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SOIL SALINISATION AND RECLAMATION IN COMMAND AREAS

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Perface

Land drainage is one of the main facets of reclaiming and improving agriculture lands in humid regions. In arid regions where irrigated agriculture should not be hampered by water logging and salinisation, land drainage is a neccesary complement to irrigation. In India irrigation potential has increased significantly during the last several years with this the problem of water logging and existance of efficient drainage system have also increased. As the demand for food grains is increasing at an alarming rate control of water logging has become the need of hour. To develope expertise in the field of drainage and to share the experience of Netherlands in the field of drainage Sri M.K.Shukla and Sri R.P. Pandey, Scientist B have been sent to ILRI, the Netherlands under the Indo- Dutch collaboration project WAMATRA (Water management and training). This report is prepared by shri M.K.Shukla, scientist B, drainage division and shri R.P.Panday, scientist B, drought division of the institute. This report deals with the case studies on the problems of waterlogging, seepage and salinisation existing in command areas and their possible solutions.

(S.M.Seth)
DIRECTOR

Abstract

Land drainage is large scale drainage where the object is to drain surplus water from a large area. Efficient use of land and water resources is to a greater extent dependent upon the control of salinisation 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. When the water table reaches a height, which is within the capillary lift of the soil, the soil moisture is brought to the surface. When water evaporates, salts, which were originally present in the irrigation water or which were dissolved in the rising ground water, get concentrated on the land surface. Similar problem has been reported in the coastal area Pan De Azucar This study deals with the design of subsurface drainage system for an area suffering from the problem of shallow ground water table. A case study on the reclamation of strongly salinised sodis soil is also dealt with here.

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1.0 INTRODUCTION

Water and air, which compete for the same position in soil in the root zone, are both needed for plant growth. The soil moisture deficiency is abated through irrigation and the oxygen deficiency is done away with by providing drainage facilities in the agricultural field. It is convenient to divide overall drainage into two types: Land drainage and Field drainage.

Land drainage is large scale drainage where the object is to drain surplus water from a large area by such means as improving the flow of the streams and river, excavating large open drains, erecting dykes and levees and pumping. Schemes of this nature are associated with large areas of low-lying land, frequently in coastal areas and involve major civil engineering work. Field drainage is removal of surplus water, that otherwise restricts crop growth, from agricultural land. The surplus water may accumulate because of rain or surface flow and can not naturally be drained away fast enough. The function of field drainage is directed towards accelerating or increasing the natural outflow, either on the surface by means of open drains or ditches or below the ground by a system of closed under drains. If the primary object is to avoid surface water logging then surface drainage is provided, but if a permanent lowering of water table is desired besides removing the water from the root zone, then a system of sub surface drain is often used.

1.1 Soil Salinisation and Drainage

Efficient use of land and water resources is to a greater extent dependent upon the control of salinisation problem. The long history of irrigation has recorded severe deterioration of land resources due to salinisation and waterlogging. It is a well known phenomenon that, when an area is irrigated excessively over an extended period of time, the ground water level rises. When the water table reaches a height, which is within the capillary lift of the soil, the soil moisture is brought to the surface. When water evaporates the salts, which were originally present in the irrigation water or which were dissolved in the rising ground water, get concentrated on the land surface by the so called 'tea kettle effect'. This causes soil salinity and some times alkalinity which are harmful to plant growth. When a saline water table rises and remains in the root zone longer than about 48 hours, resulting in an abnormally high saline moisture condition, agricultural production is usually seriously affected. Vast areas, which once open a time were productive under irrigation, have become sterile and saline waste land in Mesopotamia, North Africa and in the Far East. In modern times, the rate of salinisation and land destruction has been greatly accelerated, especially in areas irrigated with plentiful, low cost water, which contains dissolved salts. Although the growth of salinity of irrigated soils is practically universal, there are a few encouraging example of successful prevention of deterioration and the improvement of originally saline lands. In many irrigation systems in USSR, salinization processes were completely stopped and saline soils were desalinized and returned to cultivation with good results. This was achieved by deep horizontal drainage, leaching of salts in accordance with the salt balance concept, selective application of vertical pumping drainage, introduction of effective hydroisolation in the canals, and overall sound management of the water resources (Drainage manual).

1.2 Waterlogging and Salinization

Plants require oxygen as well as water for their growth. They obtain their oxygen requirement from two sources: from the soil air and from the open atmosphere. Oxygen supply through the leaves and from there through the plant to the terminal oxides in the roots is sufficient to maintain growth in plants adapted in aquatic condition (i.e. rice), and to support at least the upper 2 cm of roots in many cereal seedlings (Jen sen et al, 1964, Greenwood and Good man 1971; vide Briggs and courtney, 1985 vide drainage manual). Nevertheless it is rarely adequate to satisfy requirements in more active and mature arable crops. Consequently, conditions affecting the supply of oxygen from the soil air are critical.

Movement of oxygen through the pore system of the soil to the plant roots is only indirectly a function of the size of the pores. In air-filled pores, oxygen diffusion is rapid and oxygen deficiencies are rare. In saturated pores the effective coefficient of oxygen diffusion is much lower, possibly only 1/1000th or less of the rate in free air (Briggs and Courtney, 1985 vide drainage manual). During waterlogged condition oxygen diffusion is unable to sustain root or microbial requirements for any length of time. In the absence of sufficient oxygen, substance such as alcohol and cyanide may be formed in the plan tissues and plant growth may be severely curtailed (Rose 1968, Smith and Russel 1969). It is however, not only the direct consequence of a reduced supply of oxygen which inhibits plant growth in waterlogged soils. Under certain circumstances, toxic compounds may built up as a result of oxygen deficiency.

The most widespread and direct factor in the formation of contemporary saline soils in different parts of the world is ground water evaporation and transpiration where runoff is either reduced or non existant. Both the intensity of ground water evaporation and salt accumulation processes attain their maximum in arid climate conditions when the ground water levels reaches a depth of 2-3 m or less.

REFERENCES

2.0 CASE STUDIES

During the course of Land drainage two case studies have been discussed apart from the class room lectures to acquaint us with the actual problem in the field. These case studies were related with the seepage, design of drainage system and salinization.

One of the case study was on leaching called CHACUPE where the reclamation of a strongly salinized sodic soil was dealt with. The other case study was PAN DE AZUCAR, this case study is dealing with design of drainage system in an irrigated area under sugarcane. These case studies are described in the report.

2.1 PAN DE AZUCAR

* Case study on Design of a drainage system in an irrigated area under sugar cane

2.1.1. Introduction

- In a coastal plain (delta) with alluvial soils in an arid region, where sugar cane is cultivated, some areas have been abandoned because of low yields, due to drainage and salinity problems (Figure 1). It was decided to reclaim an area of approximately 100 ha. The area Pan de Azucar was abandoned 2 years ago. The informations available about the area are contour map of the area, soil texture classification, location of hydraulic conductivity measurements etc. It appeared from well logs here and there in the area, that the soils at greater depth are stratified with predominantly light textures (sandy). It is the experience that drained areas in the surroundings have an average basic discharge of about 2 mm/day, under non-irrigated conditions. This means that the area receives seepage water from higher regions. In non-drained areas (other areas than the one under consideration but in the close vicinity) where the watertable is close to the surface (e.g. < 0.30 m below ground surface) the upward seepage possibly reaches a value close to open water evaporation. The latter is about 5mm/day in September. Measurements of the hydraulic conductivity by means of the augerhole method were carried out. The results are given in Table 1. Information about the hydraulic conductivity of the deeper soil layers could not be obtained, because the area was planned for immediate land preparation and cultivation with cane;

Fig 1 : Area PAN DE AZUCAR

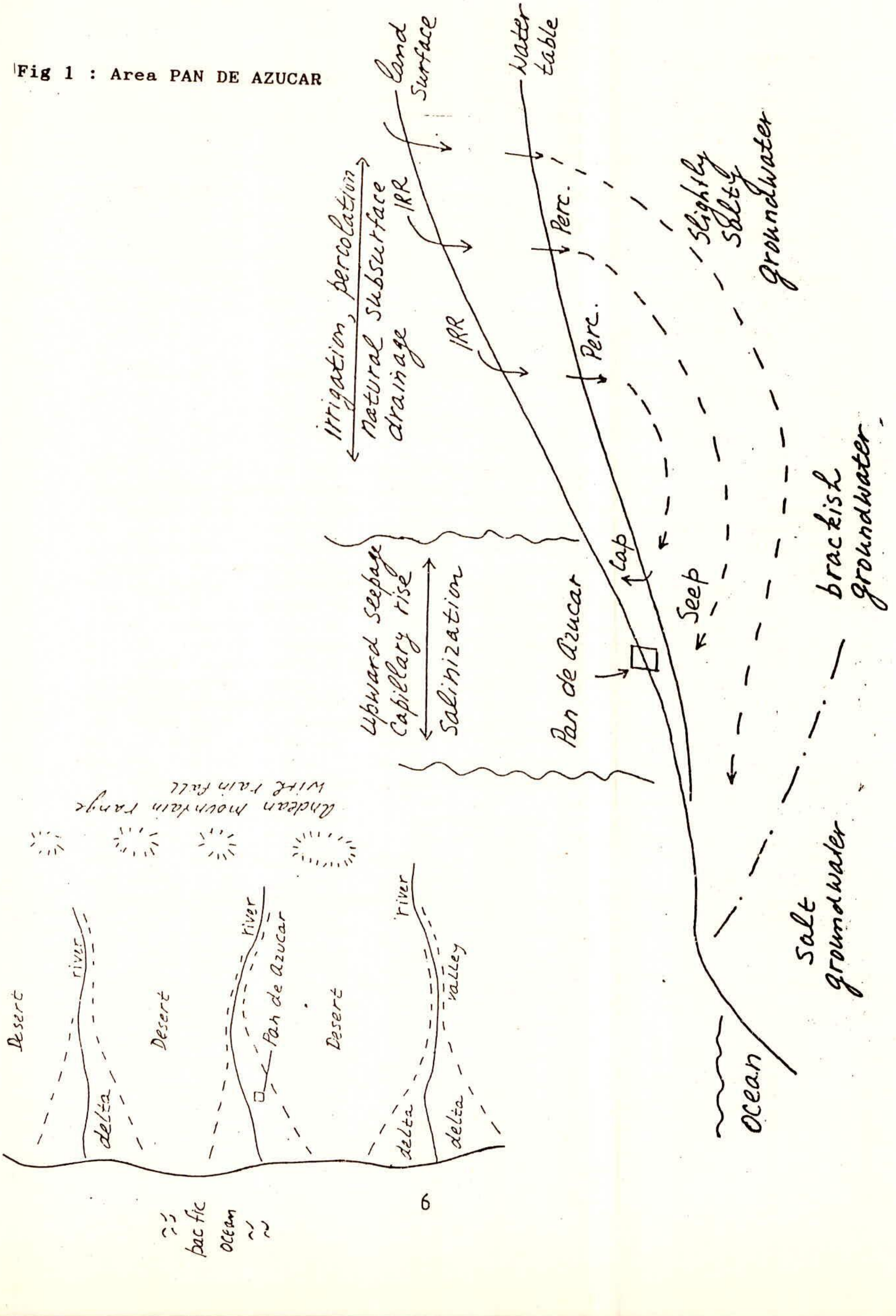


Table 1 : Measured hydraulic conductivity values in the field

Soil pit No.	Depth of auger hole (m)	Hydraulic conductivity (m/day)
1	1.85	0.1
2	1.85	0.6
3	2.35	1.1
4	2.35	0.7
5	2.35	1.7
6	2.35	0.4
7	2.35	0.3
8	2.35	0.6
9	2.35	1.0
10	2.35	0.9
11	2.35	2.5
12	2.08	0.5
13	2.35	0.4
14	2.05	1.2
15	2.05	0.4
16	2.05	0.5
17	2.35	0.7
18	2.35	0.9
19	2.35	0.9

A study made of irrigation in the sugarcane plantations of the area shows that irrigations are given monthly. In one study it is estimated that annual irrigations amount to 200 cm, of which 50% is used by the plant and 50% is lost to the underground, i.e. 2.8 mm/day on average. Another study estimates, that irrigation can be improved in such a way so as to provide 240 cm of water annually of which 2/3 will be used by the plants and 1/3 is lost by deep percolation, i.e. 2.2 mm/day on average.

During the irrigation period of the crop, the minimum permissible average depth of the watertable should not harm root development and plant growth. (Can be found from established production functions). Following the irrigation, there is a dry spell of some months during which the cane augments its sugar content. During this period, the watertable is not allowed to come closer to the soil surface than 1.50 m. In addition to the above information it can be mentioned that rainfall can be neglected. Soils have salinized but they are easy to reclaim it sufficient irrigation water is available. High priority was given to early implementation of a tile drainage system and an urgent request was directed to the technical staff for preparation of a layout (i.e. design specifications). Because the field operations, especially the harvest, are heavily mechanized, open drains in the field should not be used so that a composite drainage system should be made. Clay pipes are available in diameters (inside) ranging from 10, 12, 15, 20, 25 to 30 cm. They are handlaid in mechanically excavated trenches. So far, filter materials have not been applied but existing drains (in other units), show siltation problems. The available outlet is an open ditch bordering the area in the extreme south, along the road.

2.1.2 Task designer

On basis of the information indicated so far, a layout and design of a composite drainage system should be prepared, included the preparation of a longitudinal profile of the collector drains and the determination of pipe diameters.

2.1.3 Basic steps and tasks in preparing layout and design

I Explain why drainage is required. Illustrate this qualitatively using water-salt balances;

II Indicate on the map the layout of the collector drains (see note). Indicate also the direction of the lateral drains;

III Estimate the upward seepage of groundwater. This can be done with the aid of Map 2 (depth to watertable map). The guiding principle should be that the higher the watertable the greater the velocity of capillary rise and the more upward seepage is to be expected. Make a graph or table of seepage rate versus depth of watertable, going from a maximum of 5 mm/day at a shallow watertable to a minimum of 0 mm/day at a deep watertable (say 1.5 to 2 M);
Decide whether you use a linear relation or one of the attached tables for capillary rise as a function of depth of watertable, soil type and moisture content of the topsoil. What will be the suction in the topsoil? Explain why, in this particular situation, use can be made of the theory of capillary rise in steady state to estimate the upward seepage;

IV Indicate on the map the seepage units in which the seepage rate will be assumed constant. The subdivision of these units should be based on the layout of the collector drainage system and the direction of the lateral drains and on the information obtained from the relation between watertable depth and seepage rate. Calculate the average seepage rate per drainage unit. Do not take the drainage units too small; they should contain at least 5 lateral drains. Check this later, when the drain spacings have been calculated and correct the units if necessary;

V Indicate on the map the zones in which the hydraulic conductivity is the same. The subdivision of these zones should be based on the layout of the collector drainage system and the direction of the lateral drains and on the information on hydraulic conductivity. Do not take the K-zones too small; they should contain at least 5 lateral drains and at least 5 points of K-measurement. Take practical limits of the K-zones in relation to the limits of the S-units. The K-zones should compromise one or more full S-units or the S-units should comprise one or more full K-zones;
Estimate the average hydraulic conductivity of each zone. Discuss whether you take an arithmetic mean, geometric mean, model value or median value on the basis of a frequency distribution of K values;

VI Indicate on the map the drainage blocks with equal seepage and hydraulic conductivity values. These blocks will have equal drain spacing;

VII For both the irrigation and the ripening (dry) period the drainage discharge has to be indicated for each block, the drainage discharge being equal to the upward seepage and the deep percolation:

VIII Find out whether the irrigation or the ripening period is determining the drain depth and choose two alternative values of drain depth. Discuss the depth of the impermeable layer in relation to the seepage phenomena and estimate the ratio of depth of the impermeable layer to drain spacing. Correct later if necessary;

IX Determine the available hydraulic head (h) for drainage; h = g - i, where g = drain depth, and i = permissible average depth of the watertable. Make a distinction between i values for the irrigation and ripening period;

X This step involves the calculation of the drain spacing. Try first the smallest drain piles (r = 0.05 m) and correct later (after step XIII) if necessary. Calculate the spacings separately for irrigation season and ripening period, for each drainage block, and for each drain depth. Choose the critical spacing for each block and adopt a practical value for the final design;

XI Indicate on the map the layout of the lateral drains. The minimum slope of the laterals is 0.2%. The minimum length is 2 to 3 times the drain spacing. Maximum length and slope are determined by the boundary and topographic conditions of the area (See Note). If necessary. adjust the layout of the collectors, the S-units, the K-zones and the drainage blocks, etc.;

XII Number the collectors, the lateral drains and the corresponding sections of the collector;

XIII Prepare a longitudinal profile of a collector drain and its laterals. Indicate in the profile of the collector the outlets of the laterals, and in the profile of the laterals the inlet to the collector. Check whether the depth of laterals corresponds to the design depth;

XIV Calculate for the laterals and each section of the collector drain the required discharge capacity and diameter;

XV Assuming a gravel envelope (filter) is required for the drains, determine the required grain (=particle) size distribution.

2.1.4 Note on Layout of the Drainage System:

- The regularity of the drainage pattern is important, i.e. the best layout will provide
  - the pattern that fits best within the shape of the area
  - a pattern in which the drains are reasonably parallel, with laterals joining the collectors at angles greater than 60
  - a pattern in which the lateral drains are of uniform length;
- The slope of the collector is important; it should be as steep as possible to allow small-diameter pipes to be used and thus saving money;

- The slope of the laterals should be as regular as possible; they should have a minimum slope of 0.2% and should otherwise be parallel to the field;

- If possible, a collector should be located along the boundary of an area in order to have easy access to the inspection chambers. When placed along the boundary, these chambers need not be buried, because they will not hamper agricultural operations;

- The maximum length of the laterals is bound to restrictions. In flat land the laterals cannot be much longer than 200 m, because of the minimum drain slope required. In sloping land they can be longer. However, cleaning and maintenance operations impose a limit of approximately 300 m, unless buried manholes are installed along the drains, in which case laterals can be longer. However, the longer the drain, the less opportunity there is to adapt depth or spacing to variations in topographic, soil, or hydrological conditions. It seems that in the area Pan de Azucar the maximum length of the lateral drains is approximately 500 m provided that manholes can be installed along the drains;

The minimum length of a lateral drain stands in relation to the spacing. If the ratio length: spacing were to be too small (say less than 2:1), the lateral drain would be inefficient. So, if the drain spacing is 100 m, the minimum length of a lateral is 200 m.

2.2 SOLUTION TO CASE STUDY PAN DE AZUCAR

STEP I: Subsurface drainage is required because without the drainage the upward seepage of groundwater does not permit leaching of the soil, and there would be continuous salt accumulation according to

$$A = Irr \times C_i + Seep \times C_s$$

where

A = Annual salt accumulation per ha
Irr = Annual amount of irrigation water applied per ha
C_i = Annual amount of seepage water per ha
$Seep$ = Annual amount of seepage water per ha
C_s = Salt concentration of the seepage water

Note that the evapotranspiration (ET) equals

$$ET = Irr + Seep$$

So that the amount of irrigation water is less than ET. Too much irrigation would create waterlogging conditions. After applying a subsurface drainage system and giving an amount of irrigation water greater than ET, the excess water can percolate (Perc) down through the rootzone, leaching the soil and maintaining an acceptable salt balance for salinity control. At the same time the seepage water is intercepted by the drains, and it contributes not any more to the salinization. The salt balance in the rootzone now becomes

$$A = Irr \times C_i - Perc \times C_p$$

C_p is the salt concentration of the percolating water, which depends in the salt concentration (Cr) of the water in the rootzone: $C_p = f.C_r$ so that

$$A = Irr \times C_i - f \times Perc \times C_r$$

Initially the value of C_r is high so that A becomes negative (salt removal). Then C_r diminishes and A becomes smaller until A

= 0. The equilibrium salt concentration in the rootzone is

$$C_r^* = Irr \times C_i / f \times Perc$$

Thus, the soil salinity is controlled and agriculture is made possible.

STEP II: See the sketches on next page (fig 2) and to find which solution is the best. Following are some of the criteria of a good drainage pattern.

- The regularity of the drainage pattern is important, i.e. the best layout will provide

  * the pattern that fits best within the shape of the area
  * a pattern in which the drains are reasonably parallel, with laterals joining the collectors at right angles
  * a pattern in which the lateral drains are of uniform length;

From the point of view of regularity, Solutions A or A' appear to be the best;

- The slope of the collector is important; it should be as steep as possible so as to allow small-diameter pipes to be used and thus saving money;

In this respect Solutions B' and BA appear to present a drawback. Laterals in Solution D are of very different lengths.

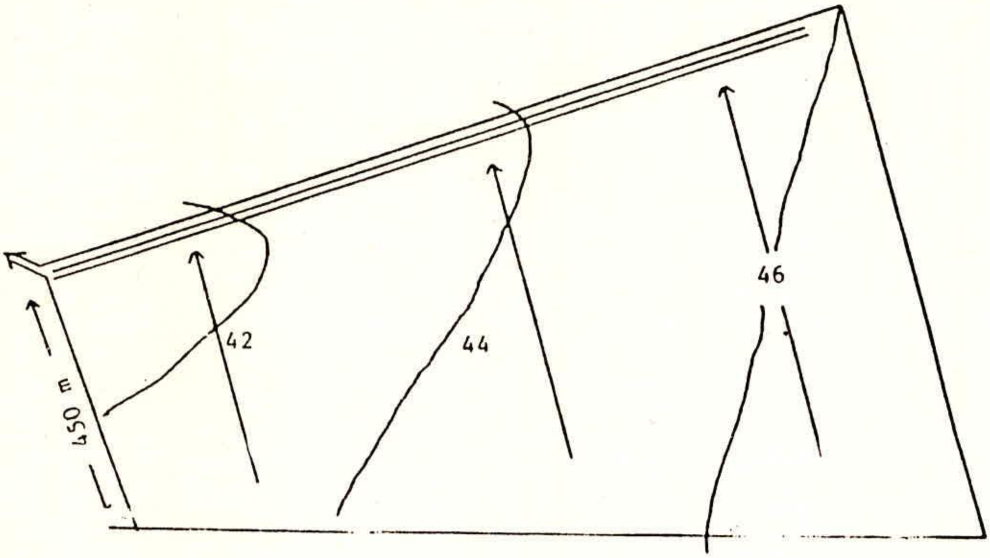
- The slope of the laterals should be as regular as possible: they should have a minimum slope of 0.2% and should otherwise be parallel to the field;

As regards this aspect there seems to be little difference between the various solutions. It should, however, be noted that there is an along depression in the SW part of the field. If this depression is not leveled, a collector or a field drain should be placed in the longitudinal axis of the depression or otherwise the average depth of the drains should be increased;

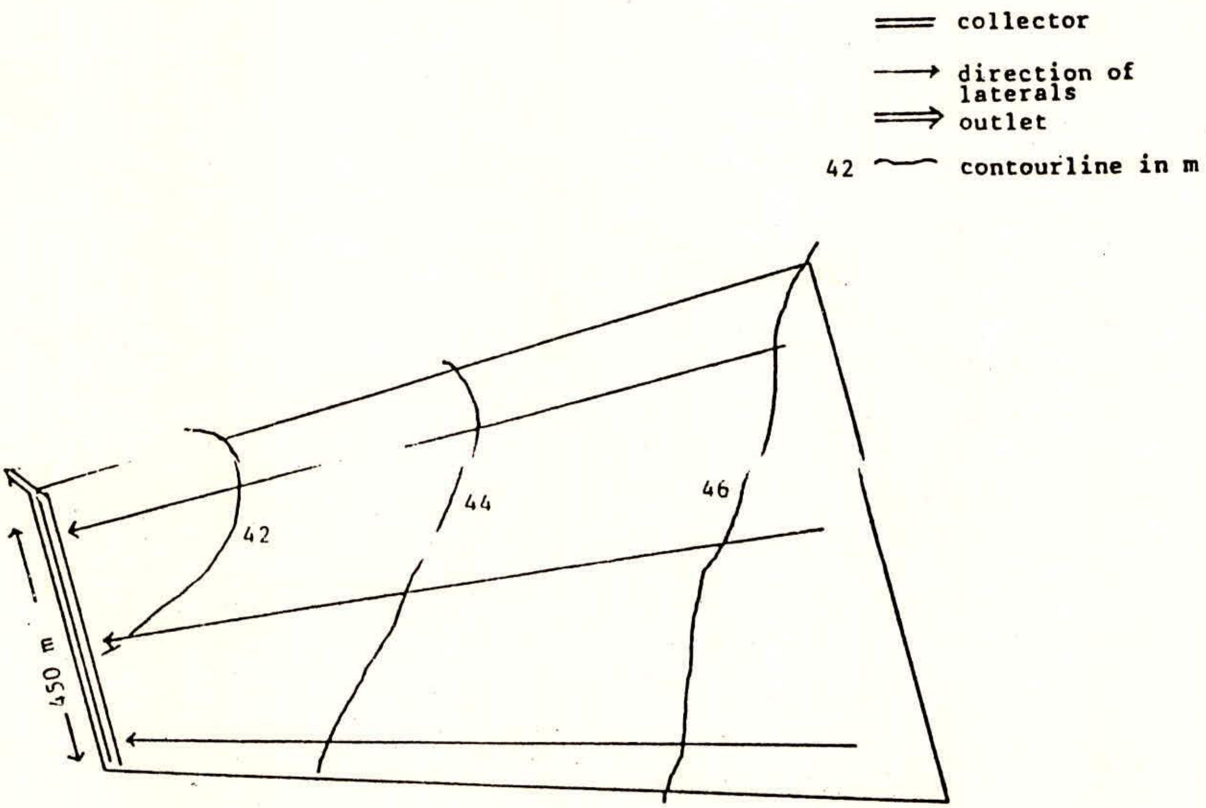
If possible, a collector should be located along the boundary of an area in order to have easy access to the inspection pits. When placed along the boundary, these pits need not be buried, because they will not hamper agricultural operations. Both Solutions A and B are favorable from this point of view;

-The maximum length of the laterals is bound to restrictions. In flat land the laterals cannot be much longer than 200 m, because

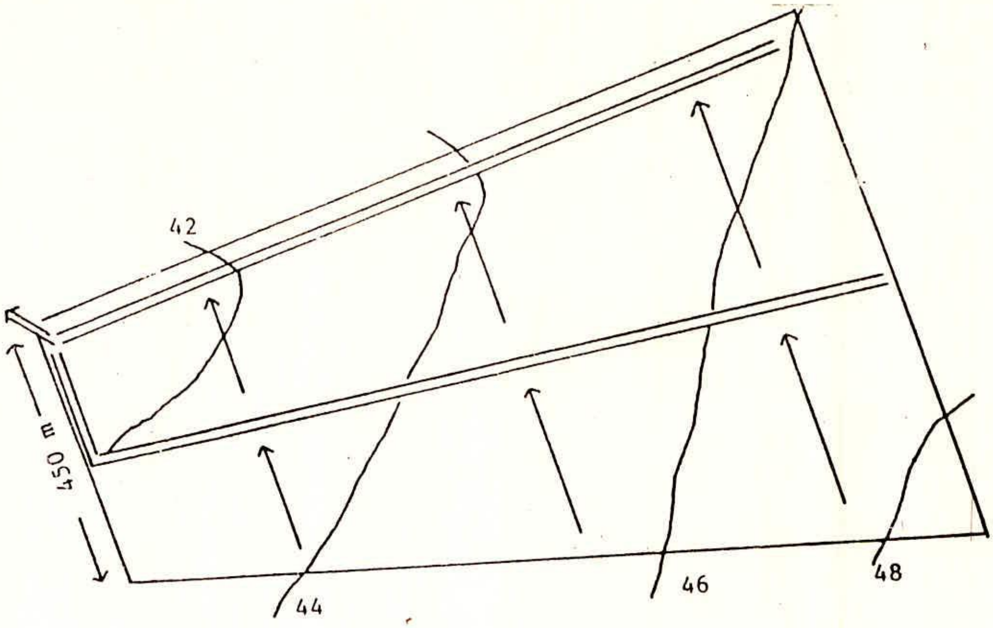
Fig 2 Possible solutions for the location of the collector pipe drains,



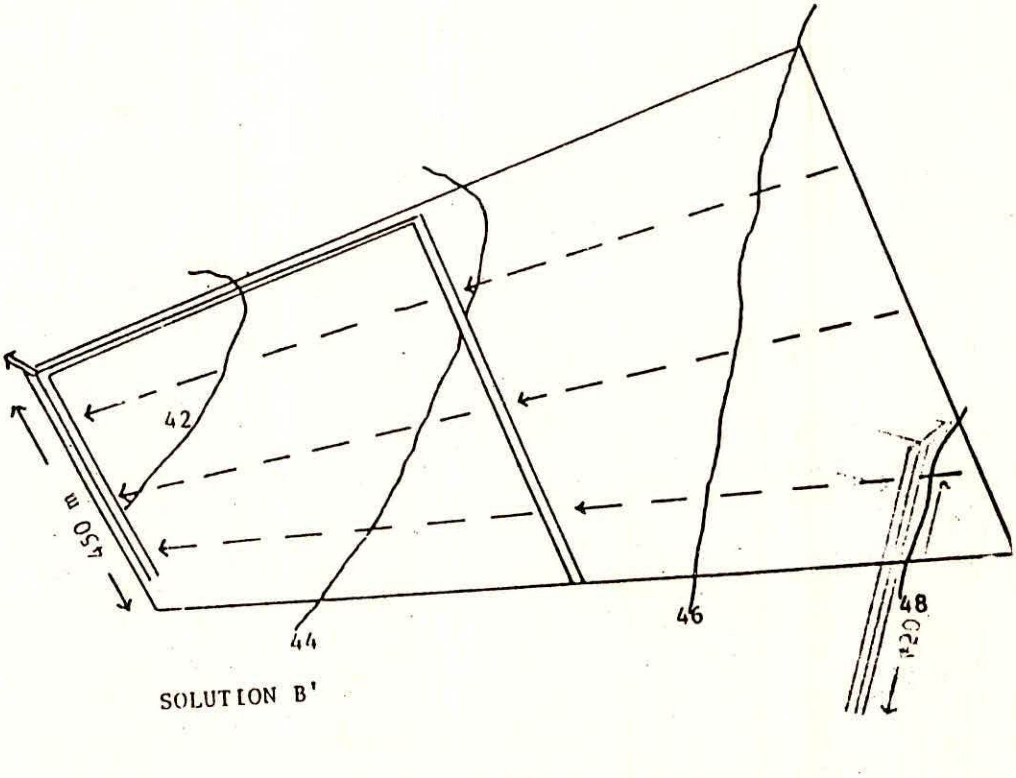
SOLUTION A



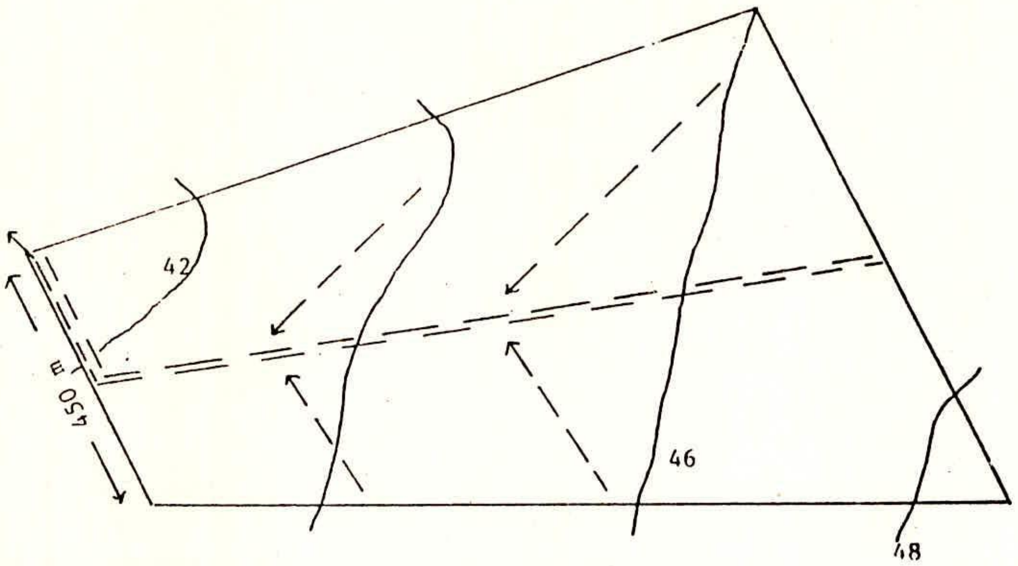
SOLUTION B



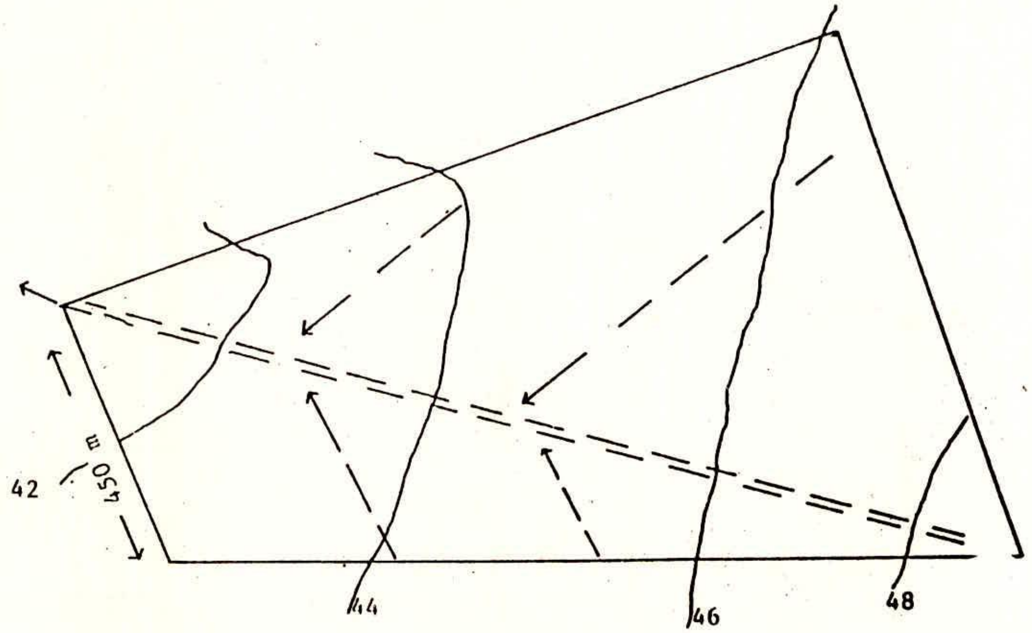
SOLUTION A'



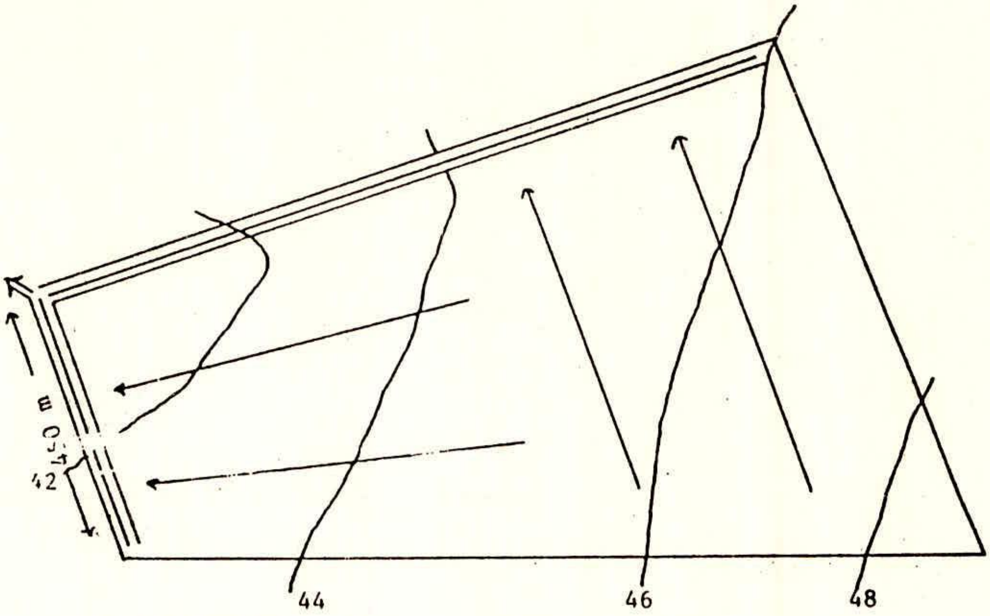
SOLUTION B'



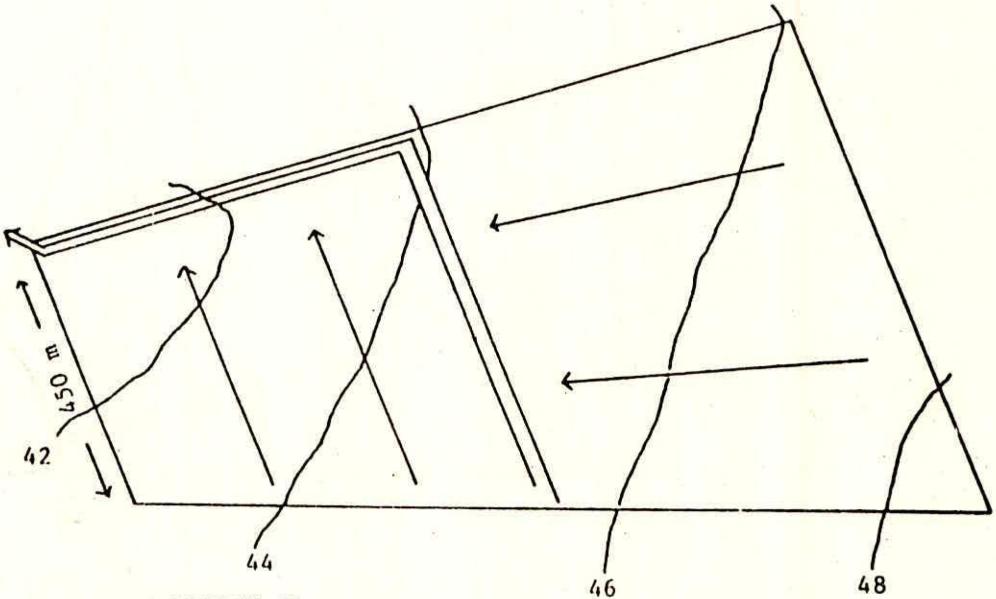
SOLUTION C



SOLUTION D



SOLUTION AB



SOLUTION BA

of the minimum drain slope required. In sloping land they can be longer. However, cleaning and maintenance operations impose a limit of approximately 300 m, unless buried manholes are installed along the drains, the less opportunity there is to adapt depth or spacing to variations in topographic, soil, or hydrological conditions. It seems that in the area Pan de Azucar, keeping in mind the differences in hydrological conditions, the maximum length of the lateral drains is approximately 500 m provided that manholes can be installed along the drains. Solutions A', B', BA and C fulfill these requirements.

-The minimum length of a lateral drain stands in relation to the spacing. if the ratio length: spacing were to be too small (say less than 2:1), the lateral drain would be inefficient. So, if the drain spacing is 100 m, the minimum length of a lateral is 200 m. Solution D has a disadvantage in this respect.

Conclusion: Considering that the northern part of the area (which has been left out of consideration so far) has also to be drained, Solution A' appears to be the most attractive. The provisional layout of the collector drains for the whole area is sketched in the Figure 2.

STEP III: Under dry conditions, the upward seepage of groundwater is transformed into capillary rise in the unsaturated zone, followed by evaporation. Under steady state conditions and in the absence of rainfall and irrigation, a relation can be found between the rate of capillary rise, the depth of the watertable, the dryness of the topsoil and the hydraulic properties of the soil. Under such conditions the rate of capillary rise (and subsequent evaporation) equals the rate of upward seepage, otherwise there would be no steady state. Hence, the upward seepage can be estimated from the capillary rise, and thus can be deducted from the depth of the watertable. If irrigation or rainfall occur, the above procedure is not applicable.

Assuming a dry topsoil (pF = 4, suction h = 10 000 cm) we find form the tables of capillary rise the following information.

	Depth of watertable (cm)	Rate of capillary rise (cm/day) in steady state
Light loamy	60	0.15
Medium course	90	0.06
Sand	120	0.04
Medium fine	60	0.50
Sand	90	0.12
	120	0.05

It is seen that the two different soil textures give appreciably different results for capillary rise at shallow watertable, even though both textures concern light soils. The assessment of capillary rise becomes still more complicated when the soils are stratified, when a mulch layer develops, or when the soil is vegetated by salt and drought tolerant plants and shrubs. Therefore, we opt for a more general and perhaps more practical approach as is illustrated in the figure 3.

STEP IV: The following seepage units are discerned (see also the sketch in the figure 4).

Unit *)	Average depth to watertable	Seepage (mm/day) **)
A	90 cm	2.5
B	60 cm	3.5
C	90 cm	2.5
D	120 cm	1.5

*) Note the correspondence to the collector layout
**) Derived from the figure in Step III

STEP V: It is seen from the data that no clear relationship can be discovered between soil texture, depth to watertable and hydraulic conductivity, because only three data refer to course textures (soil pits 6, 10 and 17), two refer to fine textures (13 and 19), whereas the other 14 data refer to medium texture.

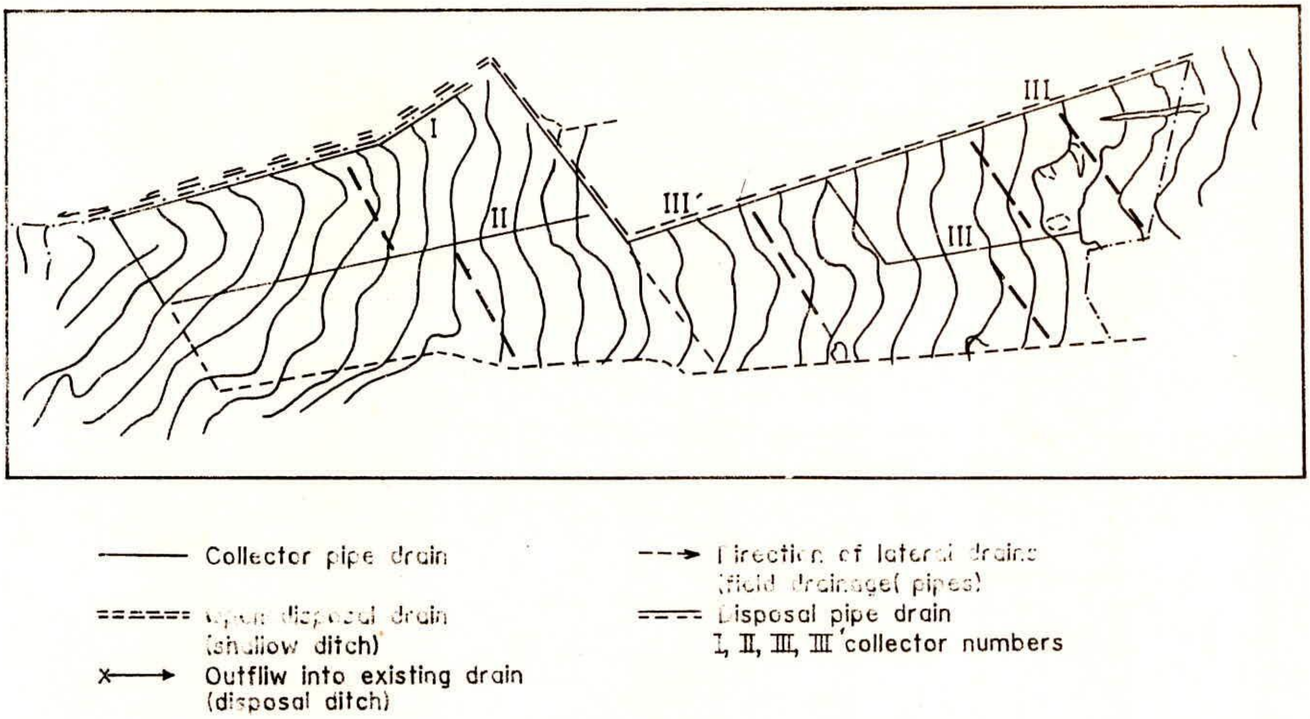
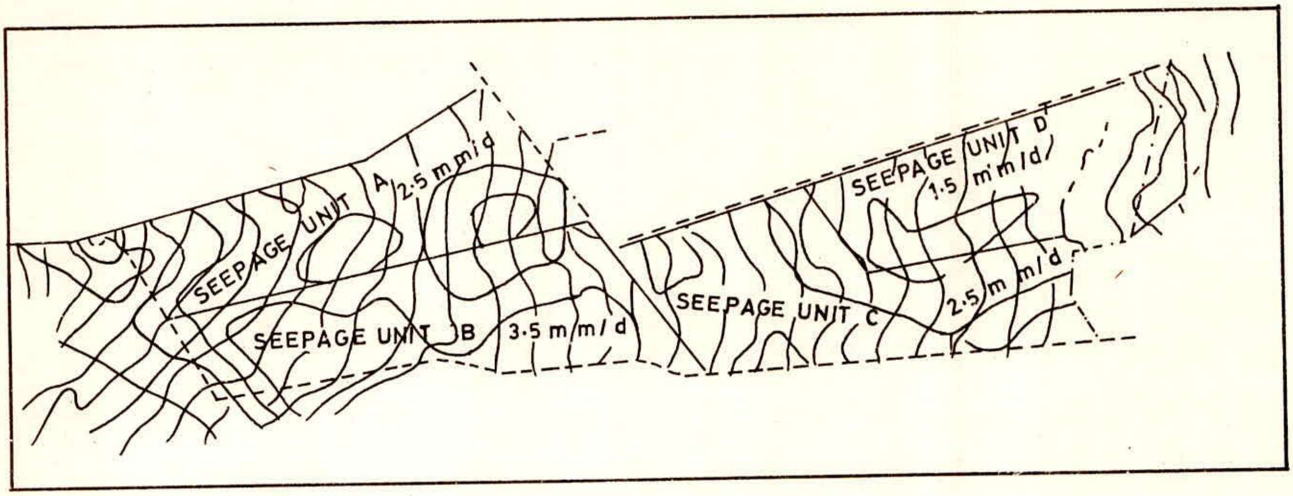


FIG.3-Sketch of provisional layout of collector



Unit A: average depth to watertable 0.9 m
Unit B: " " " " 0.6 m
Unit C: " " " " 0.9 m
Unit D: " " " " 1·2 m

FIG.4: SETCH OF SEEPAGE UNITS

Assuming, that the variation of K found at the surface will be representative of K for deeper layers as well, then an average of the presented K values can be used in the drainage formula. The assumption is not unreasonable with a view to the geologic formation of the area. Inspection of the measured K values in the figure 5 reveals that it is hardly possible to distinguish zones with equal hydraulic conductivity. Therefore, one single K value will be assigned to the whole area.

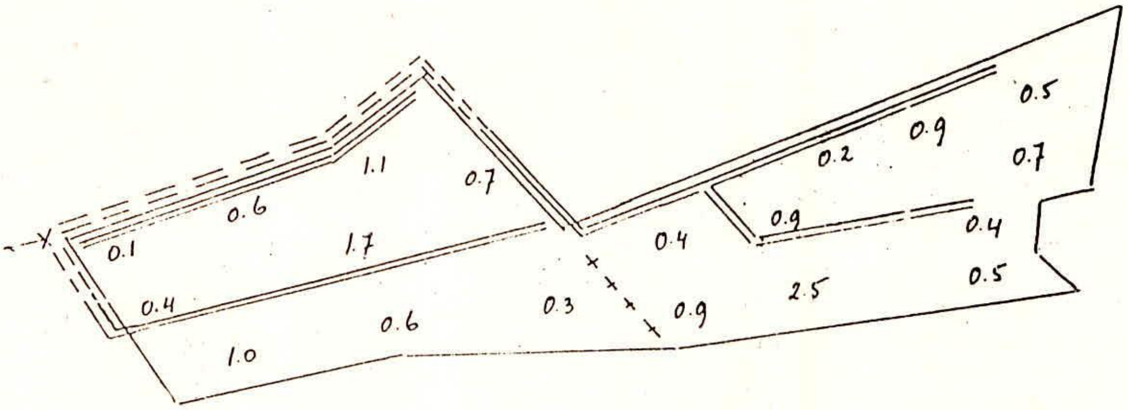
From the frequency distribution of all the k values in the figure 6 it is seen that median, modal and geometric mean are approximately the same (0.6 mm/day), whereas the arithmetic mean is somewhat higher (0.8 m/day). Given the shape of the frequency distribution (which is skew and approaches more a log-normal than a symmetric normal distribution), the value of K = 0.6 m/day is adopted.

STEP VI: The drainage blocks are the same as the seepage units (seep Step IV). Because the hydraulic conductivity has been taken the same anywhere.

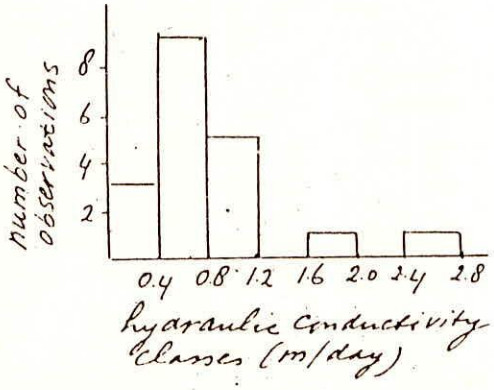
STEP VII: The drain discharge (q) equals the percolation (P) plus seepage (S) so that q = P + S. The K-value is 0.6 m/d for all units

UNIT/ BLOCK	SEASON	Average percolation P (mm/day)	Seepage (S mm/day)	Average drain discharge (q mm/day)
A	dry	0	2.5	2.5
A	irr	3	2.5	5.5
B	dry	0	3.5	3.5
B	irr	3	3.5	6.5
C	dry	0	2.5	2.5
C	irr	3	2.5	5.5
D	dry	0	1.5	1.5
D	irr	3	1.5	4.5

STEP VIII, IX and X: Since the depth of the impermeable layer is very deep, the following (radial flow) drain spacing equation can be used:



overview of the measured K-values



STATISTICS

no of observations	19
arithmetic mean	0.8
median	0.6
mode	0.6
geometric mean	0.6
st. dev.	0.6

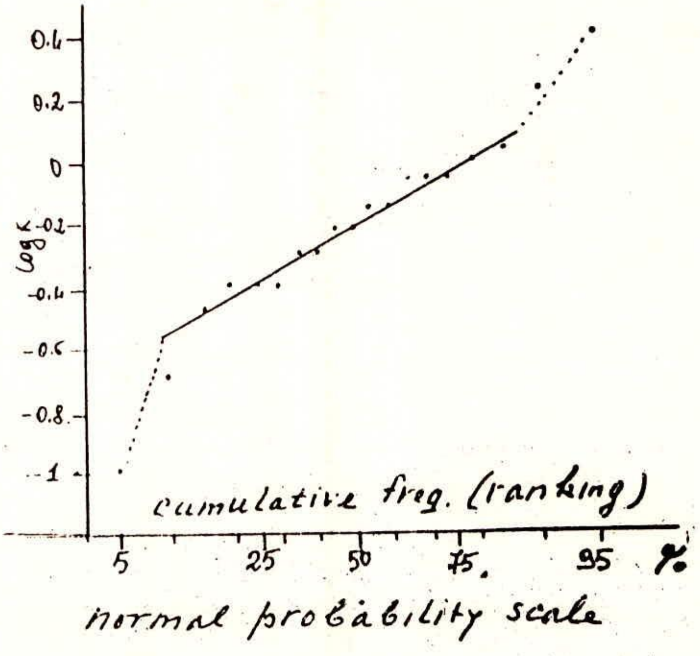
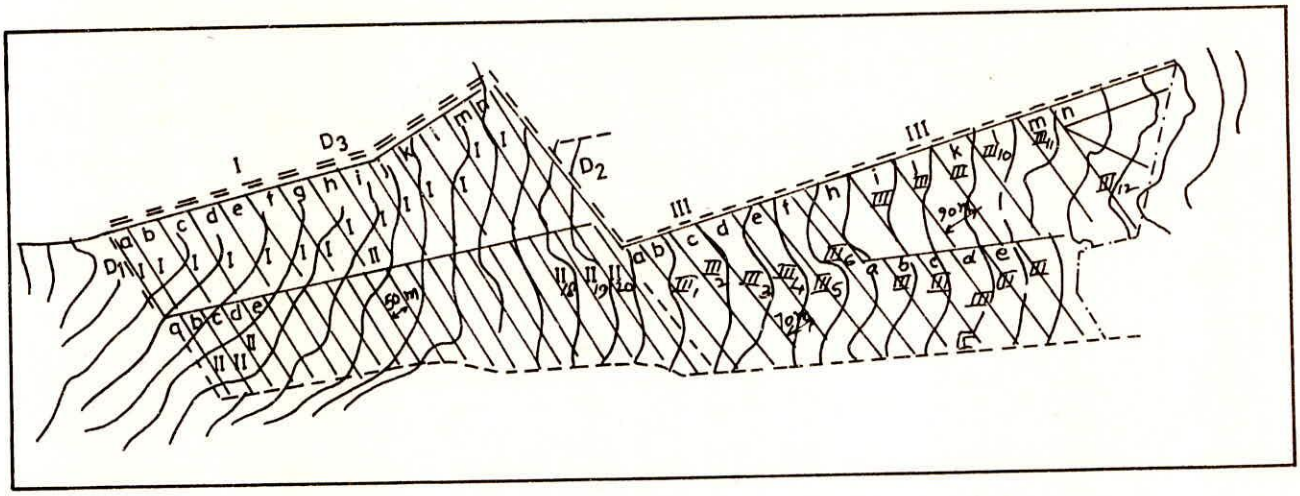


Fig 5 Overview of the measured K-values



D_1, D_2, D_3 disposal drains (pipes or ditch)

I, II, III collector pipe(drains

a, b, c,-------- Section of collector

I_1, I_2------II_1, II_2------etc. number of lateral drain of collector I, II,---- etc.

FIG.6: Sketch of final layout of the drainage system

$$h = \frac{qL}{\pi K} \ln \frac{L}{\pi r}, \text{ of: } Y = L \ln \frac{L}{n}, \text{ where: } u = \pi r \text{ and } Y = \pi Kh/q$$

The solution is $L = a\,Y^{\beta}$,

where $a = 0.56\,u^{0.29} = 0.40$ and $\beta = 0.85 - 0.046 \log u = 0.873$.

The hydraulic head (h) depends on the depth of the drain (g) and the required depth of the watertable (j): h = g - j.

The depth of the watertable in the dry season should be at least 1.5 m, so that the depth of the drains should be more than that. Two alternative values of g are chosen: g = 1.8 m and g = 2 m, so

	g(m)	j(m)	h(m)	g(m)	j(m)	h(m)
dry season	2.0	1.5	0.5	1.8	1.5	0.3
irrigation	2.0	0.8	1.2	1.8	0.8	1.0

The drain spacing (L) can now be calculated.

	Irrigated season (g=1.8)			Dry season (g=1.8)		
UNIT/BLOCK	q(m/day)	Y	L	q	Y	L
A, C	0.0055	370	70	0.0025	339	65
B	0.0065	313	60	0.0035	242	48
D	0.0045	453	83	0.0015	565	101

	Irrigated season (g=2.0)			Dry season (g=2.0)		
UNIT/BLOCK	q(m/day)	Y	L	q	Y	L
A, C	0.0055	411	77	0.0025	377	71
B	0.0065	348	66	0.0035	269	53
D	0.0045	503	91	0.0015	628	111

It is seen that for areas A, B and C the dry season is the critical season and requires the shortest spacings. For area D the reverse is true, because it has the smallest seepage rate.

For practical reasons the following spacings are chosen:
L = 70 m for UNITS/BLOCKS A and C

L = 50 m for UNIT/BLOCK B
L = 90 m for UNIT/BLOCK D
with a minimum depth of 1.8 and preferably not deeper than 2 m.

NOTE: Usually it is not recommendable to install drains so deep, but the presence of continuous seepage of groundwater and the agricultural requirements of the ripening season make this great depth unavoidable.

STEP XI: The layout of the field drains is given in the figure 6.

STEP XII: The layout of the field drains is given in the figure 6. The drains have been given a number. For example, drain I.8 is the eighth lateral drain of collector drain I. This lateral connects to the Section no. h of the Collector no. I. The manholes (inspection chambers) have not yet been indicated, but in many places they are necessary, e.g. at the connection points of laterals with collectors and halfway along the laterals with more than 300 m length (e.g. I14, II20, etc.)

STEP XIII: As an example, longitudinal profiles are given of the laterals of Collector I and of the collector itself (fig 7 a to e). It is seen that the top of the collector, at its upstream end, reaches a depth of 2.1 m. In its downstream end the depth is close to 2.5 m. This is because the laterals 1 to 7 extend under a depression in the land, so that their average depth is more than 2 m, and because the top of the collector drain must be some 5 cm below the bottom of the lateral drains. Also it is seen that the laterals do not have the required depth under the depression. This irregularity is accepted to save on the cost of installation of the collector, which should be still deeper if the irregularity is not accepted. Further, it may be expected that the depression will be leveled to a certain extent for irrigation purposes. Due to topographic differences, the laterals 1 to 6 have the minimum permissible slope (0.2%), whereas the other laterals have larger slopes, corresponding to the slopes of the soil surface. The collector drains has different slopes between 0-300 m (0.67%), 300-625 m (0.43%) and 625-975 m (0.60%) to follow the slope of the land surface as much as possible.

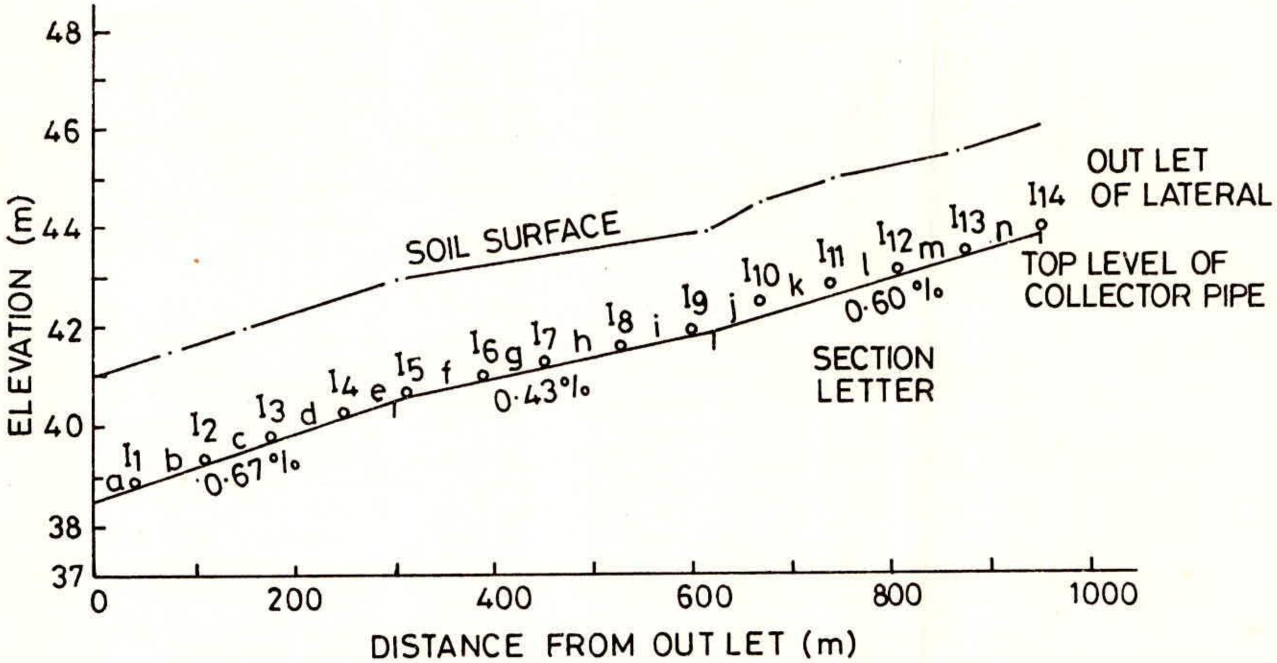
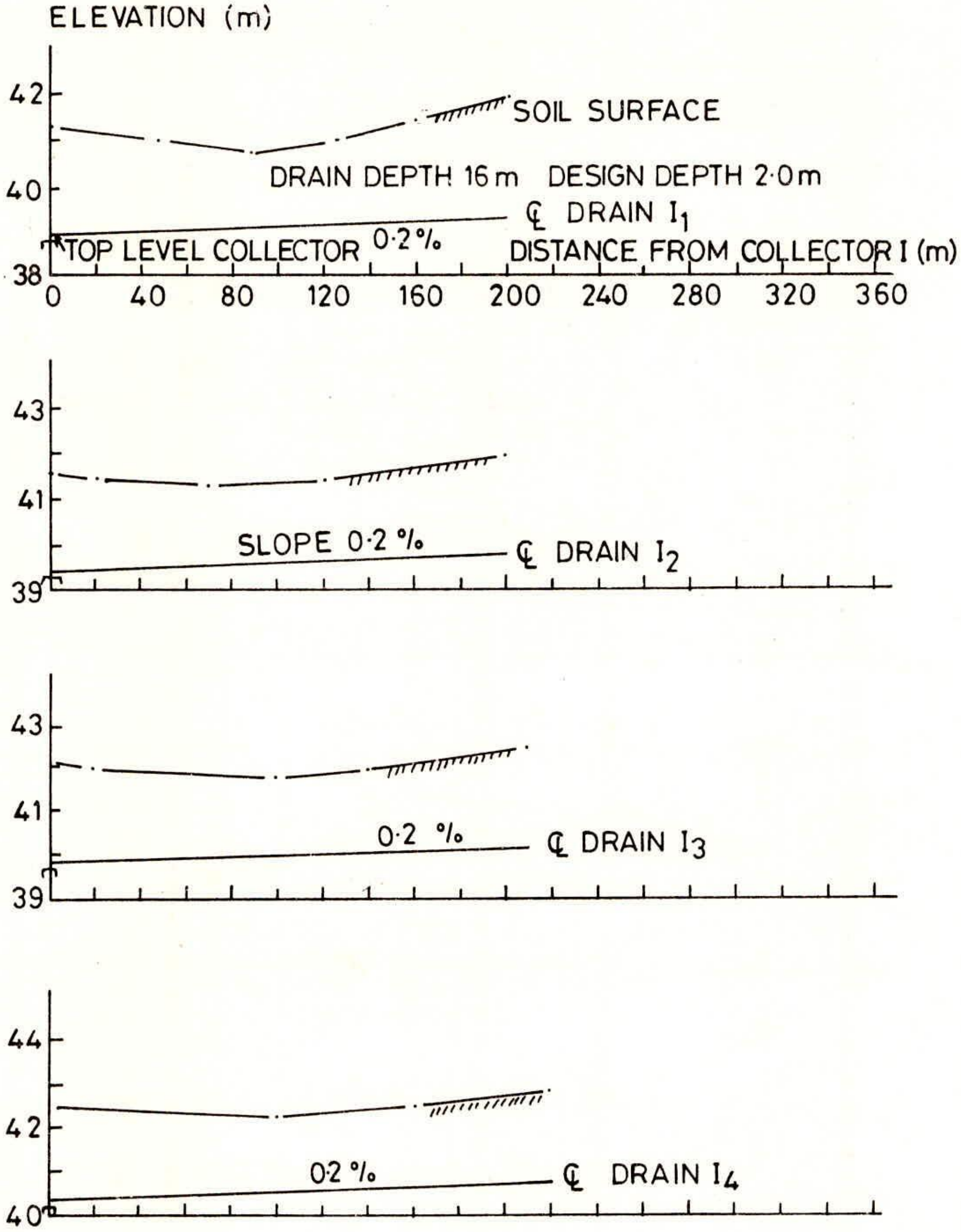
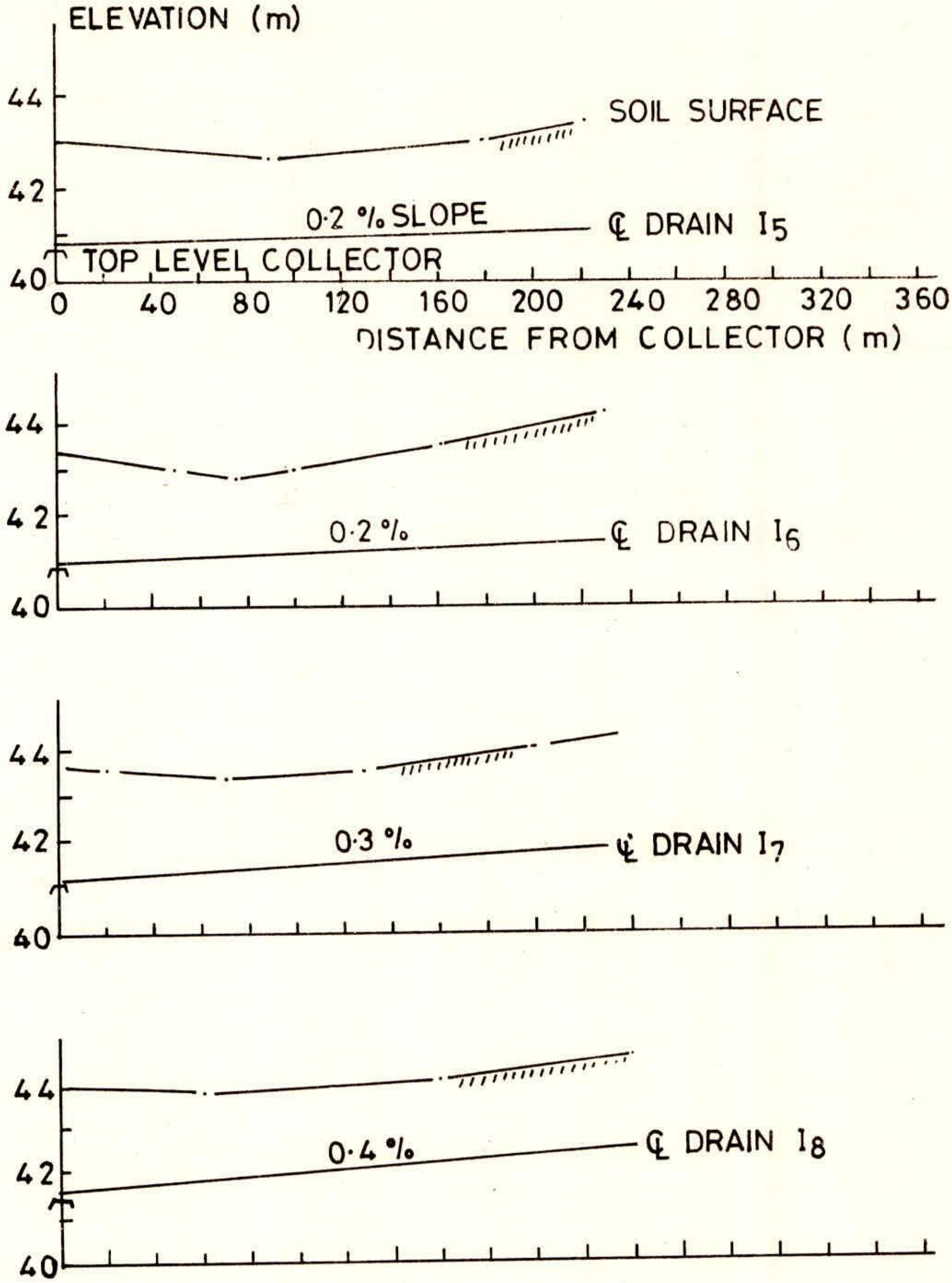


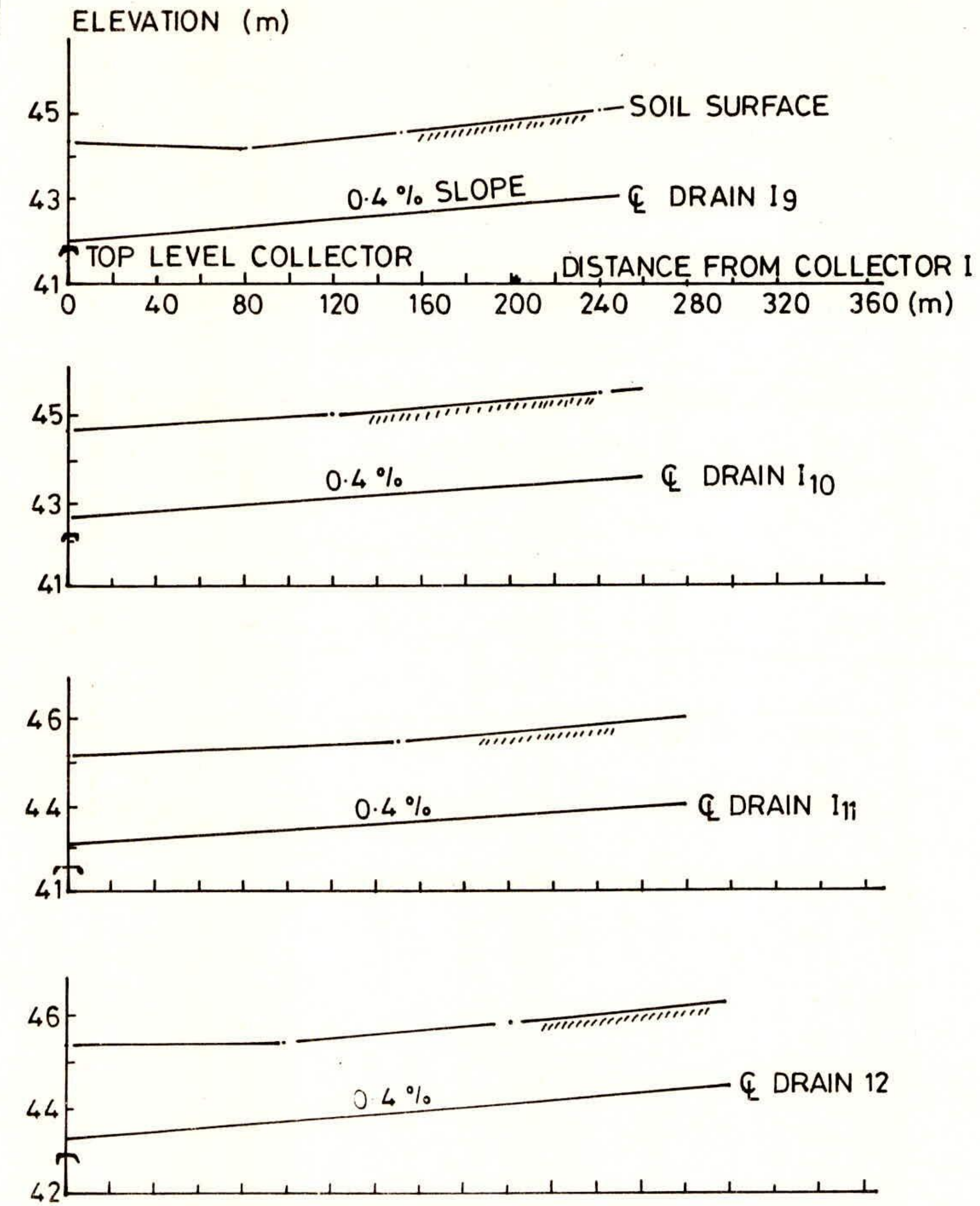
FIG. 7.a - LONGITUDINAL PROFILES COLLECTOR I



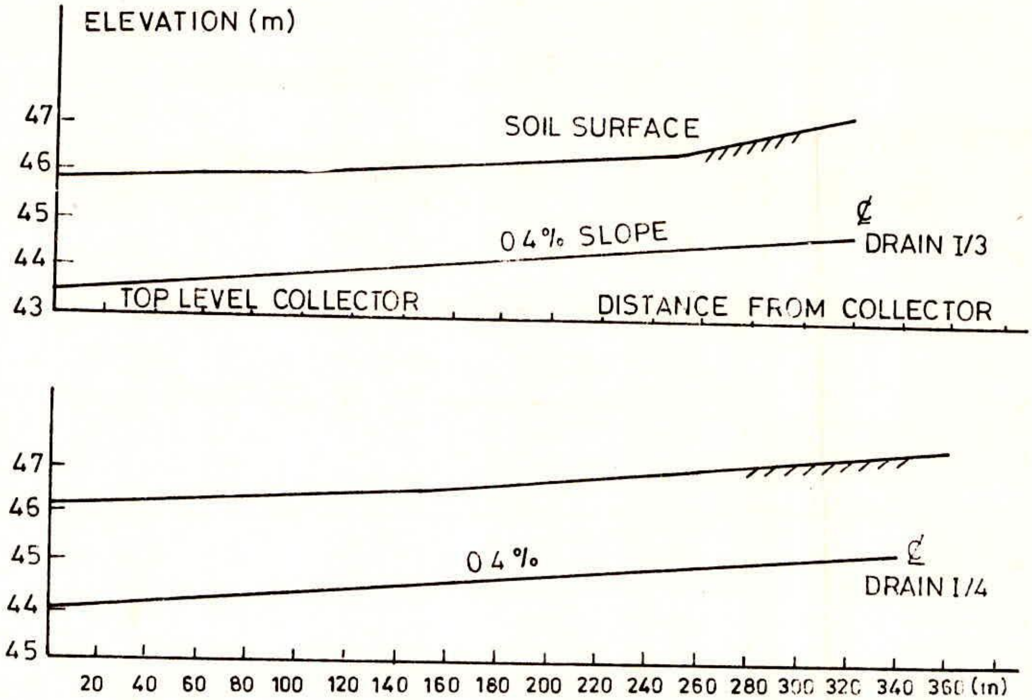
b- LONGITUDINAL PROFILES (SKETCH)



C- LONGITUDINAL PROFILES (SKETCH)



d - LONGITUDINAL PROFILES (SKETCH)



e Longitudinal profiles (sketch)

Table 2 : Calculation of pipe diameter for lateral (field) drains

Drain no.	length (m)	spacing (m)	area[2] (ha)	specific[2] discharge mm/day	discharge[4] (m^3/day)	slope[5] (%)	diamete[6] calcula (mm)
I14	340	70	2.4	7.0[1]	170	0.4	82
I13	320	70	2.2	5.5	120	0.4	72
I12	300	70	2.1	5.5	115	.0.4	71
I11	280	70	2.0	5.5	110	0.4	69
I10	260	70	1.8	5.5	100	0.4	67
I 9	245	70	1.7	5.5	95	0.4	66
I 8	240	70	1.7	5.5	95	0.4	66
I 7	235	70	1.7	5.5	95	0.3	70
I 6	230	70	1.6	5.5	90	0.2	74
I 5	225	70	1.6	5.5	90	0.2	74
I 4	220	70	1.5	5.5	85	0.2	72
I 3	215	70	1.5	5.5	85	0.2	72
I 2	210	70	1.5	5.5	85	0.2	72
I 1	210	70	1.5	7.0[1]	105	0.2	78

[1] This drain also receives water from the adjoining undrained area

[2] Area = length x spacings

[3] Average during irrigation season = seepage + percolation

[4] Discharge = specific discharge x area, rounded to 5 m^3/day

[5] Taken from the longitudinal profiles

[6] As the smallest available pipe has a diameter of 100 mm, this wil used for all lateral drains.

Table 3 : Calculation of pipe diameter for collector drain

Collector I section	Cumulative discharge[1] (m^3/day)	Slope[2] (%)	diameter calculated (mm)	diameter adopted[3] (mm)
n	170	0.60	9[illegible]	100
m	290	0.60	115	120
l	405	0.60	130	150
k	515	0.60	143	150
j	615	0.60	155	150[4]
i	701	0.43	171	200
h	805	0.43	179	200
g	900	0.43	187	200
f	990	0.43	193	200
e	1080	0.67	184	200
d	1165	0.67	190	200
c	1250	0.67	195	200
b	1335	0.67	200	200
a	1440	0.67	205	200[4]

[1] Discharge of all the lateral drains giving to the section, derived from the table for calculation of pipe diameter for lateral (field) drains

[2] Taken from the longitudinal profile

[3] Standard sizes are 100, 120, 150 and 200 and 300 mm

[4] Pipe diameter slightly too small, but accepted because safety factor is included in diameter calculated.

STEP XV (Gravel envelope): The soil texture (medium/coarse) is taken as fine sandy loam. From the textural triangle we estimate 10% clay (particle size < 0.002 mm), 25% silt (0.002 - 0.05 mm) and 65% sand (> 0.05 mm). The sand fraction is estimated to consist of 30% fine sand (0.05 - 0.25 mm), 20% medium sand (0.25 - 0.50 mm) and 15% coarse sand (0.5 - 2.0 mm). The cumulative particle size distribution is as in the table on next page.

Particle size less than	Logarithm particle size limit	%
2.0 mm	0.3	100
0.5 mm	-0.3	85
0.25 mm	-0.6	65
0.05 mm	-1.3	35
0.002 mm	-2.7	10

The logarithmic cumulative distribution is plotted on in the following graph, with the log values of the upper and lower particle size limits of the corresponding gravel envelope, according to the USBR method and the SCS method, together with the recommended limits (Figure 8).

3.0 CASE STUDY LEACHING

3.1 Introduction

In many parts of the world soils have been salinized due to the presence of a shallow groundwater table. To reclaim these soils the groundwater table should be lowered by the installation of a drainage system, followed by leaching to get the salts out of the soil profile. Sometimes special problems like sodification should be tackled as well. Although knowledge on saline soil reclamation is widespread, due to a great variation in soil, drainage and climatic conditions, applied research on pilot areas is sometimes required prior to the execution of a large-scale reclamation project. In this case study the reclamation of a strongly salinized sodic soil is dealt with.

3.2 Description of the reclamation experiment:

In the study area originally the groundwater table was found at a depth of 0.8-1.1 m. The climate is arid and agriculture depends completely on irrigation. A detailed reclamation experiment was carried out on a 4.9 ha plot which formed a part of a longer pilot area in which a drainage system was installed. The reclamation plot is underlain by 6 field drains at a depth of 2.0 m and a spacing of 36 m, discharging into an open collector drain.

The soil from the surface down to a depth of approx. 1.0 m is fine textured; the deeper layers are more sandy although clay

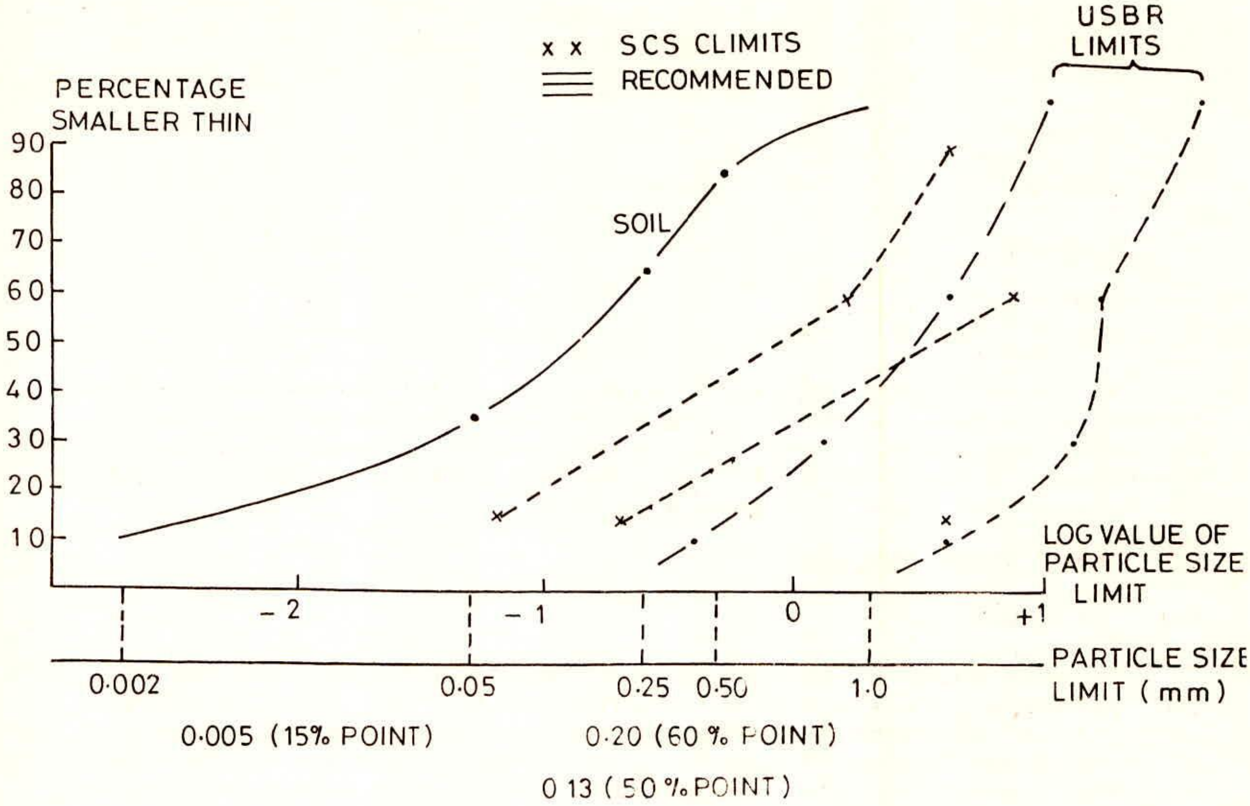


Fig. 8 Soil particle size distribution and gravel envelope grading

lenses occur. In Table 4 description is given of a typical soil profile and in Table 5 of some initial characteristics. Clay mineral analyses were also made. The soil taken in this reclamation experiment represents the worst case of salinity and sodification in the region under consideration. The major portion of the saline soils are less saline and topsoils are somewhat more loamy in texture. After the installation of the drainage system the soil was leveled as well as possible and plowed to a depth of 15 cm. The depth of plowing could not be more because of the hardness of the soil. Eight tons of gypsum per ha were applied and incorporated at shallow depth.

After a short leaching period rice was planted. The rice season in the region is about 150-200 days depending on climatic conditions and the rice variety. During the fallow season no water is available for a second crop or for leaching. Next year again a rice crop will be grown. Water used for leaching and rice cultivation is of good quality: EC=0.6 dS/m at 25 C and SAR value = 2. Predominant anions are Cl and SO_4.

Table 4 : Description of a typical soil profile

0 - 130 cm testpit
130 - 400 cm auger bore hole

0 - 10 cm	clay loam, dry, without structure, powdery, salt crystals moderate angular and subangular blocky with platy elements little porosity salt crystals
30 - 70 cm	clay, moist, 10 YR 3/2, weak subangular blocky, little porosity, $CaCO_3$ concretions, iron mottling
70 - 100 cm	silty clay loam, moist, 10YR 3/2, weak subangular blocky, little porosity, $CaCO_3$ concretions, iron mottling
100 - 130 cm	loam wet, 10 YR 4/2, structureless, little porosity, $CaCO_3$ concretions, iron mottling, watertable in this layer
130 - 400 cm	loam to loamy sand with clay lenses.

Table 5 Initial soil characteristics

Depth in cm	EC_e[7] dS/m	SP[6] %	pH[1]	ES[2] meq/ 100 g	CEC[5] meq/ 100 g	$CaCO_3$ g/ 100 g	gypsum g/ 100 g	Ca+Mg[3] meq/l	Na[3] meq/l	Cl[3] meq/l	BD[4] kg/dm^3
0- 10	169	44	7.4	12	28	4.3	0.5	993	2256	3047	1.42
10- 20	130	48	7.5	12	28	5.0	0.4	796	1629	2258	1.47
20- 40	75	55	7.8	15	30	5.4	0.4	292	738	785	1.52
40- 60	42	57	8.0	18	30	4.9	0.3	103	415	414	1.54
60- 80	34	55	8.1	18	33	5.4	0.3	77	334	288	1.57
80-100	30	55	8.1	19	31	5.3	0.4	71	277	233	1.58
100-120	27	54	8.0	17	30	5.3	0.3	60	216	184	1.50[4]
120-160	23	52	7.9	14	27	4.8	0.3	69	154	160	1.50[4]
160-200	19	45	7.9	10	25	5.9	0.2	59	133	135	1.50[4]

[1] pH measured in saturated paste

[2] ES is exchangeable sodium

[3] in saturation extract

[4] bulk density estimated

[5] cation exchange capacity

[6] saturation percentage of paste g water/100 g soil

[7] electrical conductivity of saturation extract (from paste)

3.3 The leaching period

The leaching period prior to the transplanting of rice was 61 days only (15 Nov. 1970 - 15 Jan. 1971). In total 22, 100 m^3 of irrigation water was given in 4 applications of which 6,170 m^3 were stored in the soil profile down to 2.0 m in order to bring the soil to field capacity. The remainder part either percolated through the soil profile or evaporated at the soil surface. No rainfall was recorded during the leaching period. The discharge of the tile drainage system totaled 8,500 m^3 of water and the EC of the drainage water was 33 dS/m at 25 C (=22.0 grams of salt per liter).

It should be noted that there is a basic recharge to the drainage system, caused by upward seepage from deeper strata. This upward seepage is independent of the excess of irrigation water percolating through the soil profile. The seepage water has an EC of 10 dS/m at 25 C. The total basic recharge for the 4.9 ha plot amounts to 0.6 l/sec.

Table 6 : Mineralogical composition of the clay fraction (in percentage)

Depth in cm	Amorfic	Na-Ca (feld-spars)	Quartz	Kaolinite	Illite	Montmorillonite
0-10	9	5	6	15	35*	30
20-40	8	5	10	12	29*	36
120-160	10	5	6	10	19*	50

* partially (less than 50%)
random - interstratisfied illite - Montmorillonite

3.3.1 The first rice crop

From the 15th of January to the 1st of July, 1971 (167 days) a rice crop was grown. The yield obtained, 580 kg/ha, was very low, mainly due to high salinity at the moment of transplanting (Table 7). In total 57,700 m^3 of irrigation water was applied and a rainfall of 50 mm measured.

The change in soil moisture content in the soil profile can be considered zero, because the soil was wetted prior to transplanting time. The tile drainage system discharged 27,785 m^3 and the average EC of the drain water was 30 dS/m at 25 C (=19.9 grams of salt per liter). Surface drainage was considered necessary in case water pounded in the rice fields attained an EC of more than 4 dS/m at 25 C. In total an amount of 6,300 m^3 of surface was let off having an average salt content of 3.1 g/l.

3.3.2 Second rice crop

A second rice crop was grown from the 1st of January to the 31st of May, 1972 (151 days). The yield obtained 4,850 kg/ha, was slightly above the regional average. The total amount of irrigation water applied was 83,000 m^3, while there was an additional rainfall of 74 mm. The change in soil moisture content in the soil profile again can be considered zero.

The tile drainage discharge amounted to 24,200 m^3 of water having an average salt concentration of 15.3 g/l. Surface discharge totaled 10,600 m^3 with an average salt concentration of 3.1 g/l.

3.4 Final Information

In Table 7 some chemical characteristics of the soil after the leaching period are given, while in Table 8 and 9 EC_e, pH and SAR values of the soil after the 1st and 2nd rice crop have been listed. In Table 8 also the gypsum content in the soil after the 1st rice crop is mentioned.

Table 7 : Chemical characteristics of the soil after the leaching period

Depth in cm	EC_e dS/m	SP %	SAR
0-10	35	57	31
10-20	46	62	42
20-40	54	64	54
40-60	46	60	72
60-80	42	57	54
80-100	41	57	48
100-120	35	54	46
120-160	30	49	42
160-200	29	41	27

Table 8: Chemical characteristics of the soil after the first rice crop

Depth cm	EC_e dS/m	SP %	SAR	pH	gypsum %
0-10	20	59	25	7.8	0.3
10-20	22	62	29	7.9	0.3
20-40	32	63	40	7.9	0.2
40-60	33	62	48	8.0	0.4
60-80	36	60	54	7.9	0.5
80-100	37	58	53	7.8	0.6
100-120	35	56	52	7.8	0.4
120-160	29	51	49	7.8	0.3
160-200	22	43	37	8.0	0.3

Table 9: Chemical characteristics of the soil after the second rice crop

Depth cm	EC_e dS/m	SP %	SAR	pH
0-10	17	56	13	7.3
10-20	16	57	17	7.5
20-40	21	59	28	7.7
40-60	26	60	38	7.7
60-80	29	59	45	7.6
80-100	30	57	47	7.5
100-120	28	56	47	7.5
120-160	24	55	43	7.6
160-200	20	43	35	7.7

3.5 ITEMS TO BE STUDIED

The effect of the leaching and the two rice crops on the desalinization of the soil should be studied in more detail and conclusions drawn on when there comes a moment that less salt tolerant crops could be cultivated. To that purpose the salt and water balance for the various periods should be studied. When dealing with saline-sodic soils another problem to be studied is whether chemical amendments such as gypsum are required.

Item 1. The salt balance

The general equation for the salt balance for the soil profile down to a depth of 2.0 m is

$$Z = Z_d + Z_{sr} - Z_i - Z_s \qquad (1)$$

in which

Z = change in salt content; a positive value stands for a decrease in salt content

Z_d = output of salts from subsurface drainage

Z_{sr} = output of salts from surface drainage

Z_i = input of salts from irrigation

Z_s = input of salts from upward seepage

Express values in tons of salt per ha.

Compare the change in salt Z as calculated from the salt balance, with the change in salt content actually found from laboratory analysis. To that purpose EC data from the Tables, 5, 7, 8 and 9 should be converted into salt content in tons/ha over the soil profile down to a depth of 2.0 m. Keep in mind that the salt content in tons/ha per soil layer of 10 cm

$$= BD \times SP \times EC_e \times 666 \times 10^{-5}$$

Item 2. The water balance

Often the relation is given between the change in soil salt content and the total amount (depth of the layer) of water applied. However, the total amount of water applied does not contribute completely to the desalinization of the soil; a part is lost by evapotranspiration and surface run-off prior to infiltration. Moreover, water that infiltrates not always contribute to leaching the salts out of the soil profile, but it leads only to a redistribution of salts. It is the fraction of water percolating through the soil profile down to the groundwater that leaches the salts out of it. For a better understanding of the leaching process, therefore, the amount of percolating water should be calculated from a water balance

$$Perc = D - S$$

where Perc = percolation
D = tile drain discharge
S = upward seepage

It is also possible to calculate the evapotranspiration E_t

from the following balance

$$P + I + S = S_r + E_t + D + \text{storage}$$

where

P = precipitation
I = irrigation
S_r = surface drainage
storage= change in moisture content of the soil

The term of the water balance should be expressed in m^3/ha or mm.

Item 3. Leaching

The EC after leaching/EC initial, EC after 1st crop/EC initial and EC after 2nd rice crop/EC initial for the various soil layers can be calculated. Then a graph can be prepared giving the relation between the various EC ratios versus the amount of irrigation water applied or the quantity of water that is percolated through the soil profile (leaching curve). Although all layers of the soil profile should be scrutinized, a study of two representative layers, i.e. the layer 0-10 cm and 40-60 cm will surface.

. Estimation of the amount of irrigation water required (and time involved) to arrive at an acceptable EC value in the rootzone, at which less salt tolerant crops can be cultivated, by extrapolating the leaching curve.

Item 4. Gypsum requirement

The initial soil chemical properties (Table 5) give an indication that the soil is highly saline-sodic. The question therefore also arises whether an application of a chemical amendment, e.g. gypsum ($CaSO_4.2H_2O$) *) is required (in fact 8 tons of gypsum per ha have been applied prior to leaching) or that an application could have been omitted. Consider 30 cm depth of soil to be improved. The efficiency of gypsum application is estimated at 60%.

The quantity of gypsum, S_z, required for replacement of sodium by calcium at the exchange complex can be computed with

$$S_z = \frac{(ESP_a - ESP_f) \times CEC \times d \times BD \times 8.6}{f}$$

*) atomic weight Ca=40, S=32, O=16, H=1, molecular weight gypsum is 172, equivalent weight gypsum is mol,w,/2 = 86

where f = gypsum application efficiency and d = depth soil layer in cm.

The soil contains a small quantity of gypsum and a substantial amount of calcium carbonate. Calculate these quantities and compare with the gypsum requirement.

4.0 SOLUTION TO CASE STUDY

Item 1

Salt balance leaching period

tons of salt/ha

$Z_d = 8500/4.9 * 22 * 0.001$ = 38.2

$Z_{sr} =$ = o

$Z_i = 22100/4.9 * 0.4 * 0.001$ = 1.8

$Z_s = 0.6*86400*61/4.9 *6.6*10^{-6}$ =4.3

$Z = 38.2 - 1.8 - 4.3$ = 32.1

So 32.1 tons/ha were leached from the soil profile during the leaching period.

Salt balance 1st rice crop

$Z_d = 27785/4.9 *19.9*0.001$ =112.8

$Z_{sr} = 6300/4.9 *3.1*0.001$ =4.0

$Z_i = 57700/4.9 *0.4*0.001$ =4.7

$Z_s = 0.6*86400*167/4.9 *6.6*10^{-6}$ =11.7

$Z = 112.8 +4.0 -4.7 -11.7$ =100.4

So 100.4 tons of salt/ha were leached from the soil profile during the first rice crop

Salt balance 2nd rice crop

$Z_d = 24200/4.9 *15.3*0.001$ = 75.6

$Z_{sr} = 10600/4.9 *3.1*0.001$ = 6.7

$Z_i = 83000/4.9 *0.4*0.001$ = 6.8

$Z_s = 0.6*86400*151/4.9 *6.6*10^{-6}$ = 10.5

$Z = 75.6 +6.7 -6.8 -10.5$ = 65

So 65 tons of salt/ha were leached from the soil profile during the second rice crop.

The salt content in the soil in tons/ha can be computed from the available EC-values and per soil layer of 10 cm depth it equals to

$$BD * SP * EC *666 *10^{-5}$$

E.g. the initial salt content in the 0 -10 cm layer is
1.42 *44 *169 *0.00666 = 70.3 tons of salt/ha

Hereafter the results are given of the calculation of the salt content per soil layer and for the whole soil profile (0.0 -2 m depth) for the initial situation as well as for the soil status after the leaching period, the first rice crop and the 2nd rice crop respectively.

Salt content in tons/ha

Depth in cm	Initial	After leaching	After 1st rice crop	After 2nd rice crop
0- 10	70.3	18.9	11.2	9.0
10- 20	61.1	27.9	13.4	9.0
20- 40	83.5	70	40.8	25.1
40- 60	49.1	56.6	42	32
60- 80	39.1	50.1	45.2	35.8
80- 100	34.7	49.2	45.2	36
100- 120	29.1	37.8	39.2	31.3
120- 160	47.8	58.6	59.1	52.8
160- 200	34.2	47.5	37.8	34.4
Total profile	448.9	416.7	333.9	265.4
Change in saltcontent		32.2	82.8	68.5

* It is assumed that bulk density remained constant during the reclamation experiment

It can be concluded that the change in salt content computed from EC measurements and from a salt balance are reasonably well in agreement.

Item 2 : The general equation for the water balance is

$$P + I + S = S_r + E_t + D + \text{storage}$$

in which the various in - and out factors in cu.m/ha are:

Leaching period

P : nil

I 4510

S 0.001*0.6*86400*61/4.9 = 645

S_r nil

D 1735

Storage 1259

thus the factor E_t is: 2161

1st rice crop

P 50 *0.001 *10000 = 500

I 11776

S 0.6 *86400 *167/49 = 1767

S_r 1286

D 5670

Storage nil

thus the factor E_t is: 7087

2nd rice crop

P 74 *0.001 *10000 = 740

I = 16939

S 0.6 *86400 *151/49 = 1598

S_r 2163

D = 4939

Storage nil

thus the factor E_t =12175

To compute the infiltration or percolation the water balance for soil surface should be considered

PERC. = D -S

in which the various in- and out factors in cu.m/ha are

	Leaching period	1st rice crop	2nd rice crop
D	1735	5670	4939
S	645	1767	1598
Thus percolation is	1090	3903	3341
The cumulative percolation is			
cu.m/ha	1090	4993	8334
mm	109	499	833

Item 3 :

Depth	EC leaching	EC 1st rice crop	EC 2nd rice crop
	EC initial	EC initial	EC initial
0 - 10	0.21	0.12	0.10
10 - 20	0.35	0.17	0.12
20 - 40	0.72	0.43	0.28
40 - 60	1.10	0.79	0.62
60 - 80	1.24	0.06	0.85
80 - 100	1.37	1.23	1.00
100 - 120	1.30	1.30	1.04
120 - 160	1.30	1.26	1.04
160 - 200	1.53	1.16	1.05

Now graphs (Figures **9** and **10**) can be prepared plotting the various Ec ratios of the two crucial soil layers (0-10 and 40-60 cm) against the depth of irrigation water (plus rainfall) applied as well as against the depth of water that percolated through the soil profile.

It is assumed that most field crops other than rice, can be established and give an adequate production when the salinity in the rootzone drops to an EC_e -value of 8 dS/m. For the two representative layers the EC-ratios then are

Depth	EC final/EC initial
0-10 cm	8/169 = 0.05
40-60 cm	8/42 = 0.20

Per rice crop a depth of water of at least 1,6000 mm is required, corresponding to a percolation of about 350 mm. By extrapolating the two graphs (Figures 2 and 3), it can be seen that the required EC final/EC initial ratios will be obtained at a total depth of irrigation water (plus precipitation) of 11,500 - 13,000 mm corresponding to an accumulated depth of percolation of 2,000 - 2,200 mm. It may be concluded now that at least 4

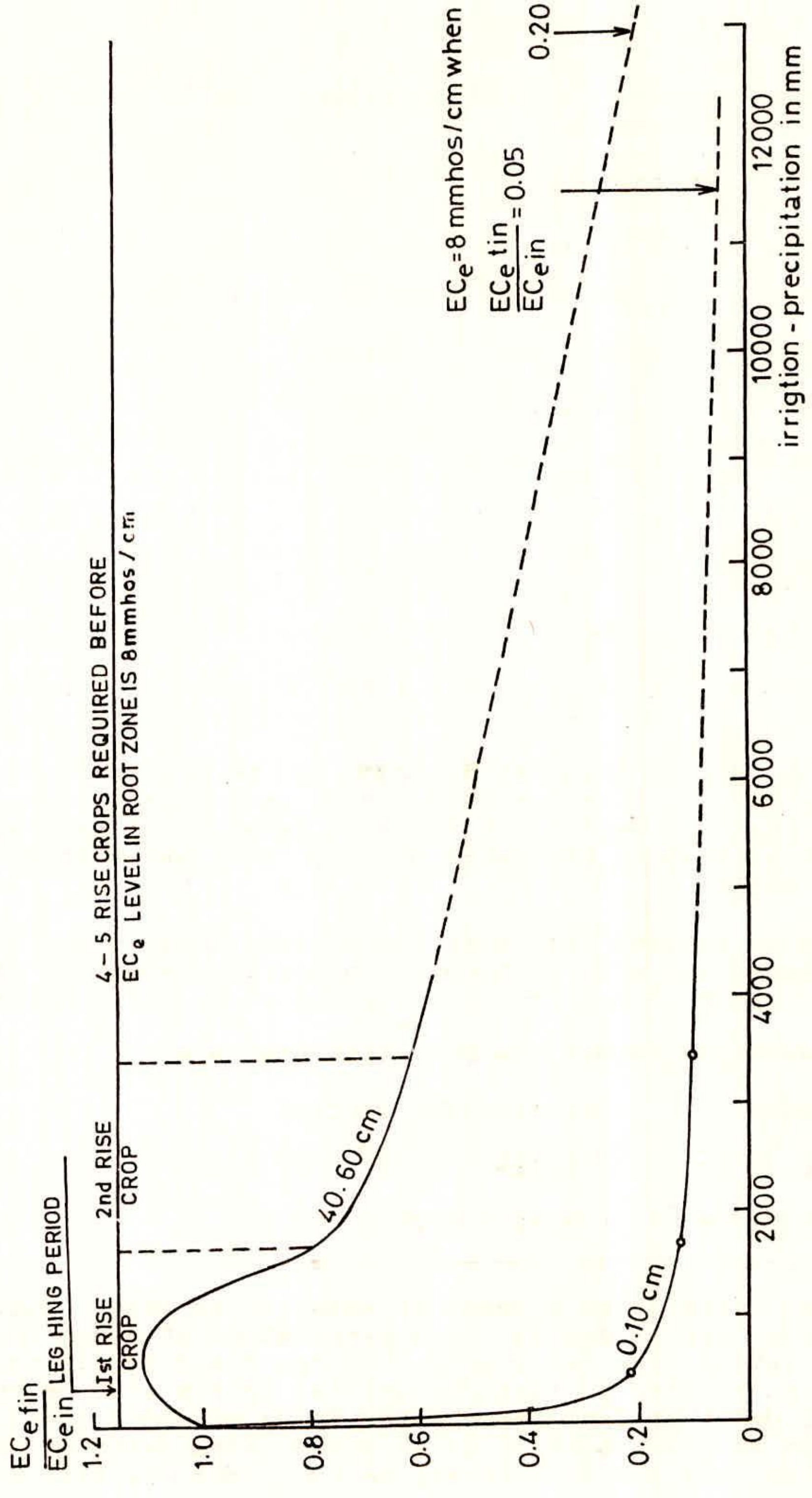


Fig. 9. EC ratio vs irrigation plus precipitation .

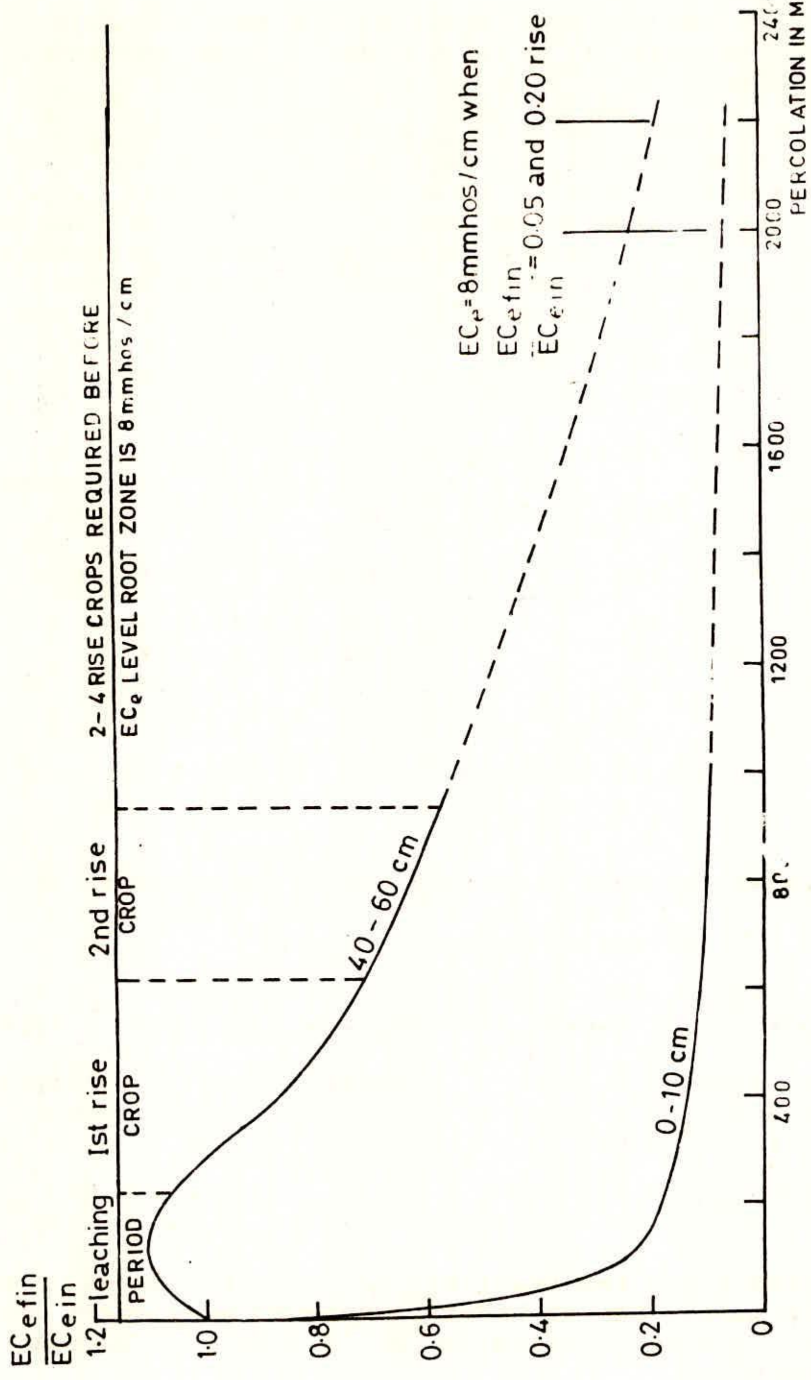


Fig.10 E C ratios vs infiltration

years more of rice cultivation, but most probably 5 years are required in order to bring the salinity in the rootzone down to an EC_e-value of 8 dS/m.

Item 4: First of all the amount of gypsum required is computed, taking into consideration that the value for ESP final should be 5. Such a low value is taken because the soil (topsoil) has a high clay content; moreover it contains montmorillonite. Apparently soils containing montmorillonite are more sensitive for soil structural decline than soils that do not contain this clay mineral. To improve the first 30 cm of soil, about 74 tons of gypsum per ha are required. The amount of gypsum present in the soil (0 - 30 cm depth) arrives at about 19 tons per ha, and the quantity of calcium carbonate at 217 tons per ha.

The calculations are given below.

Depth in cm	ESP_a	ESP_p	CEC meq/100 g	BD kg/dm^3	Gypsum req. tons/ha
0-10	43	5	28	1.42	21.7
10-20	43	5	28	1.47	22.4
20-30	50	5	30	1.52	29.5

The amount of gypsum and $CaCO_3$ in the soil is calculated as follows:

Gypsum (or $CaCO_3$) in tons per ha 10 cm depth of soil =

BD x % gypsum (or $CaCO_3$) x 10

Depth in cm	% Gypsum	Gypsum tons/ha	% $CaCO_3$	$CaCO_3$ tons/ha
0-10	0.5	7.1	4.3	61.1
10-20	0.4	5.9	5.0	73.5
20-30	0.4	6.1	5.4	82.1

Summarizing the results: the soil (0 - 30 cm) contains 19.1 tons of gypsum per ha versus a gypsum requirement of 73.6 tons per ha. So a net application of 54.5 tons of gypsum, per ha may be required.

The soil contains a huge reservoir of $CaCO_3$: 217 tons of $CaCO_3$ which equals 87 (20/50 * 217) tons of calcium. Comparing this amount with the required net application of 12.7 (54.5 * 20/86.1) tons of calcium, one may assume that the Ca-source in the soil is ample sufficient to replace the exchangeable sodium.

The amount of calcium added by irrigation water is calculated as follows:

EC = 0.6 dS/m = 6 meq/1 = conc of Ca + Na and SAR = Na/ Ca/2 = 2, from which follows that C_o (Na) = 2.6 meq/1 and C_o (Ca) = 3.4 meq/1 or 3.4 x 20 = 68 mg/1 = 68 g/m^3 = 0.068 kg/m^3. Hence with 10,000 m^3 (1 m depth of water over 1 ha) 680 kg of calcium is added per ha of soil. This quantity is small compared to requirements and the Ca-source in the soil.

From the calculations one may assume - at a first glance - that no application of gypsum is required at all. However a doses of 8 hons of gypsum per ha was applied prior to leaching. The reasons behind the decision to apply gypsum were:

- $CaCO_3$ is almost insoluble. The release of calcium from soil - $CaCO_3$ is extremely slow, unless the pH is reduced drastically, viz. by the application of sulfur (was extremely expensive in the Chacupe case) or other acidifying agents (were not commercially available);

- At extremely high salinity values, as were measured in the topsoil samples, neither the gypsum analysis, nor the determination of the ESP-values are reliable;

- The topsoil, prior to leaching was "structureless". So some kind of improvement measure had to be tried-out;

- Applying the theoretically calculated gypsum requirement of 54.5 tons/ha, disregarding soil $CaCO_3$ and irrigation water as Ca-source, would have been a very costly exercise. Moreover, to dissolve 54.5 tons/ha of gypsum at least 54.5 * $10^6/2.6$ =/ $2.1 * 10^6$ 1 = 21,000 m^3 of water (per ha) are needed. This volume of water is not applied in a single season.

To avoid any problem a basis doses of 8 tons of gypsum per ha was given. Soil chemical properties were monitored regularly. It was found that no further application of gypsum was needed. fig2 p18,19

5.0 SALTMOD :

The main aim of SALTMOD is to develop a calculation method for predicting the long term effects of varying water management options on desalinization or salt accumulation in the soil of irrigated agricultural lands. The water management options include irrigation, drainage, and the reuse of surface drainage water or subsurface drainage water from pipe drains, ditches or wells for the irrigation. In addition, predictions are made on the depth to watertable, the salt-concentration of the groundwater and of the drain or well water.

For that purpose, a computer program was elaborated in Fortran 77, using the computer facilities available at ILRI: Digital Equipment Corporation - VAX/VMS Version V4.3. The program SALTMOD. FOR or SALTMOD.EXE can be made available of floppy discs for use on MS-Dos personal computers. A 360 Kb RAM memory is amply sufficient.

The present version of SALTMOD is only a representation of an early development phase of the calculation method.

5.1 PRINCIPLES OF SALTMOD

The computation method SALTMOD is based on seasonal water balances of agricultural lands (Figures 11 to 16). Two seasons in one year are distinguished, e.g. a dry and a wet, or a cold and a hot season. Day to day water balances are not considered for three reasons:

- daily inputs would require much information, which may not be readily available;
- the method is especially developed to predict long term trends;
- predictions for the future are more reliably made on a seasonal (long term) than on a daily (short term) basis, due to the high variability of short term data.

The method uses water balance components as input data. These are related to the surface hydrology (like rainfall, evaporation, irrigation, reuse of drainage water, run-off), and the aquifer hydrology (like upward seepage, natural drainage, pumping from wells). The other water balance components (like downward percolation, upward capillary rise, gravity drainage) are given as output. The quantity of drainage water, as an output, is determined by two drainage intensity factors for drainage above and below drain level respectively - to be given with the input data - and the height of the watertable, resulting from the computed water balance. Variation of the drainage intensity factors gives the opportunity to simulate the impact of different drainage systems.

The input data on irrigation, evaporation, and surface run-off are to be specified for three kinds of agricultural practices; rainfed agriculture of fallow land, irrigation of "dry foot" crops, and irrigation of submerged rice fields (paddy

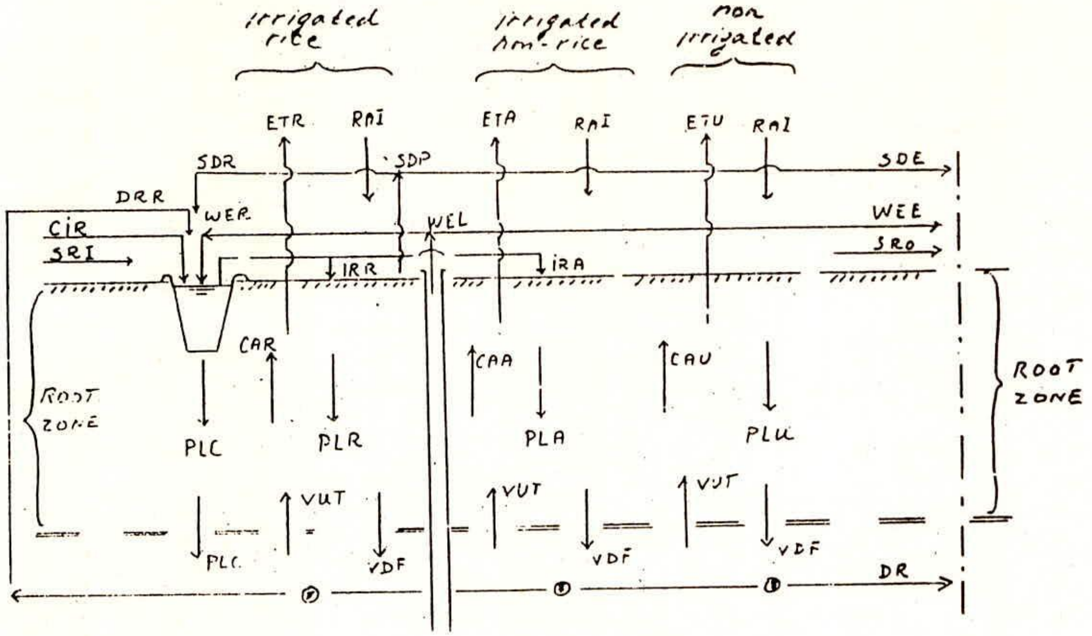


Fig 11 Water balance factors on soil surface and in root zone (the watertable can be in, above, or below the root zone, see Figure 2)

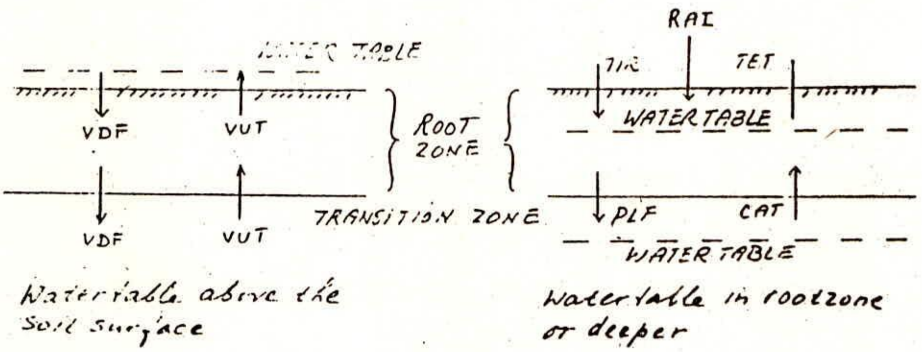


Fig 12 Water balance factors in the root zone in dependance of the watertable depth
(TIR=IRR+IRA; PLF=PLR+PLA+PLU; TET=ETR+ETA+ETU; CAR=CAR+CAA+CAU)

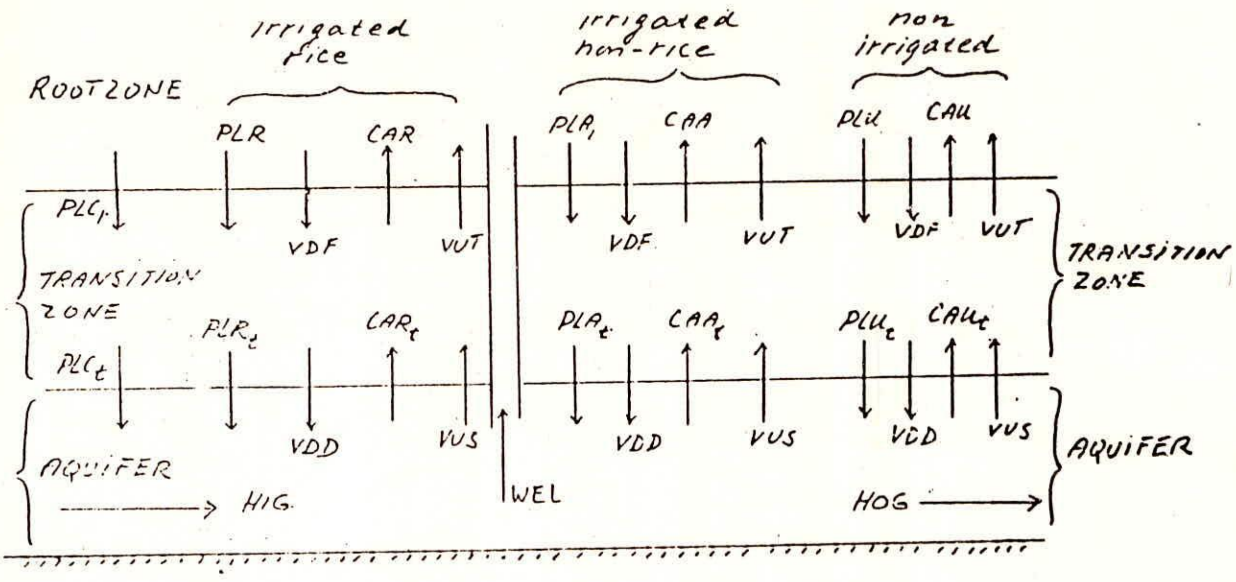
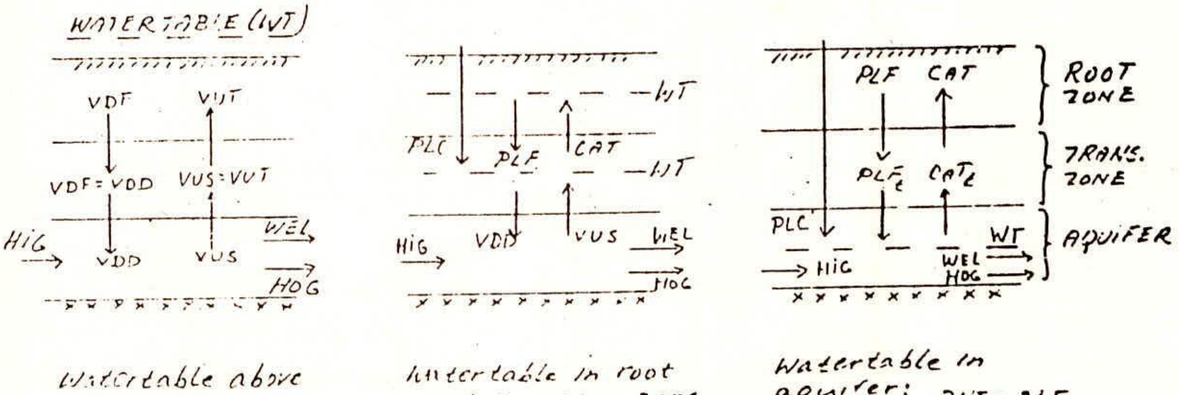


Fig 13 Water balance factors in aquifer and transition zone (without subsurface drainage (the watertable can be in, above or below the transition zone, see Figure 4)

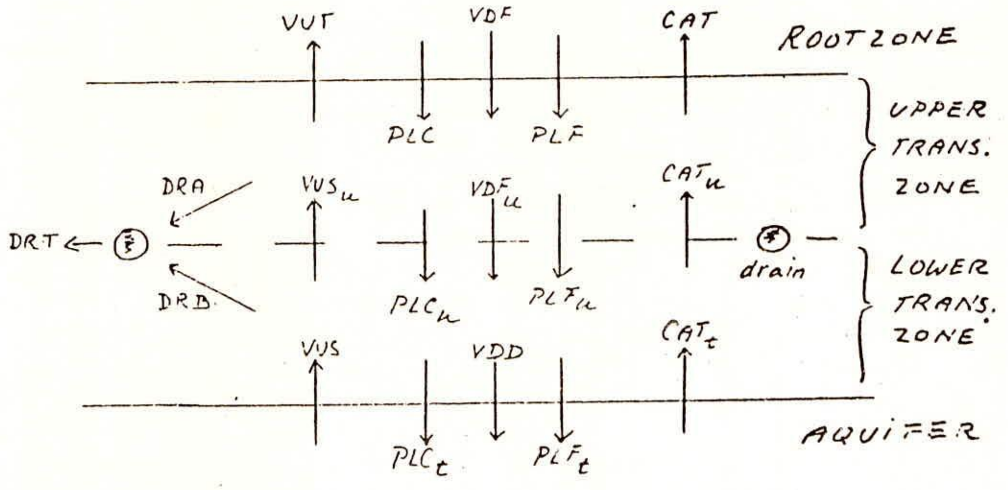


watertable above soil surface

watertable in root or transition zone

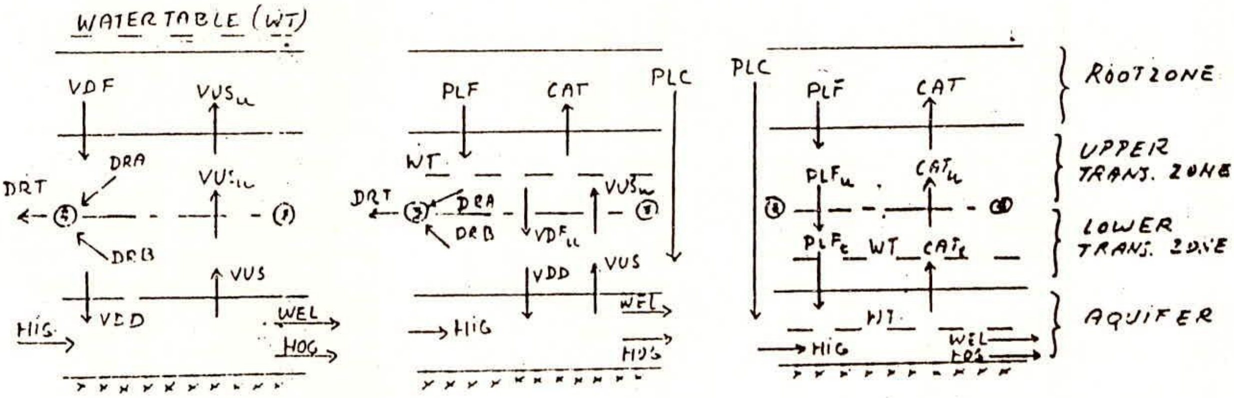
watertable in aquifer: $PLF = PLF_t$ $CAT = CAT_t$

Fig 14 Water balance factors in transition zone and aquifer in dependance of watertable depth (no subsurface drainage) ($PLF=PLR+PLA+PLU$; $VUS=HIG-HOG-WEL\geq 0$; $CAT=CAR+CAA+CAU$; $VDD=HOG+WEL-HIG\geq 0$)



PLF = PLA + PLR + PLU
CAT = CAA + CAR + CAU

Fig 15 Water balance factors in the transition zone in presence of a subsurface drainage system (the watertable can be inside, above or below upper or lower transition zone, see Figure 6)



Watertable above soil surface

Watertable in upper transition zone

Watertable in lower transition zone or aquifer : $PLF = PLF_u = PLF_t$
$CAT = CAT_u = CAT_t$

Fig 16 Water balance factors in upper and lower transition zone (in presence of a subsurface drainage system) in dependance of watertable depth
(PLF=PLR+PLA+PLU; VUS=HIG-HOG-WEL≥0; CAT=CAR+CAA+CAU;
VDD=HOG+WEL-HIG≥0)

land), for which aerial fractions have to be given with the input data. Variation of these fractions gives the opportunity to simulate the impact of different agricultural practices on the water and salt balance.

Under certain conditions, the height of the watertable influences the water balance components. For example, if the watertable comes close to the soil surface, it may lead to an increase of evaporation, surface run-off, and subsurface drainage or a decrease in percolation losses from the canals. This, in turn, leads to a change of the water balance, which again influences the height of the watertable, etc.

The above chain or reactions is one of the reasons why SALTMOD has been developed into a computer program. It takes a number of iterative calculations to find the final equilibrium of the water balance, which would be a tedious job if done by hand. Other reasons are that a computer program facilitates the computations for different water management options over long periods of time - with the aim to simulate their long term impacts - and for trial runs with varying parameters.

SALTMOD accepts four different reservoirs in the soil profile: a surface reservoir, an upper (shallow) soil reservoir or rootzone, an intermediate soil reservoir or transition zone, and a deep reservoir or aquifer. If a horizontal subsurface drainage system is present, the transition zone is divided into two parts; an upper transition zone (above drain level) and a lower transition zone (below drain level). (Note: if one wishes to distinguish an upper and lower part of the transition zone in the absence of a subsurface drainage system, one may specify in the input data a drainage system with zero intensity). Water balances are calculated for each reservoir separately. The excess water leaving one reservoir is converted into incoming water for the next reservoir. The three soil reservoirs can be assigned different thicknesses and storage coefficients, to be given as input data. In a particular situation, the transition zone or the aquifer need not be present. Then, they must be given a minimum thickness.

The upper soil reservoir is defined by the soil depth from which water can evaporate or be taken up by plant roots. It can be taken equal to the rootzone. It can be saturated, unsaturated, or partly saturated, depending on the water balance. All water movements in this zone are vertical, either upward or downward, also depending on the water balance, except the drainage flow, if existing. The transition zone can also be saturated, unsaturated or partly saturated. All flows in this zone are vertical, except the flow to subsurface drains, if present. The aquifer has mainly horizontal flow. Pumped wells, if present, receive their water from the aquifer only.

The salt balance are calculated for each reservoir separately. They are based on their water balances, using the salt concentrations of the incoming and outgoing water. Some concentrations must be given as input data, like the initial salt concentrations of the water in the different soil reservoirs, of the irrigation water and of the incoming groundwater in the aquifer. The concentrations can be expressed in any, consistent, units e.g. mmho/cm or mg/l.

Salt concentrations of outgoing water - either from one reservoir into the other or by drainage - are computed on the basis of the salt balance, using different leaching or salt mixing efficiencies to be given with the input data. The effects of different leaching efficiencies can be simulated by varying their input value. If drain or well water is reused for irrigation, the method compute the salt concentration of the mixed irrigation water in the course of the time and the subsequent impact on the soil and groundwater salinities, which again influences the salt concentration of the reused drainage water, etc. By varying the fraction of reused drain or well water (to be given in the input data), the long term impact of different reuse policies can be simulated.

The dissolution of solid soil minerals or the chemical precipitation of poorly soluble salts is not included in the computation method, but to some extent it can be accounted for through the input data, e.g. by increasing or decreasing the salt concentration of the irrigation water or of the incoming water in the aquifer.

The output of SALTMOD is given for each season of any year during any number of years, as specified with the .input data. The output consists of the seasonal average depth of the watertable, the average salt concentration of the different soil reservoirs, of the drainage and mixed irrigation water, as well as some indicators of irrigation efficiency and sufficiency. If required, farmer's responses to waterlogging and salinity can be accounted for. The method can gradually shallower or gradually reduce the fraction of cultivated land and the amount of irrigation water applied as the watertable becomes shallower or the soil salinity increases. These adjustments influence the water and salt balance, which - in turn - slows down the process of waterlogging and salinization. Ultimately an equilibrium situation will arise.

Some of the input data are inter-dependent, notably the irrigation data. These data can, therefore, not be indiscriminately varied. In very obvious illogical combinations of data, the program will give a warni no more than that. The correctness of the input data rem responsibility of the user.

The selection of the area to be analyzed by SALTMOD should be governed by the uniformity of the distribution of the cropping, irrigation and drainage characteristics over the area. if these characteristics are randomly varied in space, it is advisable to use a larger area. If, on the other hand, the spatial distribution can lead to the designation of more uniform subareas, it is advisable to use the subareas separately for the analysis. It is also possible to use first the larger area approach and use some of the outputs as inputs in the restricted area approach. For example, an area may have unirrigated, the fallow land can be obtained as output from the larger area approach, and used as groundwater input in a separate approach for the fallow land or as a groundwater output in a separate approach for the irrigated land.

In a future version of SALTMOD, a stochastic spatial distribution of soil salinity may be included. The distribution is to be made dependent on size of area and magnitude of the average salinity.

The output data are filed in the form of tables. The interpretation of the output is left entirely to the judgment of the user. The program offers the possibility to develop a multitude of relations between varied input data, resulting outputs and time. Different users may wish to establish different cause-effect or correlational relationships. The program, therefore, offers no standard graphics. However, the output files may be used as input into a spreadhseet program by which the required graphics can be produced.

If the user wishes to determine the effect of variations of a certain parameter on the value of other parameters, he/she must run the program repeatedly according to a user-designed schedule. SALTMOD is a highly interactive program.

6.0 REMARKS

The course on land drainage is one of the several courses offered /collaborate by International Institute for Land reclamation and Improvement (ILRI), Wageningen, The Netherlands.

Drainage is a key to development. In the humid areas of the world land drainage is one of the main facets of reclaiming and improving agricultural lands, in arid regions where irrigated agriculture must not be hampered by waterlogging and salinization, land drainage is a necessary complement to irrigation.

The course was dealing with surface drainage systems in flat and undulating lands with high rainfall and with subsurface drainage systems in humid areas and in arid areas with irrigation. The program was devised in such a way that class room lectures were followed by the classroom exercises. A good blend of field excursions was also provided i.e. learning by seeing. The case study which was undertaken near the end of the course and was presented after completion justified the saying of some noble man that

> " A student is a learner and when the status of a student is changed from a student to a teacher he becomes a better learner"

At the end of the course based upon the knowledge we could add to ourself a case study for design of drainage system for Bulandshahar area was prepared. The tital of the study was given as waterlogging and salinity problems in Bulandshahar area and their solution by a surface drainage system. The study is described below.

6.1 Introduction

The demand of agricultural products are continuously on the rise in view of India's growing population, but the country's land resources. A strategy to meet the rising demand is to aim for higher productivity per unit area. A valuable contribution could be obtained through development of adequate drainage techniques. The studies in surface drainage problems on field basis have been a neglected phase of agricultural drainage. In the field of surface drainage for agri-culture the demand of a well documented case-study may provide a better understanding and appraisal of surface drainage problems and improvements in the present practices of developing water-resources projects in the country. It is reported that in Bulandshahar water-logging is a serious problem. Therefore a case-study of surface drainage in extensive alluvial plains is undertaken in the surfacially water-logged in the district of Bulandshahar.

6.2 Objectives

- Study of depth-extent-frequency relations of water-logged fields.
- Identification of the origin of stagnant water.
- Assessment of the impediments to the excess drainage water.

Assessment of the agricultural damages inflicted by waterlogging in affected lands.

- Assessment of soil deterioration due to waterlogging, intransibility of the area, damage to infrastructural elements etc.

- development of a comprehensive package for alternative solutions.

6.3 Data Requirement

1. Map of the area
   a. Topographic map
   b. Contour map at less than 0.5 m interval
   c. Map having Khasara no. of the field (field no.)

2. Daily rainfall data
3. Daily evaporation data
4. Cropping pattern of the area also the cropping maps
5. Soil classification report
   a. Soil map of the area
   b. Well-log
   c. Soil structure /texture /infiltration capacity / hydraulic conductivity etc.
   d. Chemical soil properties i.e. salinity /Alkalinity
6. Ground water table data especially depth of watertable below soil surface
7. Method of irrigation / water conservation measures adopted
8. Crop production statistics of area with and without waterlogging problem
9. Remote sensing imageries
10. List of farmers of the area .
11. Pounding of water in the field
    a. Depth of pounding from ground surface
    b. Duration of pounding
    c. Frequency of pounding
    d. Extent of pounding
12. a. Canal discharge (if any)
    b. Time of run of canal
    c. Seepage from canal
13. Ground water extraction data

6.4 Methodology

The study will be undertaken as follows
1. As a first step the map of the area will be collected and the areas reported to have surface waterlogging problem in monsoon will be marked on it. One or more suitable sample areas will be selected for the case study.

2. A discussion with the farmers of the sample areas will be made for verifying the area reported to have surface waterlogging problems. Also the depth, frequency, duration and extent of surface waterlogging will be found out (as a rough estimate of severity of the problem). The possible causes of waterlogging will also be discussed with the farmer.

3. The origin of stagnant water will be found out, which could be due to excess water from irrigation systems, run-off of rain water from neighbouring fields, inundations from rivers and / or drains or local rainfall.

4. The restrictions to the drainage of the sample area will be assessed which may be due to topography of the area, low infiltration capacity of the soil, blockage of water by infrastructural elements such as rail, road, canal etc. , lower drain capacity, shallow groundwater table etc.

5. The daily observation of depth of water standing on the fields will be made in a large number of points. These observations will be taken with respect to the soil surface. These observations will be used in the preparation of waterlogging maps reflecting the depth extent and frequency relations.

6. An attempt will be made to develop the rainfall run-off relationships of the Nala / river existing in the sample area.

7. The estimates of seepage, if any, taking place from the Nala / river will be made and water balancing of the sample area having stagnant water will be made

8. Efforts will be made to assess the qualitative aspects of the problem. These assessments will be made by using various models available with us. The deterioration caused to the soil, such as loss in structure, salinity problem etc. will be assessed by soil sampling techniques.

9. The total damages caused by surface waterlogging will be assessed. Loss in production will be assessed by collecting the crop production data for the last several years. These results will be compared with the production (profit) data for other similar areas where no waterlogging problem is reported as such. An attempt will be made to formulate the criteria for the degree to which waterlogging problems have to be reduced and what degree of waterlogging is tolerable.

10. A suitable method will be suggested for the area to prevent waterlogging and to drain the water from problematic area. This may include surface drainage systems, flood control systems, water conservation practices, subsurface drainage (tile drainage)

or vertical drainage (by pumping) etc.

11. The benefit cost analysis of the measures suggested above will be made. Based on this the more feasible method / solution will be suggested.

Nearly 70% area of The Netherlands is below sea level. Therefore the country as a whole was unsafe for habitation. This was true only a long time back. To prevent the flooding as a first step dikes were constructed. For the better management, administration and service of the dikes Polders were formed. Then came the wind mills (developed around 16th century). The wind mills for the first time provided the facility for lifting the water from low lying areas to the areas at higher elevations. These were subsequently replaced by steam and then by Diesel Engines. Today Netherland has a very efficient drainage system to lower as well as maintain water table for good agriculture. Netherland have also succeeded in snatching land from the sea. The closer and partial drainage of an inland sea have made available some 165000 ha of new land which is proven fit for agriculture, recreation, urban and nature development. The way Dutch have snatched the land from the sea was really one of the greatest achievements of land improvement in the world. In this way the training proved to be a good blend of class room lectures, field exercises, field excursions slide shows, film shows and seminars. . At the end of the training a certificate of attendance was provided.

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