation)	Rehmankhera and Lucknow	132.3
G.	Northeastern Himalaya Alpine grass and meadow region	16,000	0.50	-	4,750	287	Forest (Sal)	Dehradun	1.4
					16,000	Nil			
					25%-4,000 No erosion				
					75%-12,000 Meadow erosion	50	Forest	Shillong	0.6
H.	Northeastern forest region	161,000	4.97	-	161,000	Nil			
					25%-40,000- No erosion				
					50%-81,000- Medium erosion	287	Forest	Dehradun	23.2
					25%-40,000- Shifting cultivation	4,095	Jhuming (Agrl.)	Shillong	163.8
I.	Assam Valley region	88,500	2.73	88,500	-	2,850	Maize (Up and down cultivation)	Dehradun	249.1
						2,850	Agri. (Food Crops)	Shillong	
		2,815			Av.	2,815			
J.	Rajasthan desert region	191,000	5.87	-	-	Negligible			-
K.	Runn of Kutch region	46,500	1.44	-					

L. Gujarat Alluvial plain region	62,750	1.94	58,750	-	480	Bidi-tobacco	Vasad	28.2
				4,000 (ravines)	3,320	Ravine	Vasad	13.3
M. Mixed yellow red and black soil region	115,750	3.58	89,000	-	240	Jowar (kharif)	Kota	26.7
					360	Jowar and Castor (Av.)	Hyderabad	26.7
				Av.	300			
				26,750	100	Forest	Estimation	2.7
N. Black soil region	673,500	20.73	523,500		11,250	Bidi Jowar-Sholapur (1.2%)	Kanikar	3,375.5
					5,724	Rabi Jowar-Majri (3.0%)		
					2,730	Cultivator method Bijapur (1.25%)		
				Av.	6,448			
				15,000	Nil			
				25%-37,500- No erosion				
				25%-37,500- Low erosion	50	Forest	Estimation	33.8
				25%-37,500- Medium erosion	300			
				25%-37,500- Severe erosion	500			

O.	Eastern red soil region	573,500	17.65	408,000	-	359	Jowar and Castor (Av.) (2.5% slope)	Hyderabad	141.2
						333	Maize	Deochanda-Hazaribagh	
					Av.	346			
					165,500 25%-40,000- No erosion	Nil			
					25%-45,500- Low erosion	50	Forest	Estimation	
					25%-40,000- Medium erosion	287	Forest (Sal)	Dehradun	37.8
					25%-40,000- Severe erosion	500	Forest	Estimation	
P.	Ganga Delta region	25,250	0.77	-	-	Negligible			
Q.	Western coastal region	61,000	1.88	59,750	-	3,930	Potato-Potato (Up and down cultivation)	Ootacamund 25% slope	234.8
					1,250	Negligible	-		

R.	Red soil region	347,750	10.72	264,750	-	359	Jowar and Caster	Hyderabad	95.0
					83,000	Nil			
					25%-20,000- No erosion				
					25%-23,000- Low erosion	50	Forest	Estimation	
					25%-20,000- Medium erosion	287	Forest (Sal)	Dehradun	
					25%-20,000- Severe erosion	500	Forest	Estimation	
S.	Eastern coastal region	93,500	2.90	93,500	-	3,930	Potato-Potato (Up and down cultivation)	Ootacamund 25% slope	367.5
	Roadside erosion	10,000 km		-	1,969	-	Mussoorie-	19.9 Tehri road	
								Total	5,333.7

TABLE 5 Salient Hydrological Details of River Basins of India (V V D Narayana and Ram Babu, 1983)

River basin (1)	Catchment Area, in Million of Hectares: India (2)	Catchment Area, in Million of Hectares: Outside India (3)	Annual total runoff, in millions of ha meters (4)	Annual precipitation, in centimeters (5)	Annual El30, in metric units (6)	Sediment load, in millions of tons (7)
1 Ganga basin	86.15	18.18 = 105.03	55.01	116	489	586.00
2. Brahmaputra	18.71	39.29 = 58.00	42.20	122	510	470.00
3. Barakar and other rivers (DVC)	7.82		17.50	286	1,089	210.00
4. West flowing rivers below Tapi	11.21		21.79	279	1,064	252.22
5. Tapi including Kim	6.69		1.97	78	354	101.98
6. Narmada	9.88		4.01	121	508	61.37
7. Mahi including Dhadhar	3.76		1.18	83	372	22.10
8. Sabarmati	2.17		0.37	76	347	8.39
9. Luni and others of Saurashtra and Kutch	32.19		1.23	38	213	22.88
10. Indus	32.13		7.69	56	277	105.70
11. East flowing rivers between Ganga and Mahanadi	8.10		4.35	147	598	65.69
12. Mahanadi	14.16		7.07	146	594	98.54
13. East flowing rivers between						

	Mahanadi and Godavari	4.97	1.72	111	471	30.27
14.	Godavari	31.28	11.54	110	467	79.15
15.	Krishna	25.00	5.78	81	365	96.82
16.	Pennar and other east flowing rivers between Krishna and Cauvery	14.49	2.53	82	368	41.78
17.	Cauvery	8.79	8.46	99	429	32.31
18.	East flowing rivers below Cauvery	3.51	0.95	91	400	18.44
	Average			118	496	

TABLE 6 Sediment Data of Selected Reservoirs of India

	Reservoirs (1)	Catchment area, in square kilometers, x1 (2)	Average annual silt load, in millions of tons y (3)	Weights, in thousands of tons per squre kilo-meters, w = y/x1 (4)	Surface Runoff in Millions of Hectare Meters x (5)	xw = w x x (6)
1.	Bhakra	56,980	35.1	0.616	1.49	0.906
2.	Matatila	20,720	11.0	0.531	0.79	0.419
3.	Maithan	5,206	7.6	1.460	0.23	0.336
4.	Panchet	9,920	11.9	1.200	0.39	0.468
5.	Hirakud	82,880	46.0	0.555	4.06	2.253
6.	Gandhisagar	22,533	11.0	0.488	0.47	0.229
7.	Nizamsagar	21,694	14.7	0.678	0.43	0.291
8.	Shivajisagar	892	1.45	1.626	0.33	0.536
9.	Ramganga	3,134	7.3	2.329	0.36	0.838
10.	Mayurakshi	1,792	4.1	2.288	0.82	1.876
11.	Girna	4,729	5.3	1.121	0.45	0.504
12.	Lower Bhawani	4,200	1.8	0.429	0.21	0.090
13.	Tungabhadra	28,179	23.8	0.845	1.26	1.064
14.	Machkud	1,956	0.6	0.307	0.12	0.037
15.	Dantiwala	2,862	12.6	4.403	0.06	0.264
16.	Mahi	25,330	31.9	1.259	0.59	0.743
17.	Tawa	5,983	6.8	1.137	0.43	0.489
	Average			1.251		

The data presented in Table 4 indicate that the maximum soil losses (64.5 ton/ha) occur in the cultivated areas of the black soil region followed by the northeastern region (41 ton/ha), ravine region (33 ton/ha), and Assam Valley (28 ton/ha). Total estimates soil erosion (displacement of soil) in the country is 5,334,000,000 tons. which averages about 16.35 ton/ha for the country; the permissible value for soil in the USA is 4.5-11.2 ton ha.

The characteristics of 18 river basins are summarized (Gupta, 1975) in Table 5. This table includes data on catchment area and annual values of precipitation, runoff, EI30 and sediment loads. The EI30 values of the Gujarat and DVC river basins are higher than 1,000, and those of Ganga, Brahmaputra, Mahanadi and other eastflowing rivers between Mahanadi and Godavari are above 500 which is the average EI30 (metric units) for the country. The total sediment loads of Ganga and Brahmaputra are the highest (586,000,000 and 470,000,000 tons) and more than 1/3 of these 18 rivers carry sediment loads of 100,000,000 tons or more.

The data on catchment area, runoff inflow, average annual silt loads, and the weightage factor, w, of 17 reservoirs are presented in Table 6 (CBIP, 1981). The data show that major reservoirs like Bhakra, Hirakud, Tungabhadra and Mahi have the highest annual sedimentation, ranging from 24,000,000-46,000,000tons.

V.V. Dhruva Naryana and Ram Babu (1983) developed regression equations for annual sediment loads of rivers as functions of catchment area, average annual discharge, annual erosion index and rainfall. Data from 21 Himalayan and 15 non himalayan rivers were used. Total sediment discharges of the Indian rivers were computed by the best fit equation. These analysis shows that 5,334,000,000 tons of soil (16.4 ton/ha)is being annually eroded. Ram Babu et.al (1978) computed the average annual erosion index values for various regions of the country.

References

1. **Abrol, I.P. (1971);** Salinity Control in irrigated agriculture. Agric Digest. 22. pp 35-40.

2. **Abrol, I.P. and D.R. Bhumbla (1971);** Saline and alkali soils in India their occurrence and management. FAO World soil resource report. 41. pp. 42-51.

3. **Abrol, I.P. and D.R. Bhumbla (1973);** Field Studies on salt leaching in a highly saline sodic soil. Soil Science, Vol.115. pp. 429-433.

4. **Abrol, I.P. Gaul, B.L. and C.L. Acharya (1975);** Efficient water management - Key to success in alkali soils. Indian Farming. 25(4). pp 15-17.

5. **Aggarwal, J.R. and V.S. Dinker (1990);** Water logging. salinization and plant growth. Proceedings of All India Seminar on Water Logging and Drainage. Dec. 7-8, Roorkee, pp. I1-I21.

6. **Abrol, I.P. (1990);** Caring for our Soil Resources. Proceedings Int. Symp. on water erosion. sedimentation and resources conservation. Oct. 9-13. 1990. Dehradun.

7. **Anonymous (1989);** Report of the working group on Soil & Water Conservation. including watershed management formulation of 8th five year plan. Dept. of agri & cooperation. Ministry of Agriculture. New Delhi.

8. **Bhumbla, D.R. (1972);** Reclamation of saline and alkali soils, Indian Farming, 22(2) pp 19-21.

9. **Babu, R., Tejwani, K.G., Agarwal, M.C. and L.S. Bhushan (1978);** Distribution of erosion index and iso-erodent map of India, Indian J. of Soil Cons., Vol.6, No.1, pp 1-14.

10. **B.Das (1985);** Surface drainage and runoff criteria for agricultural areas, Proced. National Seminar on estimation of runoff for surface and subsurface drainage, Dec. 9-10, New Delhi.

11. **C.B.I.P. (1981);** Sedimentation studies in Reservoirs, Technical Report No.20, New Delhi.

12. **C.W.P.R.S. (1987);** Annual Report of Central Water and Power Research Stations, pp. 53-55.

13. **Dhillon, G.S., Singh, T. and D. Paul (1986);** Technology for skimming Canal seepage water in saline areas, Proceedings of 53rd R&D Annual Session of CBIP held at Bhubaneswar, May 8-10, pp. 29-40.

14. **D. Rai et al (1990);** A prevention and reclamation methodology of water logged and Usar soil in Sharda Canal Command of U.P., Proceedings of All India Seminar on Water Logging and Drainage, Dec. 7-8 1990, Roorkee, pp. I 33-42.

15. **Gupta, S.K., Tejwani, K.G., Mathur, H.N., & M.M. Srivastava (1970);** Land resources regions and areas of India, J. of the Indian Society of Soil Science, Vol.18, No.2, pp. 187-198.

16. **Gupta, G.P. (1975);** Sediment production - Status report on data collection and utilization, Soil Conservation Digest, Vol.3, No.2, pp. 10-11.

17. **Gupta, S.K. and V.V.D. Narayana (1972);** Surface drainage methods for saline-alkali soils, National Symp. Waterlogging, Causes and measures for its prevention, CBIP, New Delhi, Pub. 118, pp. 129-134.

18. **Gurmel Singh (1990);** Soil and Water Conservation in India, Proced. Int. Symposium on Water Erosion, Sedimentation & Resources Conservation, 9-13 Oct., Dehradun.

19. **J.S. R. Mohan Rao (1985);** Surface drainage provided for Nagarjunasagar project right canal Ayacut areas, proced. National Seminar on Estimation of Runoff for surface and subsurface drainage, ., Dec. 9-10, New Delhi, pp. I-JMR-1 to I-JMR5.

20. **Kanwar, J.S. (1961);** Reclaiming deteriorated soils, Fertilizer News 6 (2). pp. 19-21.

21. **Kanwar, J.S. (1962);** Reclamation of saline-alkali soils, Proc. Symp. Salinity and Alkalinity, I.A.R.I., New Delhi.

22. **K V Jayakumar (1985);** Optimal design of drainage and sewerage system, Proced. National Seminar on Estimation of Runoff for Surface and Subsurface Drainage, I.A.H., Dec. 9-10, New Delhi, pp. IV-KVJ to IV-KVJ-9.

23. **Mishra, G C and B Soni (1988);** Surface drainage system for agri. watershed, Jal Vigyan Sameeksha, Vol.III, No.2, Dec. pp. 72-82.

24. **N K Tyagi (1988);** Managing salinity through Conjunctive Use of water resources, Ecological Modelling, Vol.40, pp. 11-24.

25. **Pandey, R S and O P Singh (1986);** Hydrological Investigations for subsurface drainage in saline soils - a Case Study, Proced. 53rd annual R&D Session of CBIP, May 9-10, Bhubaneswar, Tech. Session V, paper No.6.

26. **Puri, S R Sharma, S C and A K Mehra (1985);** Generalised charts of maximum one day rainfall for different return periods for the state of Haryana, Proced. National Seminar on Estimation of runoff for surface and subsurface drainage, I.A.H., Dec. 9-10, New Delhi, pp. II-PSM-1 to II-PSM-VI.

27. **R Kumar and J Singh (1985);** Management of saline ground water through skimming wells, Proced. National Seminar on Estimation of runoff surface and subsurface drainage, I.A.H., Dec. 9-10, New Delhi, pp IV-KJS-1 to IV-KJS-VI.

28. **Ram Babu and V V D Narayana (1985);** Flood frequency analysis for small watershed in Doon Valley, Proced. National Seminar on Estimation of runoff for surface and subsurface drainage, IAH, Dec. 9-10, New Delhi, pp. III-RBD-1 to III-RBD VII.

29. **Rao, K V G K and P B Leeds Harrision (1991);** Desalinization with subsurface drainage, Agri. Water Management, Vol.19, Elsevier Science Pub., pp. 303-311.

30. **S K Gupta (1986);** Subsurface drainage studies for waterlogged lands, a Case Study of Rohtak and Sonepat distt. of Haryana, Proced. 53rd Annual R&D Session of CBIP, May 8-10, Bhubaneswar, Tech. Session X, paper no.5.

31. **Singh O P and R S Pandey (1986);** Operational performance of vertical subsurface drainage system in saline soils of Haryana, Proced. 53rd annual R&D Session of CBIP, May 8-10th, Bhubaneswar, Tech. Session X, paper no.4.

32. **Singh, O P and R S Pandey (1985);** Effect of subsurface drainage on hydrological aspects of saline soil reclamation and crop performance, Proced. National Seminar on Estimation of Runoff for surface and subsurface drainage, IAH, Dec. 9-10th, pp. IV-SP-1 to IV-SP-IV.

33. **Singh, R D and B Soni (1990);** An application of Unit hydrograph technique for estimation of design flood for agri. drainage, Proced. All India Seminar on waterlogging & drainage, Dec. 7-8, Roorkee, pp. II-37 to 46.

34. **S K Gupta (1985);** Subsurface drainage design - comparison of unsteady state design equations, Proced. National Seminar on Estimation of runoff for surface & subsurface drainage, IAH, Dec. 9-10, New Delhi, pp. IV-SKG 1 to 7.

35. **Satyanarayana, T V and S Chittaranjan (1985);** Synthetic unit graph parameters for three small watersheds in Black Soils of Karnataka, Proced. National Seminar on Estimation of Runoff for surface and subsurface drainage, IAH, Dec. 9-10, New Delhi pp. III-SSC-1 to X.

36. **Sharma, S C, Kaur, S and A K Mehra (1985);** Rainfall depth duration frequency studies for design of urban drainage system in Delhi, Proced. National Seminar on Estimation of Runoff for surface and subsurface drainage, IAH, Dec. 9-10, New Delhi pp. IV-SSM-1 to IX.

37. **Subhash Chander and P N Kapoor (1985);** Drainage of Agricultural lands, Proced. National Seminar on Estimation of runoff for surface & subsurface drainage, IAH, Dec. 9-10, New Delhi, pp. I-SCK-1 to VIII.

38. **Soni B and G C Mishra (1987);** Leaching Requirement of agri. land and study of movement of salts, NIH Report, TR-22, Roorkee.

39. **Tejwani, K G and V V D Narayana (1961);** Soil Conservation survey and land use capability planning in the ravine land of Gujarat, J. of the Indian Society of soil science, Vol.9, No.4, pp. 235-244.

40. **Tyagi, N K and V V D Narayana (1982);** Ground water recharge under alkali soils during reclamation, J. Agri. Water, Manage. Vol.5, pp. 51-60.

41. **Tyagi, N K and V V D Narayana (1983);** Planning for alkali land reclamation under rainfall uncertainty, Ecological Modelling, Vol.20, pp. 243-258.

42. **Tyagi, K C Pillai, N N and N K Tyagi (1987);** Ground water simulation for planning salinity management, Proced. National Symp. on Hydrology, Dec. 16-18, NIH Roorkee, pp. V 52-V 66.

43. **V V D Narayana & Ram Babu (1983);** Estimation of Soil Erosion in India, J. of Irrig. & Drainage Engg. Vol.109, No.4, Dec. pp.419-434.

44. **Yadav, J S P (1972);** Co-ordinated research on water management and salinity in India, Indian Farming, 22(2), pp. 43-45.