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OPERATIONAL RESEARCH IN WATER AND SALT MANAGEMENT AT HARYANA AGRICULTURAL UNIVERSITY IN INDIA, CONSULTANTS REPORT

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ACKNOWLEDGEMENTS

The author whishes to express his gratitude for the hospitality and fruitful cooperation offered by the staff of the Soils Department of Haryana Agricultural University in Hissar, which made his stay at the University Campus from 2 March 1986 till 19 March 1986 a very pleasant experience. Especially the efforts of dr. M.C. Agarwal, dr. S.S. Khanna, eng. R. Kumar and eng. J. Singh should be mentioned in this respect. Their personal interest and cooperation have been appreciated very much.

RECOMMENDATIONS

Based on the assumption that discharge from the aquifer in the central part of Haryana State does not significantly contribute to the State's water balance, in the long term a solution has to be provided to maintain the overall salt balance in Haryana State. In equilibrium conditions the salt added to the soil with the 10×10^9 m^3 irrigation water annually with an electrical conductivity of about 0,35 $mmho.cm^{-1}$ has also to be removed from the soil. Since on many locations in the State the groundwater table has risen close to the surface the subsoil leaves not sufficient space for disposal of leached salts. It is recommended that alternatives such as: disposal to the sea through a transport canal; disposal by evaporation lakes in lower lying parts of the State, are evaluated.

Based on the above given problem definition it is recommended that Haryana Agricultural University contributes through its research to the solution of the water and salt management problems of Haryana State. This concerns amongst others the following research items:

- study of the behaviour of the ground water system(s) in Haryana State;
- study of the maximum permissible salinity of the soil and the irrigation water that still safely can be used in conjunction with the good quality canal water under different phreatic water level conditions;
- study of the minimum required amount of irrigation for different crops under different phreatic water level conditions.

These three studies have already been initiated in the framework of the "Operational Research Project" in cooperation with ILRI, Wageningen, on the experimental farm of the University on fields with a very high watertable. The last two studies are situated in the area where the skimming well drainage project will be operational and it can be expected that in the future the watertable will be substantially lowered.

It is recommended that the above mentioned two studies be complemented with mathematical model investigations. The outline of such a model is included in this report. Basic to the application of such a water and salt balance model is the availability of good quality input and verification data. After verification of the model it can be used to simulate the experiments performed also for other conditions than those specific during the experiments.

In this context it is recommended that the field observations are intensified in the future:

- daily observation of phreatic waterlevels; especially before and after irrigation;
- weekly, but at least before and after irrigation, measurement of soil moisture tension at different depths;
- accurate measurement of the actual amount of irrigation water supplied to the experimental fields under study. The available Parshall flume is suitable for this purpose, provided that continuous measurements of the head(s) takes place during irrigation;
- the seepage/leakage conditions need to be investigated. Two main aquifers appear to be of significance at the experimental farm: a phreatic aquifer till about 13 m deep and a deep aquifer from 28 m till 50 m deep. A deep piezometer into the second aquifer needs to be installed and the vertical permeability of the clay layers separating both aquifers has to be estimated.

The experiments with reduced water application for the wheat crop shows peculiar results. Although the number of ears and the average ear length is different the wheat crop without post-sowing irrigation shows the same healthy appearance as the crop that received 3 irrigations of roughly 6 cm untill the beginning of March. Due to the small plot size no difference in phreatic level has been observed between the irrigation treatments. It is strongly recommended to continue these experiments on greater plot sizes of about 0.5 - 1 acre complemented with a number of groundwater observation wells to check for gradients in the phreatic aquifer.

If the available manpower and funds is a constraint to fulfil the above mentioned intensification of field measurements it is considered preferable to have less treatments with less crops with an intensive monitoring programme above many replications and treatments on small plots. Model calculations with a well-calibrated model can easily fill in the gaps in the not-included treatments.

For the operational research on the skimming well drainage project and the horizontal drainage project it is recommended to concentrate research efforts on the performance of both drainage systems. This means measurements of watertable behaviour in relation to skimming well/drain discharges. It is recommended to monitor the overall water and salt balance of both areas.

It is recommended to reduce the irrigation water supply to both drainage areas with the expected quantity of drainage water that will be reused. For the skimming well project the long term drainage rate is estimated at 0.75 $mm.day^{-1}$ giving a reduction of irrigation supply of 330,000 m^3 annually. For the horizontal drainage project these figures are estimated at 1.25 $mm.day^{-1}$ and 55 000 m^3 annually.

Due to the ill distributed rainfall the need for drainage during the rainy season cannot easily be evaluated by field research. It is recommended to extend the model formulation with a drainage module and analyse a number of hydrological years on the probability of such events. If the drainage water cannot be disposed of during the rainy season much of the potential economic benefit of drainage may be lost. In due time it may be required to construct evaporation pans in order to allow rainfall to infiltrate into the soil and discharge water to these pans, hereby improving the salt balance during periods of excess precipitation.

Due to the rising watertable at the experimental farm, all agricultural research at the farm is threatened by secondary salinisation. It is recommended that, after thorough model analyses for the evaluation of the required dimensions of drainage systems and storage facilities for excess drainage water, an overall water and salt management plan for the experimental farm is drafted. As such, the experimental farm could serve in the future as a pilot scheme on good water and salt management practices.

The operational aspects of the water and salt management research studies presently being performed can be further promoted by field researches on farmers practices with respect to irrigation. Based on the calculation method for crop water use presented in this report and the actual irrigation practices a State-wide estimation of drainage needs can be made. The alternative goal of such an exersize could be the optimization of the water management of Haryana State including reuse of drainage water and the required disposal facilities for excess drainage water and excess salts.

It is recommended that staff of the Soils Department of Haryana Agricultural University be trained in the formulation and operation of the mathematical models required for the analysis of water and salt management. A period of 2 months for 2 HAU researchers familiar with the 'FORTRAN' language is recommended.

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1. INTRODUCTION

The State of Haryana covers a total acreage of 4.4 million ha of which 3.9 million ha is net arable land. The major soil types are sandy loam, loamy sand and loam.

The climate in Haryana State is of a semi-dry monsoon type with a hot period from March till October. Four seasons can be distinguished: a dry summer season from July till September; a warm season in October and November and a cold dry season from December till February. Average annual rainfall varies from more than 1200 mm annually in the north-east till less than 300 mm in the western part of the State (fig. 1). The rainfall distribution over the rainy season is erratic and irregular and also the yearly total rainfall normally deviates considerably from the average. In about 2/3 of the State the average annual rainfall is less than 600 mm and due to the erratic distribution in this part of the State satisfactory crop production during the Kharif season is not safeguarded without supplementary irrigation.

Irrigation development has received much emphasis in the past and the net irrigated area increased from 1.3 million ha in 1966 till 2.2 million ha in 1980. Despite this achievements still about 45% of the agricultural land is deprived of irrigation water. Also in the area receiving irrigation water the water duty delivered at farm level is sufficient only for irrigation intensities of 45 - 60% on annual basis (AGARWAL and KHANNA, 1983). These authors report the presently utilized water resources at 18.3 billion m^3 annually. They estimate the potential water resources at 27.5 billion m^3 and the requirements for a 100% irrigation intensity at 41.2 billion m^3 annually. Obviously the available water resources will limit the ultimate crop production in Haryana State and in this respect land can be considered abundantly available.

After the expansion of the irrigation facilities since 1966 groundwater levels have been rising in the majority of the State (the central and south-western part). The average rate of rise varies from 10 cm per year till more than 50 cm per year. In the north-eastern part of the State groundwater levels have been falling during the same period. This may be partly due to the exploitation of groundwater for irrigation in the north-eastern part of the State. Also the direction of groundwaterflow is from the north-eastern part to the central part of the State. With the exception of some groundwaterflow from the north-eastern

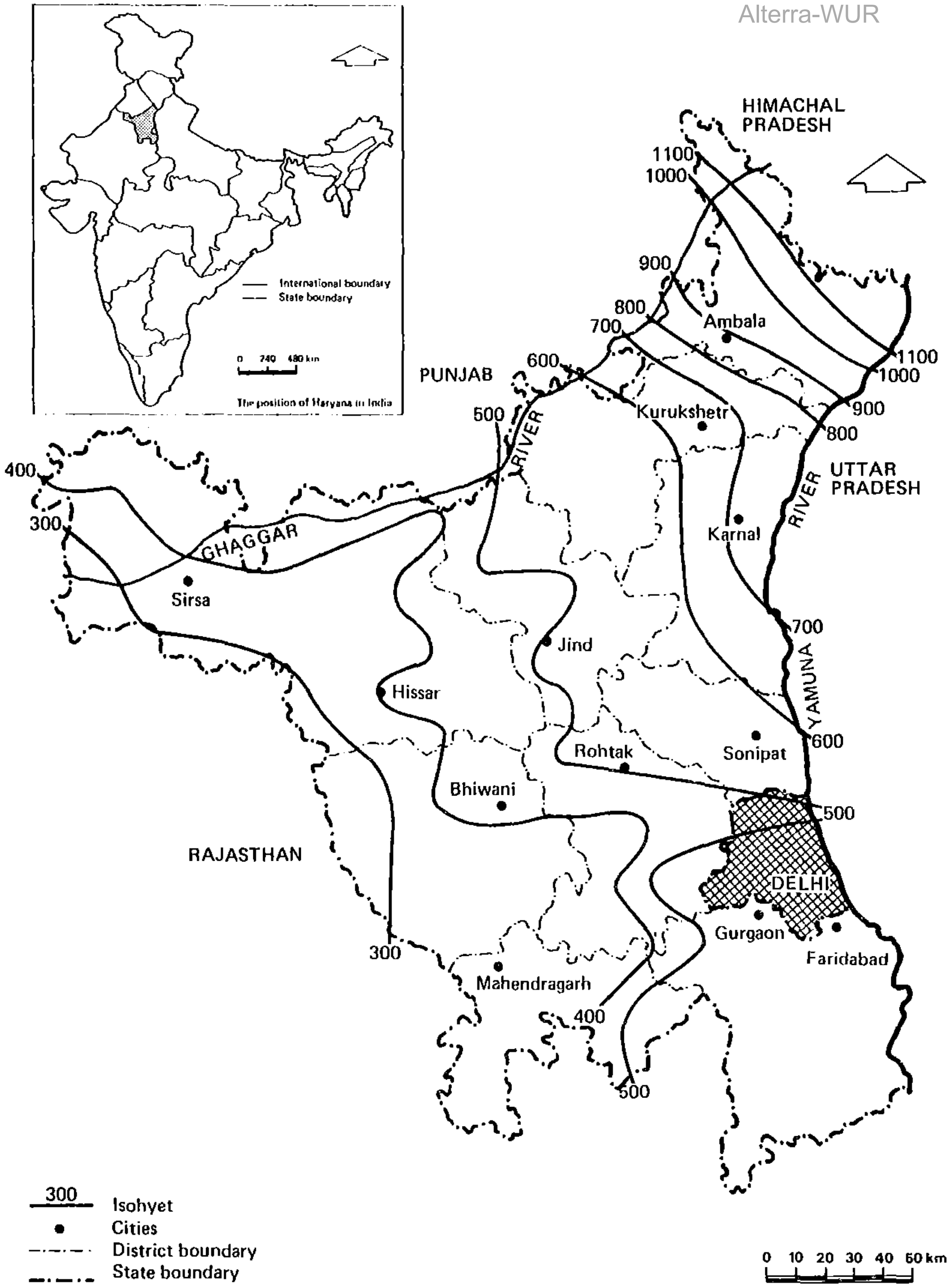

Fig. 1. Rainfall distribution pattern (AGARWAL and KHANNA, 1983)

part of the State to the western part (fig. 2) the major direction of the groundwaterflow is to the central part of the State being bowl-shaped where the groundwater accumulates. The natural subsurface discharge from this central area is either absent or too small to prevent rising water tables.

Surface drainage in Haryana State is effectuated in the fringes along the Ghaggar river and Yamuna river to this rivers. For the remaining part of the State (2/3) no surface drainage outlets are available due to the topographic relief (fig. 2).

Due to this geological and drainage situation and the increase in irrigation water supply waterlogging and secondary salinisation has occurred in the central part of Haryana State and will continue unless preventive and curative measures are taken. At present already 0.6 million ha is affected by waterlogging and 0.5 million ha by secondary salinisation.

According to AGARWAL and KHANNA (1983) the major water management problems of Haryana State can be summarized:
- scarcity of good quality irrigation water
- poor quality of groundwater in 2/3 of the State
- erratic, ill distributed and undependable rainfall
- semi-arid to arid climate in most of the State
- inadequate natural drainage and absence of drainage outlets
- rise of watertables in the canal irrigated area's.

Much effort is being exerted in Haryana State at present to provide the irrigation water distribution network with lining materials. It is expected (AGARWAL and KHANNA, 1983) that the net utilization of irrigation water can be increased by lining of the system from 30% to 45%. Also new water resources (o.a. from the Sutley-Yamana Link Canal) will be exploited in the future.

As one of the options to combat both the rising water tables and the watershortages for crop production the conjunctive use of fresh canal water and the saline groundwater is being considered in Haryana.

In order to investigate the possibilities of the conjunctive use of saline and fresh canal water for solving (temporarily) the waterlogging and salinity problems in Haryana State the Haryana Agricultural University (HAU) has started a research programme directed towards this goal. The objective of this programma reclamation, that is executed in cooperation with the Institute for Land Reclamation and Improvement

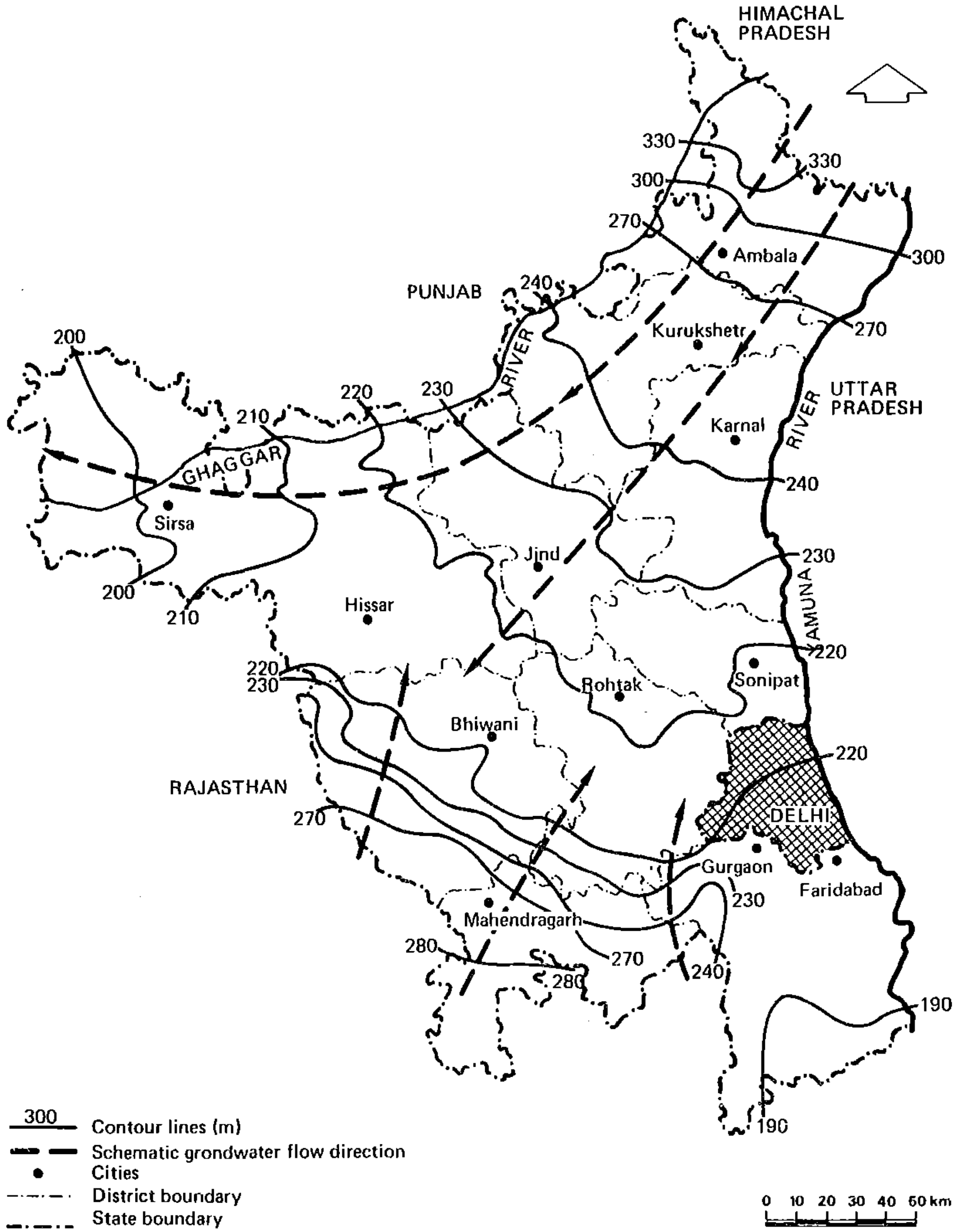

Fig. 2. Topographic relief of Haryana

(ILRI), is to investigate the problems in such a way that research findings can be applied in practice (operational research). To this purpose a number of experiments have been initiated on the experimental farm of HAU:

1. a reduced water application experiment to study the influence of irrigation on watertable behaviour and crop production;
2. a conjuctive use experiment of good quality canal water and saline groundwater to study the effects on crop yield;
3. a skimming well experiment to investigate the possibilities of controlling the watertable by shallow vertical wells and using this shallow groundwater for irrigation;
4. a horizontal drainage experiment to investigate the possibilities of controlling the watertable with a horizontal drainage system and using this water for irrigation;
5. experiments directed towards the utilization of saline water for fish cultures;
6. experiments on the disposal of salts by evaporation.

The author has been requested to proceed to Hissar, India, to advise on the research items 1 - 4 mentioned above. The terms of reference for the visit have been attached to this report (Annex 1). It is the author's opinion that due to the complex nature of the water and salt management problems and the variability in soil and hydrological conditions, rainfall and rainfall distribution throughout Haryana State the operational field studies conducted at the HAU experimental farm should be complemented by model studies. In this way the results of field experiments conducted at a specific soil type and for the hydrological and meteorological conditions of the HAU experimental farm can be translated into general applicable results for other parts of the State. The alternative for such model studies is to repeat experiments for the different environmental conditions throughout the State which is not only costly, but also time consuming. Seen the alarming rate of watertable-rise in Haryana State the factor time may be most constraining in this respect. The models required to perform such studies should comply to certain pre-requisities. They should be simple, easy to operate, require a minimum of input data and still produce reliable results. The outlines for such a model for the evapotranspiration and salinity in the unsaturated zone has been included in this report in chapter 3.

The implications of such a model approach to the water and salt management problem for the experiments at present being conducted at the HAU experimental farm will be treated as well as the anticipated future research required. In this respect it should be mentioned that no attempts have been made to discriminate between research items that still can be covered by the present cooperation project between HAU and ILRI and activities that will be beyond the scope of this project.

2. ATMOSPHERIC EVAPORATIVE DEMAND AT HISSAR

For the evaluation of irrigation experiments estimation of the actual crop water use is essential. Actual crop water use is influenced by meteorological conditions, crop characteristics, soil characteristics, hydrological circumstances and by the irrigation regime (amounts, frequency). As a first step towards the estimation of crop water use it is convenient to formulate the maximum evaporative demand as influenced by the meteorological factors in relation to the crop height and the fraction soil cover. Assuming a full soil cover by the crop and assuming the surface diffusion resistance to equal zero, meaning that the evaporating surface behaves as a wet surface the maximum water use by a full soil cover can be calculated (RIJTEMA and ABOUKHALED, 1975):

$$E_{max} = \frac{\delta H_{nt} + \gamma f(z_o,d)\, u^{0.75}(e_s - e_a)}{\delta + \gamma} \qquad (1)$$

where:

E_{max} - maximum crop water use with full soil cover in $mm.d^{-1}$
δ - slope of the temperature - vapour pressure curve in $mbar.^oC^{-1}$
H_{nt} - net radiation in $mm.day^{-1}$
γ - psychometer constant in $mbar.^oC^{-1}$
$f(z_o,d)$ - vapour transport coefficient in $mm.d^{-1}.mbar^{-1}$
z_o - roughness length of the evaporating surface
d - zero plane displacement in relation to the earth surface
u - wind velocity at 2 m high in $m.s^{-1}$
e_s - saturated vapour pressure deficit in mbar at mean air temperature
e_a - actual vapour pressure deficit in mbar

The parameter δ is dependent on temperature only and can be found in available handbooks. The next radiation H_{nt} can be calculated as follows:

$$H_{nt} = (1 - \alpha) H_{sh} - H_{lo} \tag{2}$$

where:

α - reflection coefficient of the evaporating surface
H_{sh} - global incoming radiation in $mm.d^{-1}$
H_{lo} - net longwave outgoing radiation in $mm.d^{-1}$

Although the reflection coefficient is not constant, but changes with season, time of the day and colour of the evaporating surface, for the calculation of monthly average values of evapotranspiration constant values may be introduced:

open water : $\alpha = 0.05$
cropped surface : $\alpha = 0.24$
wet bare soil : $\alpha = 0.15$

The global incoming radiation can be calculated from the solar radiation and the relative duration of bright sunshine:

$$H_{sn} = (a + b \frac{n}{N}) H_a \tag{3}$$

where:

a - empirical constant ($\equiv 0.25$)
b - empirical constant ($\equiv 0.50$)
n - average daily number of hours bright sunshine
N - maximum number of bright sunshine hours
H_a - incoming solar radiation in $mm.d^{-1}$

The daily number of hours bright sunshine is registered with a Campbell-Stokes instrument. The maximum number of bright sunshine hours and the incoming solar radiation depends on the latitude ($\simeq 29^{o}$N for Hissar) and on the time of the year and can be found in meteorological handbooks.

The long wave radiation H_{lo} can be calculated using an empirical relation assuming the surface temperature equal to air temperature:

$$H_{lo} = 433.10^{-13} (1 + 9 \frac{n}{N}) (1 - 0.142 \sqrt{e_a}) T_a^4 \quad (4)$$

where T_a - average air temperature in ^oK

The vapour transport coefficient $f(z_o,d)$ depends on the crop roughness and crop heights. The relation based on several crops between this coefficient and cropheight as given by RIJTEMA and ABOUKHALED (1975) is presented in fig. 3.

The saturated vapour pressure is related to the temperature and can be found in the available meteorological handbooks. The actual vapour pressure can be calculated from the sturated vapour pressure and the relative humidity:

$$e_a = e_s R_h k/100 \quad (5)$$

where R_h - relative humidity in %

Using the equations (1) - (5) the maximum water use in relation to crop height assuming a full soil cover can be calculated. In table 1 the basic measured meteorological data of Hissar as an average of 11 years (1971 - 1981) are given (data from AGARWAL and KHANNA, 1983). The temperature has been taken as the average of maximum and minimum temperature. The relative humidity has been taken as the average of the morning and evening observations. The windspeed has been recorded at 3 m height and has been corrected for observations at 2 m height (correction factor 0.98).

The standard meteorological data related to Hissar, the incoming solar radiation and the maximum number of bright sunshine hours have been included in table 1. Application of equations (2) - (5) to these basic data give the parameters given in table 1. Taking for the zero crop height the reflection coefficient for wet bare soil (= 0.15) using equation (1) the maximum evaporative demand for full soil cover has been calculated. The result is given in table 1 on a monthly basis.

For incomplete soil cover a reduction factor can be introduced This factor can be approximated (RIJTEMA and ABOUKHALED, 1975):

$$\beta = \frac{\delta + \gamma}{\delta + \gamma(1 + f(z_o,d)\ u^{0.75}\ r_c} \quad (6)$$

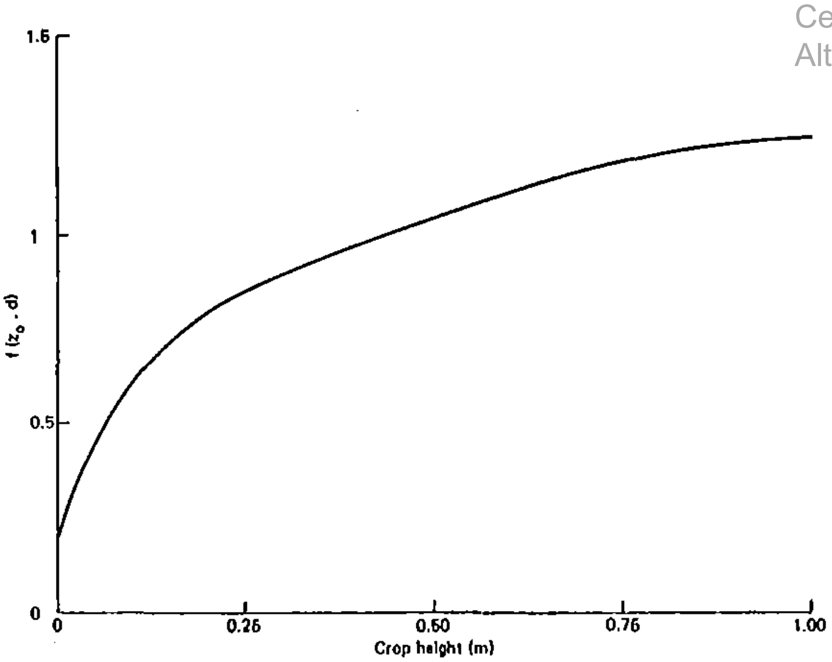

Fig. 3. Value of the vapour transport coefficient f (z_o,d) in relation to crop height (after RIJTEMA and ABOUKHALED, 1975)

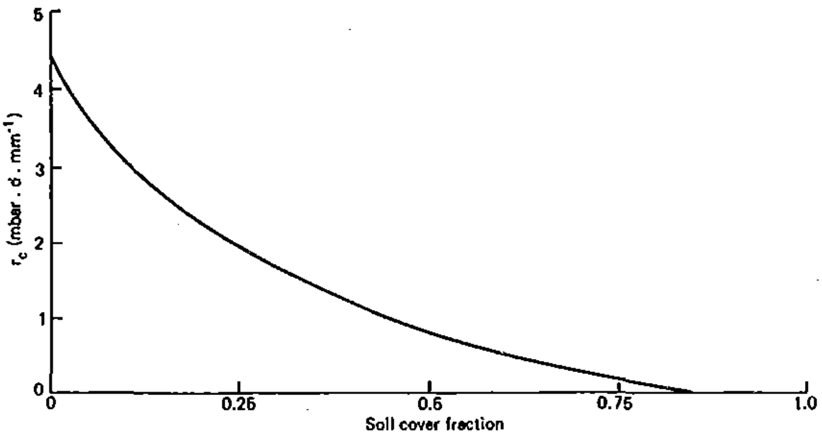

Fig. 4. Relationship between the surface diffusion resistance r_c and the soil cover fraction (after RIJTEMA and ABOUKHALED, 1975)

where:

β - reduction factor for incomplete soil cover

r_c - surface diffusion resistance in $mbar.d.mm^{-1}$

The surface diffusion resistance of the soil is strongly related to the topsoil moisture conditions, and practically independant of crop type. In fig. 4 the relation between r_c and soil cover fraction is presented for a medium dry soil.

With equation (6) the reduction factor for soil cover can be calculated for each month and crop height. The results showed two markedly different periods with respect to the magnitude of this reduction factor. During Aug.-Dec. the factor is greater than during Jan.-July. In table 1 the reduction factor β is presented as the average during these two periods.

Based in the crop development the potential evapotranspiration can be calculated using the E_{max} values and the reduction factors given in table 1.

2.1. Field crops

For the estimation of the potential evapotranspiration of the major field crops grown at the HAU experimental farm data on crop development are required. Based on discussions with several researchers at HAU the data given in table 2 have been estimated for the winter crops wheat (growing period 7 November - 15 April and "raya", mustard seed (growing period 7 October - 15 March). The calculated potential evapotranspiration E_m is included in table 2. The average maximum seasonal consumptive use of wheat is estimated in this way as 637 mm and of raya 567 mm. During the ripening phase of the crop (assumed 1 - 15 April for wheat and 1 - 15 March for raya) the potential evapotranspiration calculated according to the above mentioned method gives too high values. In fact the assumption of constant reflection coefficient is not valid here. For these periods the calculated potential evapotranspiration is reduced by assuming zero soil cover.

The crop development data for the summer crops, cotton (growing period 15 May - 1 November) and "bajra", pearl millet (growing period 1 July - 15 October) are given in table 3. The calculated potential evapotranspiration has been included. The average maximum seasonal consumptive use of cotton is estimated with this method as 1009 mm and that of bajra 530 mm.

Table 1. Calculation of monthly maximum evaporative demand E_{max} at full soil cover

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Basic measured meteorological data at Hissar												
T °C	12.7	14.7	19.9	27.4	31.4	33.0	30.7	29.7	28.5	25.0	18.7	14.2
n	7.7	8.5	8.5	9.5	8.7	6.7	5.6	6.4	7.8	9.4	8.7	7.1
v $m.s^{-1}$	1.4	1.6	1.7	1.9	2.7	3.0	2.9	2.0	1.4	1.1	0.9	0.9
R_h %	65	64	58	44	36	45	70	74	65	54	61	66
Basic meteorological data at Hissar												
H_a $mm.d^{-1}$	9.05	10.90	13.25	15.25	16.50	16.90	16.75	15.70	14.00	11.80	9.70	8.55
N	10.4	11.1	12.0	12.9	13.6	14.0	13.9	13.2	12.4	11.5	10.6	10.2
Calculated parameters												
H_{sh} $mm.d^{-1}$ (eq.3)	5.61	6.92	8.02	9.46	9.41	8.28	7.54	7.69	7.91	7.79	6.40	5.13
H_{lo} $mm.d^{-1}$ (eq.4)	1.24	1.27	1.18	1.22	1.25	0.84	0.55	0.59	0.83	1.21	1.33	1.18
H_{nt}(soil) $mm.d^{-1}$ (eq.2)	3.53	4.61	5.64	6.82	6.75	6.20	5.86	5.95	5.89	5.41	4.11	3.18
H_{nt}(crop) $mm.d^{-1}$ (eq.2)	3.02	3.99	4.92	5.97	5.90	5.45	5.18	5.25	5.18	4.71	3.53	2.72
e_s mbar	14.7	16.7	23.3	36.5	46.0	50.3	44.1	41.7	39.0	31.7	21.6	16.3
e_a mbar (eq.5)	9.6	10.8	13.6	16.3	15.4	22.6	31.1	30.9	25.3	17.0	13.2	10.8
Maximum evaporative demand in $mm.d^{-1}$ (eq.1)												
Crop height (m)												
0	2.51	3.37	4.56	6.33	7.39	6.86	5.56	5.26	5.15	4.62	3.16	2.26
0.10	3.38	4.37	6.08	9.43	12.67	11.79	7.81	6.59	6.42	5.95	3.89	2.95
0.20	3.91	4.99	6.97	11.06	15.32	14.25	9.06	7.42	7.23	6.77	4.39	3.38
0.30	4.17	5.30	7.42	11.88	16.64	15.48	9.68	7.83	7.64	7.18	4.63	3.59
0.40	4.38	5.55	7.78	12.53	17.70	16.46	10.17	8.16	7.96	7.51	4.83	3.76
0.50	4.57	5.77	8.09	13.10	18.63	17.32	10.61	8.45	8.25	7.80	5.01	3.91
0.60	4.72	5.96	8.36	13.59	19.43	18.06	10.98	8.70	8.49	8.05	5.16	4.04
0.70	4.88	6.14	8.63	14.08	20.22	18.80	11.35	8.95	8.73	8.29	5.31	4.17
0.80	4.99	6.27	8.81	14.40	20.75	19.29	11.60	9.12	8.90	8.46	5.40	4.26
0.90	5.06	6.36	8.94	14.65	21.15	19.66	11.79	9.24	9.02	8.58	5.48	4.32

Reduction factor for incomplete soil cover

soil cover fraction	0	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
Jan. - July	0.33	0.41	0.48	0.56	0.64	0.73	0.82	0.90	0.95	1.00	1.00
Aug. - Dec.	0.41	0.50	0.57	0.65	0.72	0.79	0.87	0.92	0.97	1.00	1.00

crops at Hissar

	wheat				raya			
Date	Crop height (m)	Root zone (m)	Soil cover	E_m (mm.d^{-1})	Crop height (m)	Root zone (m)	Soil cover	E_m (mm.d^{-1})
7 Oct.	-	-	-	-	0	0	0	1.89
15 Oct.	-	-	-	-	0	0	0	1.89
1 Nov.	-	-	-	-	0.05	0.05	0	1.45
7 Nov.	0	0	0	1.30	0.05	0.05	0	1.45
15 Nov.	0	0	0	1.30	0.20	0.20	0.10	2.20
1 Dec.	0.05	0.05	0	1.07	0.50	0.50	0.40	2.82
15 Dec.	0.10	0.10	0.05	1.34	1.00	1.00	0.70	3.97
1 Jan.	0.25	0.25	0.20	1.94	1.20	1.20	0.80	4.81
15 Jan.	0.50	0.50	0.40	2.92	1.25	1.25	0.80	4.81
1 Feb.	0.80	0.80	0.60	5.14	1.25	1.25	0.80	6.04
14 Feb.	0.90	0.90	0.80	6.17	1.25	1.25	0.80	6.04
1 Mar.	0.90	0.90	0.90	8.94	1.25	1.25	0	2.95
15 Mar.	0.90	0.90	0.90	8.94		harvest		
1 Apr.	0.90	0.90	0	4.83				
15 Apr.		harvest						
MAXIMUM CONSUMPTIVE USE 637 mm								567 mm

Tabel 3. Crop development and potential evapotranspiration of summer-crops at Hissar

	cotton				bajra			
Date	Crop height (m)	Root zone (m)	Soil cover	E_m (mm.d^{-1})	Crop height (m)	Root zone (m)	Soil cover	E_m (mm.d^{-1})
15 May	0	0	0	2.44	-	-	-	-
1 June	0.05	0.05	0	3.08	-	-	-	-
15 June	0.15	0.15	0.05	4.82	-	-	-	-
1 July	0.30	0.30	0.20	4.56	0	0	0	1.83
15 July	0.60	0.50	0.40	7.03	0.05	0.05	0	2.21
1 Aug.	1.00	0.70	0.60	8.04	0.40	0.20	0.20	4.65
15 Aug.	1.50	1.00	0.80	8.96	0.80	0.40	0.40	6.57
1 Sep.	1.50	1.00	0.90	9.02	1.30	0.60	0.60	7.85
15 Sep.	1.50	1.00	0.90	9.02	1.80	0.80	0.80	8.75
1 Oct.	1.50	1.00	0.50	6.78	2.20	1.00	0	3.52
15 Oct.	1.50	1.00	0	3.52		harvest		
1 Nov.		harvest			-	-	-	-
MAXIMUM CONSUMPTIVE USE 1009 mm								530 mm

2.2. Vegetable crops

Although considerable variation with respect to crop development (crop height, rooting depth, etc.) does exist between different vegetable crops, vegetable crops will be considered here as one uniform crop. The reason for this is the planned subsurface drainage experiment at the HAU experimental farm. The area being provided at present with drainage is used for vegetable crops.

Assuming on average rooting depth and crop height of 30 cm and an average soil cover of 0.60 the potential evapotranspiration has been estimated in table 4.

Table 4. Average crop development and potential evapotranspiration for vegetable crops

Month	Crop height (m)	Root zone (m)	Soil cover	E_m (mm.d^{-1})
January	0.30	0.30	0.60	2.34
February	0.30	0.30	0.60	2.97
March	0.30	0.30	0.60	4.16
April	0.30	0.30	0.60	6.65
May	0.30	0.30	0.60	9.32
June	0.30	0.30	0.60	8.67
July	0.30	0.30	0.60	5.42
August	0.30	0.30	0.60	5.09
September	0.30	0.30	0.60	4.97
October	0.30	0.30	0.60	4.67
November	0.30	0.30	0.60	3.01
December	0.30	0.30	0.60	2.33
MAXIMUM CONSUMPTIVE USE				1782 mm

3. UNSATURATED ZONE SALINITY AND EVAPOTRANSPIRATION MODEL

Based on the soil moisture conditions actual evapotranspiration by the crop may be equal to the potential evapotranspiration, or may be less than E_m (reduced evapotranspiration). The salinity in the rootzone may influence the availability of soil water for evapotranspiration due to osmotic effects. In this respect the osmotic potential caused by the soil water salinity may be considered additive to the matric potential of the soil system.

Considering a crop with a certain effective rooting depth (i.e. 90% of the crop roots are above this depth) the soil in the rootzone will decrease in moisture content. As a result a soil moisture gradient will develop below the root zone due to capillary rise. Assuming a straight relationship for this soil moisture gradient over a depth d_c below the root zone, assuming that the top soil eventually can dry till wilting point and assuming that the capillary characteristics of the soil are not limiting the maximum total available water in the soil for the crop can be expressed as follows:

$$M_o = 0.5\ (d_r + d_c)\ (\theta_{fc} - \theta_{wp}) \qquad (7)$$

where:

M_o = available water for evapotranspiration at field capacity in m
d_r = effective root zone depth in m
d_c = depth below root zone in which capillary rise takes place in m
θ_{fc} = moisture fraction at field capacity
θ_{wp} = moisture fraction at wilting point.

Transport of salts in the soil can take place only by mass transport of the soil solution. By subdividing the soil into a number of layers for each layer a salt mass balance can be drafted and solved, assuming complete mixing. When recharging the soil by irrigation or rainfall no vertical transport is assumed untill the soil is at field capacity. Upward transport (capillary rise) is assumed to take place at moisture contents below field capacity. Both assumptions can only be valid to a certain degree due to an actively transpiring plant canopy.

In the model the saturated groundwaterflow has not been taken into account. This limits the application to situations with a deep groundwater table or to situations where the groundwaterflow can be neglected. This is the case when large fields are uniformly irrigated and also crop development is uniform and no seepage/leakage takes place. The reason for omitting the groundwaterflow from the model is the available computer facilities at HAU. The unsaturated salinity and evapotranspiration model presented in this report can run on the HP 41 CV available. No extra space is available for additional calculations.

3.1. Redistribution of salts due to irrigation

The vertical profile that has to be taken into account for the unsaturated salinity and evapotranspiration model should be deep enough to cover the soil layers from which the crop canopy extracts its water for transpiration. This zone should therefore cover the root depth and the capillary rise zone:

$$NL > (d_r)_{max} + d_c \qquad (8)$$

where

N - number of layers considered in the model

L - layer thickness in m

$(d_r)_{max}$ - maximum rootzone depth used in the calculations in m.

Within the rootzone depth an uniform moisture distribution pattern is assumed. The number of layers in the rootzone should therefore be known:

$$n_r = \mathrm{Int}\left(\frac{d_r}{L} + 0.5\right) \qquad n_r \geq 1 \qquad (9)$$

where

n_r - number of layers in the rootzone

Int () - integer function; takes the integer number of the figure in between the brackets

In a similar way the number of unsaturated soil layers can be approximated:

$$n_u = \mathrm{Int}\left(\frac{h}{L} + 0.5\right) \qquad \text{if } h \leq d_r + d_c$$

$$n_u = \mathrm{Int}\left(\frac{d_r + d_c}{L} + 0.5\right) \text{ if } h > d_r + d_c \qquad (10)$$

where

n_u - number of unsaturated layers in the soil system considered

h - depth of the phreatic water level below soil surface in m.

Initially, just before irrigation takes place, the moisture deficit with respect to field capacity for each layer in the soil profile considered (layer 1, 2... N) should be known. Given these moisture deficits per layer the total soil moisture deficit for that part of the soil system that may be influenced by evapotranspiration and capillary rise can be formulated:

$$M_d = \sum_{n=1}^{n_u} M_d(n) \qquad (11)$$

where

M_d - soil moisture deficit in m of the zone in the soil system influenced by evapotranspiration

$M_d(n)$ - moisture deficit in layer n.

Assuming an equal initial moisture distribution in the root zone and a linear increase for the zone with thickness d_c below the root zone untill field capacity at the phreatic waterlevel or at the depth of $d_r + d_c$ the following relation between the moisture depletion in the root zone and the moisture deficit can be found:

$$\Delta\theta = \frac{2M_d}{(n_r + n_u)L} \qquad (12)$$

where $\Delta\theta$ - fractional moisture depletion in the root zone

The moisture deficit per layer can be calculated according to the assumption of uniformity in the root zone and linear decrease below the root zone for the n_u layers concerned:

$$M_d(n) = \Delta\theta L \qquad \text{if } n \leq n_r$$

$$M_d(n) = \Delta\theta L \left(\frac{n_u - n + 0.5}{n_u - n_r}\right) \qquad \text{if } n_r < n \leq n_u \qquad (13)$$

In the refilling and leaching process two stages can be distinguished. Assuming that no water transport takes place from one layer to the next as long as the layer is not at field capacity the layer will be refilled untill field capacity first and next transport to the next layer takes place.

Expressing the salinity of the soil moisture at constant moisture fraction (field capacity) the change in concentration due to refilling the first layer is given by:

$$c_1(t) = c_1(t_o) + \frac{M_d(1)c_i}{\theta_{fc}L} \qquad (14)$$

where

$c_1(t)$ - concentration (at field capacity) of layer 1 after refilling

$c_1(t_o)$- concentration (at field capacity) of layer 1 before refilling

c_i - concentration of the irrigation water.

After refilling the first layer part of the net irrigation applied to the field has been infiltrated. The remaining part of the irrigation water that stil has to infiltrate equals:

$$I_n = I_n - M_d(1) \qquad (15)$$

where I_n - net quantity of irrigation water in m that still has to infiltrate.

Refilling the next layer requires a quantity if irrigation water of $M_d(2)$. The concentration of the water flowing into layer 2 will have the concentration of layer 1. In general this means that for refilling layer n, the layers 1, 2,... n-1 have to be leached and that the leachate will be refilling layer n. Assuming complete mixing of the incoming flux with the moisture in the layer the mass balance for layer n can be formulated:

$$\theta_{fc}L \frac{d\, c_n(t)}{dt} = f\, c_{n-1}(t) - f\, c_n(t) \qquad (16)$$

where f - moisture flux from layer n-1 to layer n and from layer n to layer n+1 in $m.d^{-1}$.

The mass balance equation (16) can be solved under the boundary conditions $c_n(t) = c_n(t_o)$ if $t = o$ and $c_{n-1}(t) = c_i$ if $n = 1$:

$$c_n(t) = c_i + e^{-At} \sum_{k=1}^{n} \frac{(At)^{n-k}}{(n-k)\,!} \{ c_k(t_o) - c_i \} \qquad (17)$$

where

A - relative moisture flux in d^{-1}

n! - n faculty (= 1.2.3.4....n)

The relative moisture flux A has been formulated relative to the moisture content of the layer:

$$A = \frac{f}{\theta_{fc} L} \tag{18}$$

With equation (17) the end concentrations in the layers 1, 2 ... n can be calculated. For refilling the next layer (layer n+1) the quantity of salt has to be calculated. This can be done by integrating equation (17) and dividing by the time step. An easier method is to draft the salt balance of the layers 1-n:

$$S = c_i \; M_d(n+1) + \theta_{fc} L \sum_{k=1}^{n} \{ \; c_k(t_o) - c_k(t) \; \} \tag{19}$$

where S - quantity of salt leached from layer n to layer n+1.

Similar to equation (14) the concentration of layer n+1 after refilling follows then:

$$c_{n+1}(t) = c_{n+1}(t_o) + \frac{S}{\theta_{fc} L} \tag{20}$$

If the quantity of irrigation is more than the total moisture deficit in the profile (the total profile including the layers n_u, n_{u+1}, ... N) the whole system (1, 2, ... N) will be leached. The quantity of leachate can be formulated as:

$$\Delta V_s = I_n - \sum_{k=1}^{N} M_d(k) \tag{21}$$

where ΔV_s - leachate quantity in m.

The quantity of salt leached can be calculated with equations (17) and (19) introducing N for n. The quantity of leachate water will be added to the "drainable water" already present in the soil system considered. The salinity of this drainable water can be assessed by assuming complete mixing in this reservoir:

$$c_s = \frac{c_s V_s + S}{V_s + \Delta V_s} \qquad (22)$$

where

c_s - concentration of the drainable water

V_s - quantity of drainable water in m.

The quantity of drainable water after irrigation follows:

$$V_s = V_s + \Delta V_s \qquad (23)$$

Since this water is stored above field capacity the phreatic water level will rise and the depth of the watertable can be calculated:

$$h = h - \frac{\Delta V_s}{\mu} \qquad (24)$$

where μ - drainable porosity.

In fig. 5 the organisation of the calculations as given by equations (9) - (24) as programmed on the HP 41-CV is presented. The calculation procedure for equation (17) has not been included in this diagramme. In fig. 6 this subroutine "LEACH" is explained.

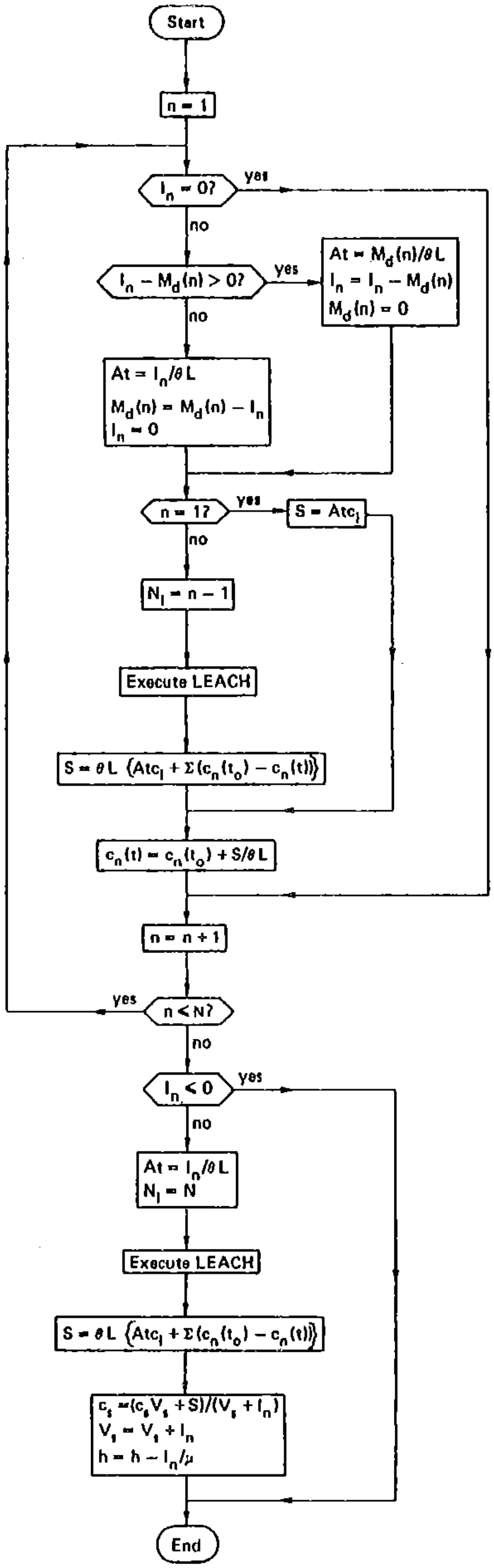

Fig. 5. Flow diagramme redistribution of salt due to irrigation

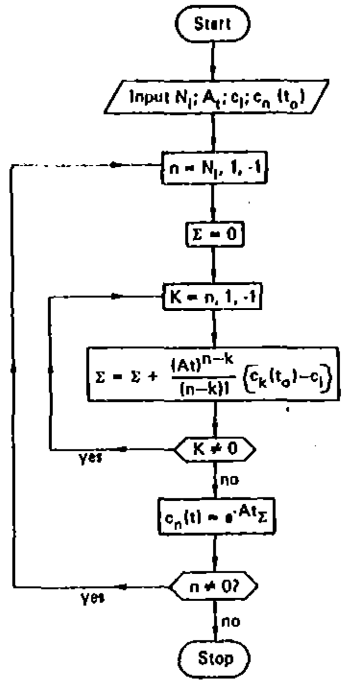

Fig. 6. Flow diagramme subroutine "LEACH"

3.2. Actual evapotranspiration

Based on the soil moisture conditions the actual evapotranspiration rate may equal the potential evapotranspiration, E_m, or may be reduced due to closure of the stomata. Assuming a certain fraction (1-a) of the available moisture at field capacity M_o (equation 7) to be easily available without reduction and assuming a proportional decrease in the actual evapotranspiration with the available soil moisture beyond this point the formulation for the evapotranspiration is:

$$E_r = E_m \qquad \text{if } M(t) > aM_o$$

$$E_r = \frac{M(t)}{aM_o} \qquad \text{if } o < M(t) \leqslant aM_o \tag{25}$$

$$E_r = o \qquad \text{if } M(t) \leqslant o$$

where

E_r - actual evapotranspiration rate in $m.d^{-1}$

$M(t)$ - available soil moisture at time t

a - fraction of available soil moisture at field capacity that is still available when evapotranspiration reduction starts.

Based on equation (25) and based on the assumption that during the period following irrigation no other fluxes take place the following soil moisture mass balance can be drafted:

$$\frac{dM(t)}{dt} = -E_r \qquad (26)$$

The solution for M(t) depends on the boundary conditions for E_r mentioned in equation(25) and the condition : $M(t) = M(t_o)$ for $t = o$:

$$M(t) = M(t_o) - t\,E_m \qquad \text{if } M(t) > aM_o$$

$$M(t) = M(t_o)\, e^{-\frac{t}{aM_o}} \qquad \text{if } o < M(t_o) \leqslant aM_o \qquad (28)$$

$$M(t) = M(t_o) \qquad \text{if } M(t_o) \leqslant o$$

The boundary condition of the first option given in equation (28) is not sufficient for calculations. If initially the available moisture is above the critical value for evapotranspiration reduction ($M(t_o > aM_o$), potential evapotranspiration will continue for a certain time untill the critical value is reached. The period during which evapotranspiration will be potential can be calculated:

$$T = \frac{M(t_o) - aM_o}{E_m} \qquad \text{if } M(t_o) > aM_o \qquad (29)$$

where T - duration of potential evapotranspiration in days.

The factor a given in equation (25) depends on the evaporative demand E_m, the crop type characterised by the critical leaf water potential Ψ_c at which the stomata start to close, and on the osmotic potential caused by the salts in the soil moisture. A detailed explanation on the relation between the soil moisture fraction a, E_m and Ψ_c has been given by RIJTEMA and ABOUKHALED (1975). ABDELKHALIK ET AL (1986) added the osmotic potential to this concept and arrived at values for the a-fraction for a medium textured soil as presented in table 5. The relation between osmotic potential and electrical conductivity can be given as (RICHARDS, 1954):

Table 5. The fraction of soil water available under plant stress conditions, a-factor, in relation to osmotic pressure, evaporative demand and critical leaf water suction Ψ_c for medium textured soils (after ABDEL KHALIK ET AL., 1986)

E_{max} mm/day	Osmotic pressure											
	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5
Ψ_c = 13												
1	.103	.124	.147	.170	.194	.220	.247	.275	.305	.337	.370	.405
2	.175	.200	.225	.252	.280	.310	.341	.373	.407	.441	.477	.514
3	.258	.286	.315	.345	.376	.408	.441	.475	.509	.544	.579	.614
4	.349	.379	.410	.441	.473	.505	.537	.570	.602	.633	.665	.696
5	.441	.471	.502	.532	.562	.591	.621	.650	.678	.706	.734	.761
6	.527	.555	.583	.610	.637	.663	.689	.715	.740	.764	.788	.812
7	.601	.626	.651	.675	.698	.722	.744	.767	.789	.810	.831	.852
8	.662	.684	.706	.728	.749	.769	.789	.809	.828	.847	.866	.884
9	.713	.733	.752	.771	.790	.808	.826	.843	.861	.878	.894	.911
10	.755	.773	.790	.807	.824	.840	.856	.872	.888	.903	.918	.933
11	.790	.806	.822	.837	.852	.867	.882	.896	.910	.924	.938	.952
12	.820	.835	.849	.863	.877	.890	.903	.917	.930	.942	.955	.967
13	.846	.859	.872	.885	.897	.910	.922	.934	.946	.958	.970	.981
14	.868	.880	.892	.904	.915	.927	.938	.949	.961	.972	.982	.993
15	.887	.898	.909	.920	.931	.942	.952	.963	.973	.983	.993	1.023
Ψ_c = 10												
1	.170	.197	.225	.256	.288	.323	.360	.399	.441	.485	.532	.582
2	.262	.294	.328	.364	.401	.441	.482	.525	.569	.613	.658	.703
3	.367	.404	.441	.479	.519	.558	.598	.638	.678	.717	.756	.794
4	.477	.513	.550	.586	.622	.658	.693	.727	.761	.794	.826	.858
5	.576	.609	.641	.673	.704	.735	.765	.794	.823	.851	.878	.905
6	.657	.686	.714	.741	.768	.794	.820	.845	.869	.893	.917	.940
7	.722	.746	.771	.794	.817	.840	.862	.884	.905	.926	.946	.966
8	.773	.794	.815	.836	.856	.876	.896	.915	.933	.952	.970	.987
9	.814	.833	.852	.870	.888	.905	.923	.940	.956	.973	.989	1.032
10	.847	.864	.881	.897	.913	.929	.945	.960	.975	.990	1.030	1.147
11	.875	.891	.906	.920	.935	.949	.963	.977	.991	1.028	1.133	1.262
12	.899	.912	.926	.940	.953	.966	.979	.991	1.026	1.122	1.236	1.377
13	.919	.931	.944	.956	.968	.980	.992	1.025	1.112	1.215	1.339	1.491
14	.936	.947	.959	.970	.982	.993	1.024	1.104	1.198	1.308	1.442	1.606
15	.951	.961	.972	.983	.993	1.023	1.097	1.183	1.283	1.402	1.545	1.721
Ψ_c = 7												
1	.267	.305	.346	.391	.440	.494	.551	.612	.676	.743	.811	.879
2	.395	.440	.489	.540	.592	.646	.700	.754	.807	.860	.911	.962
3	.531	.577	.624	.670	.716	.761	.805	.848	.890	.931	.970	1.083
4	.648	.688	.728	.766	.804	.840	.875	.910	.943	.976	1.063	1.444
5	.737	.770	.802	.834	.865	.895	.924	.952	.890	1.052	1.329	1.805
6	.802	.829	.857	.883	.909	.934	.959	.983	1.045	1.262	1.595	2.166
7	.850	.874	.897	.920	.942	.964	.985	1.039	1.219	1.473	1.861	2.527
8	.888	.908	.929	.948	.968	.987	1.035	1.188	1.393	1.683	2.127	2.888
9	.918	.936	.953	.971	.988	1.032	1.165	1.336	1.567	1.894	2.393	3.249
10	.941	.958	.974	.989	1.030	1.147	1.294	1.485	1.741	2.104	2.659	3.610
11	.961	.976	.990	1.028	1.133	1.262	1.424	1.633	1.915	2.314	2.924	3.971
12	.978	.991	1.026	1.122	1.236	1.377	1.553	1.782	2.089	2.525	3.190	4.332
13	.992	1.025	1.112	1.215	1.339	1.491	1.683	1.930	2.263	2.735	3.456	4.693
14	1.024	1.104	1.198	1.308	1.442	1.606	1.812	2.079	2.437	2.946	3.722	5.054
15	1.097	1.183	1.283	1.402	1.545	1.721	1.941	2.227	2.611	3.156	3.988	5.415
Ψ_c = 4												
1	.439	.506	.581	.662	.749	.839	.930	1.269				
2	.627	.694	.761	.827	.891	.953	1.124	2.538				
3	.768	.820	.871	.919	.965	1.083	1.686	3.807				
4	.857	.897	.936	.973	1.063	1.444	2.248	5.076				
5	.915	.947	.978	1.052	1.329	1.805	2.810	6.345				
6	.955	.981	1.045	1.262	1.595	2.166	3.372	7.614				
7.	.984	1.039	1.219	1.473	1.861	2.527	3.934	8.883				
8	1.035	1.188	1.393	1.683	2.127	2.888	4.497	10.152				
9	1.165	1.336	1.567	1.894	2.393	3.249	5.059	11.422				
10	1.294	1.485	1.741	2.104	2.659	3.610	5.621	12.691				
11	1.424	1.633	1.915	2.314	2.924	3.971	6.183	13.960				
12	1.553	1.782	2.089	2.525	3.190	4.332	6.745	15.229				
13.	1.683	1.930	2.263	2.735	3.456	4.693	7.307	16.498				
14	1.812	2.079	2.437	2.946	3.722	5.054	7.869	17.767				
15	1.941	2.227	2.611	3.156	3.988	5.415	8.431	19.036				

$$\Psi_o = 0.36\ EC \qquad (30)$$

where

Ψ_o - osmotic suction in bar

EC - electrical conductivity in $mmho.cm^{-1}$

The calculation procedure of actual evapotranspiration proceeds as follows (see fig. 7). The average salinity in the crop root zone (expressed at field capacity) is calculated in the main programme. Using table 5 the required a-value can be obtained. The initial available moisture can be calculated from the available moisture at field capacity, the moisture deficit per layer and the initial water-table.

$$M(t_o) = M_o - \sum_{n=1}^{n_u} M_d(n) + (d_r + d_c - h)/\mu \qquad \text{if } h < d_r + d_c$$

$$M(t_o) = M_o - \sum_{n=1}^{n_u} M_d(n) \qquad \text{if } h \geq d_r + d_c \qquad (31)$$

Based on the initial condition for $M(t_o)$ equation (25) is applied for the evapotranspiration rate. Negative values for the initial available moiture are only possible if after harvesting a deep rooted crop that has considerably dried out the soil, the soil is kept fallow for some time without irrigation. In this case the evapotranspiration is assumed zero.

After calculating the final avalable moisture M(t) the total moisture deficit for the crop root zone and the capillary fringe below the root zone can be calculated:

$$M_d = M_o - M(t) \qquad (32)$$

A negative value for M_d indicates that on the average the soil profile is above field capacity. In this case the moisture content is assumed at field capacity and the excess water is assumed drainable water. Based on these assumptions the new phreatic water level follows:

$$H_n = d_r + d_c - \frac{M_d}{\mu} \qquad \text{if } M_d < o \qquad (33)$$

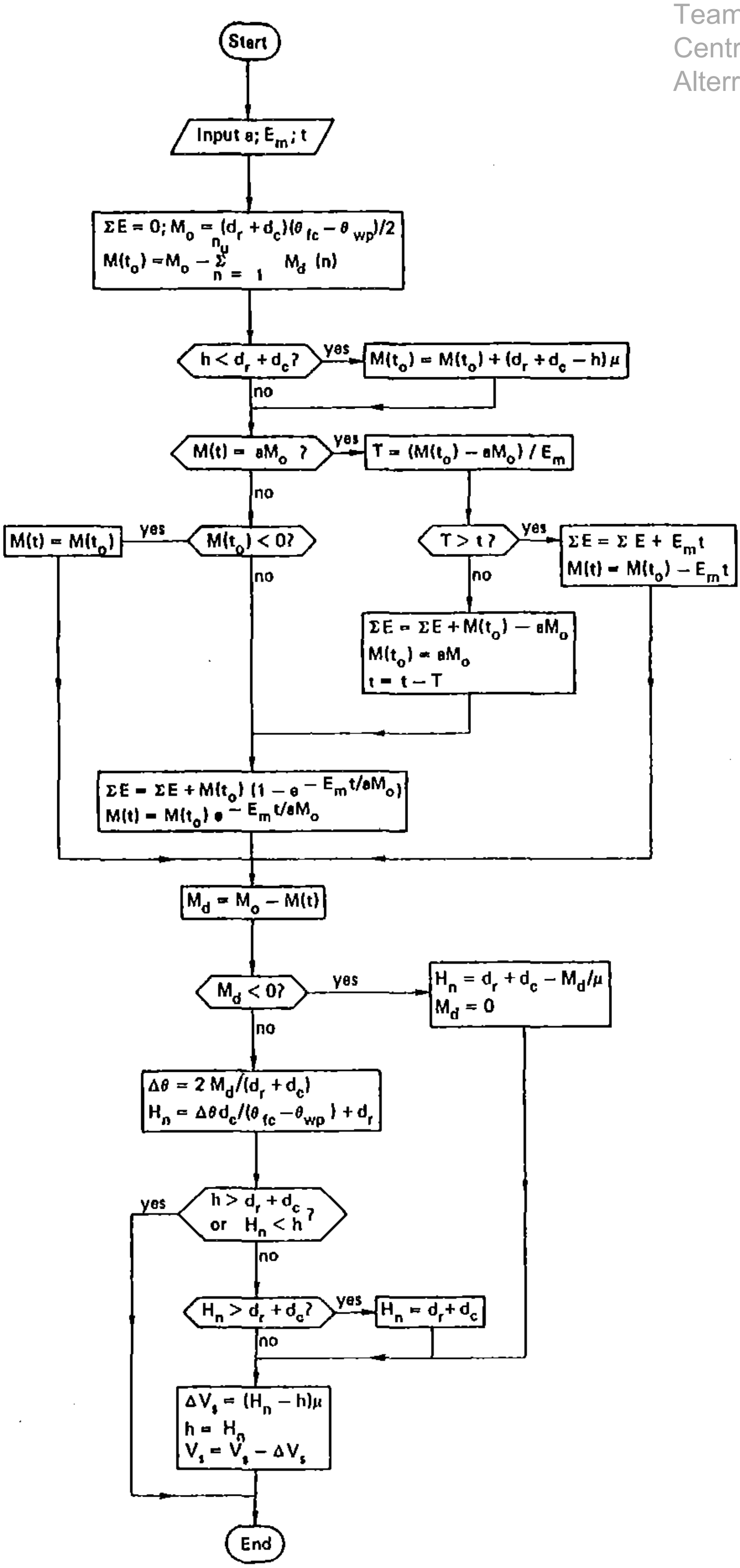

Fig. 7. Flow diagramme of subroutine "EVAP"

where H_n - new phreatic level at the end of the timestep in m.

If the moisture deficit is negative, still a waterlevel may be present in the system. By neclecting in first instance the drainable water that still may be present equation (12) can be used to calculate the decrease in moisture fraction in the root zone caused by this deficit. Assuming furhter a linear relation between this decrease $\Delta\theta$ and the maximum possible decrease $\theta_{fc} - \theta_{wp}$ the new water table can be calculated:

$$H_n = d_r + d_c \frac{\Delta\theta}{\theta_{fc} - \theta_{wp}} \qquad (34)$$

Based on the position of the old and new phreatic level the capillary contribution to the evapotranspiration can be estimated:

$$\Delta V_s = (H_n - h)\ \mu \qquad (35)$$

where ΔV_s - change in the quantity of drainable water in m.

3.3. Redistribution of salts due to evapotranspiration

The redistribution of salts due to evapotranspiration can be calculated layer by layer. The quantity of water entering the lowest layer under consideration (layer n_u) equals the capillary rise from the water table ΔV_s with a concentration of c_s. The final concentration of layer n_u can be calculated with equation (17) taking n = 1:

$$c = c_i + (c_o - c_i)\ e^{-At} \qquad (36)$$

where

c - final concentration

$At = \frac{\Delta V_s}{\theta L}$

$c_i \dagger c_s$

The quantity of water flowing from layer n_u to layer n_u-1 equals $\Delta V_s + \Delta M_d(n)$ where $\Delta M_d(n)$ is the increase in soil moisture deficit in layer n. The concentration of this upward flowing volume of water can be found by integrating equation (36) over time:

$$\underline{c} = c_i + \frac{c_o - c_i}{At} \, (1 - e^{-At}) \qquad \text{if } At \neq o$$

(37)

$$\underline{c} = c_o \qquad \text{if } At = o$$

Using equations (36) and (37) the capillary transport of salt in the capillary zone can be calculated. The final salt accumulation in the lowest layer of the root zone follows then:

$$\Delta c_{n_r} = \sum_{n=n_r+1}^{n_u} \{c_n(t_o) - c_n(t)\} + \frac{\Delta V_s \, c_s}{\theta L} \qquad (38)$$

where Δc_{n_r} - increase in salinity in layer n_r due to capillary rise.

3.4. Programme description

The unsaturated salinity and evapotranspiration model has been programmed on the HP41CV pocket calculator. The main structure of programme "SALT" is presented in fig. 8.

Before running the programme the initial soil salinity and the initial soil moisture deficit per layer has to be entered manually. The maximum number of layers that can be used is 10. The initial salinity of layers 1, 2, 3 ... 10 has to be stored in the registers 71, 72, 73, ... 80. The initial soil moisture deficit per layer in m in the registers 51, 52, 53, ... 60.

After starting the programme the general input data are requested (statements 1 - 31):

- NOLAYER - maximum number of layers that have to be used in the calculations (= NL)
- THETAL - the moisture per layer in m at field capacity (= θL)
- L - the layer thickness in m
- WLEVEL - initial depth of the phreatic waterlevel in m below soil surface (= h)
- MOIAVAI - moisture fraction available for evapotranspiration (= $\theta_{fc} - \theta_{wp}$)
- DRAINPOR- drainable porosity (= $\theta_s - \theta_{fc}$)
- CRIT D - thickness of the layer for which capillary rise is important in m (= d_c)

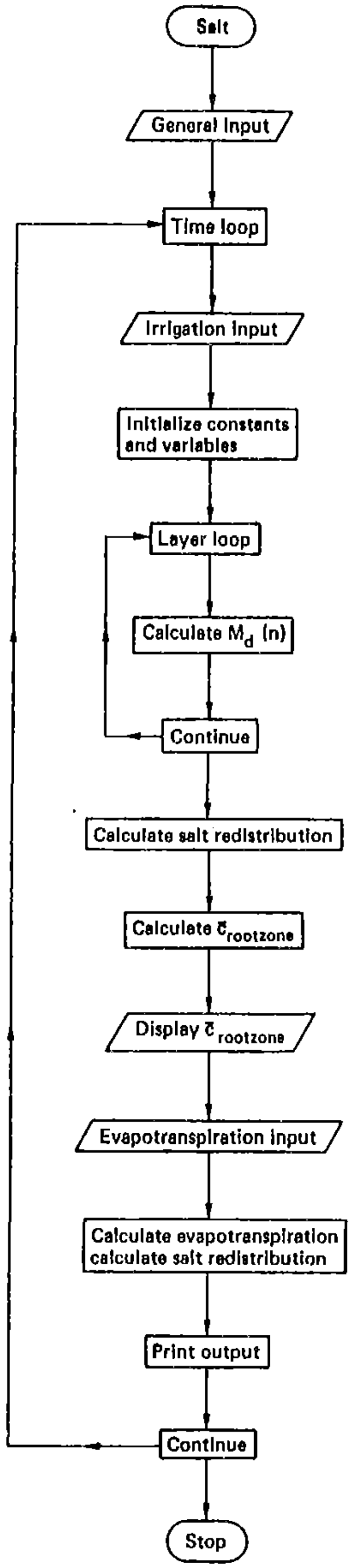

Fig. 8. General structure of programme "SALT"

- C STOR - initial concentration of the drainable water (= c_s)
- V STOR - initial amount of drainable water in mm (= V_s)

After entering these general and initial data the programme requests the time dependent irrigation and crop data (statements 32 - 44):

- IRRIG - amount of irrigation water in mm (= I_n)
- CIRR - concentration of the irrigation water (= c_i)
- DROOT - rooting depth of the crop in m (= d_r)

Next, some constants and variables are initialized (statements 45 - 66). The number of layers in the root zone is calculated. The total number of layers in the unsaturated zone n_u is calculated in subroutine "NU" and the difference of moisture fraction with field capacity is calculated based on the moisture deficit in subroutine "DELT".

In a layer loop (statements 67 - 73) the soil moisture deficit per layer is calculated in subroutine "MDN".

Next the salt redistribution due to irrigation is calculated (statements 73 - 173) along the lines given in fig. 5. After calculating the average salinity in the root zone (statements 173 - 204) the programme displays this average concentration and after starting the programme again it requests the following crop and evapotranspiration input:

- AFACT - fraction of soil moisture available under plant stress conditions only (= a)
- EMAX - potential evapotranspiration rate in $mm.d^{-1}$ (= E_m)
- TINT - length of the irrigation interval in days (= t)

In subroutine "EVAP" the actual evapotranspiration is calculated (see flow diagramme in fig. 7) and in subroutine "REDIS" the salt accumulation in the root zone.

Finally (statement 208-257) the output is printed:

- INTERVAL- length of the irrigation interval in days (= t)
- WATER DEPTH - depth of the phreatic level below soil surface in m (= h)
- EMAX - potential evapotranspiration in $mm.d^{-1}$ (= E_m)
- EREAL - real evapotranspiration in $mm.d^{-1}$ (=E_m)
- MDEF - soil moisture deficit in the whole soil profile (NL layers) in mm

- SOIL EC - salinity of each layer at the end of the time step
- RELATIVE E - cumulative real evapotranspiration devided by the cumulative maximum evapotranspiration since the start of the growing season.

After printing the output the time loop is finished and programme execution is transferred back to LBL03 (statement 32) and the programme requests the irrigation input data for the next irrigation interval.

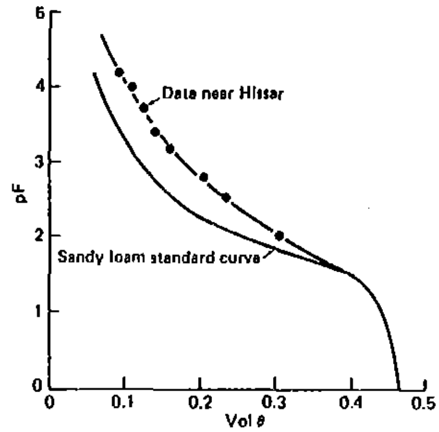

Fig. 9. Soil moisture characteristics sandy loam standard soil and data from Hissar

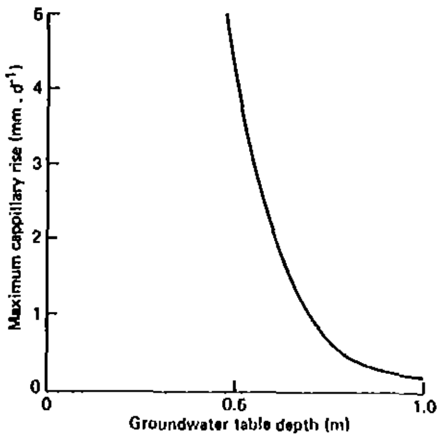

Fig. 10. Relation between capillary rise and depth of groundwater table below root zone. Sandy loam soil

4. FIELD RESEARCH PROGRAMMES

The operational research field studies are performed at the HAU experimental farm in Hissar. In the Hissar region the groundwater table has not yet risen to hazarduous levels. At the experimental farm, however, where the croppping intensity has been 200% the groundwater level is (at least at part of the farm) within 2 m of the soil surface As such the experimental farm could be considered as a pilot area for studying the control of the watertable and the soil salinity. Because only recently the watertable came in the vicinity of the effective crop root zone salinisation has not yet affected crop production, but it certainly will in the near future unless control measures are taken.

The soil type at the experimental farm is sandy loam soil with a tickness of 3 - 5 m. Below this layer a fine sand layer with thickness of about 10 m is located overlying a heavier layer with clay of 10 - 15 m thick. The upper side of this clay layer can be considered as the drainage barrier. The resistance of this layer can be estimated in the order of magnitude of 125 - 1250 days. No data are avalable on the piezometric head in the sandy aquifer of 20 - 25 m thick below the resistance layer.

The electrical conductivity of the shallow groundwater varies from 1 - 4 $mmho.cm^{-1}$. In the aquifer the electrical conductivity is about 15 $mmho.cm^{-1}$.

In fig. 9 the pF curves of the sandy loam standard soil described by RIJTEMA (1969) and the data determined on a location near Hissar have been presented. From this moisture characteristic curve (data of Hissar) it follows that the moisture fraction at saturation $\theta_s = 0.46$, at field capacity $\theta_{fc} = 0.305$, and at wilting point $\theta_{wp} = 0.095$. The moisture fraction avalable for evapotranspiration equals 0.210 in this case and the drainable porosity $\mu = 0.155$. In fig. 10 the capillary flux in relation to the vertical distance to the groundwater table for the 'standard' sandy loam soil is given, assuming a moisture content at willing point in the root zone. This curve can be used to estimate the soil depth below the root zone that will be influenced by capillary effects. Selecting arbitrarily a maximum flux of 1 $mm.d^{-1}$ as the lower limit the capillary fringe d_c equals 0.7 m.

In table 6 the long term average precipitation and class A pan evapotranspiration at the HAU experimental farm are given (data after AGARWAL and KHANNA, 1983).

Table 6. Monthly precipitation in mm and average pan evaporation rate in $mm.d^{-1}$ at Hissar

	Jan.	Feb.	Mar.	Apr	May	June	July	Aug.	Sep.	Oct	Nov.	Dec
precipitation	10.2	16.1	14.0	5.6	30.6	37.8	156.8	121.2	42.8	5.1	11.0	5.3
evaporation	2.9	3.6	5.5	9.7	12.8	12.1	7.4	5.8	6.1	5.5	3.5	2.2

The experiments performed and under preparation at the HAU experimental farm should be performed to calibrate the unsaturated salinity and evapotranspiration model. Based on experimental results the formulation may be adapted and parameters changed. The drainage experiments should provide sufficient data to succesfully extend the formulation with a drainage model. In the light of these requirements the experiments will be reviewed one by one.

4.1. Reduced waterapplication experiment

The objective of this study is to estimate the crop reaction and the soil salinity on different irrigation treatments with good quality canal water. Two wintercrops, wheat and raya, and two summer crops, cotton and bajra, are anticipated in this research. In this report discussions will be confined to the wheat crop.

Five irrigation treaments for the wheat crop have been investigated: no irrigation (I_0), one irrigation of 60 mm (I_1), two irrigations of 60 mm (I_2), three irrigations of 60 mm (I_3) and four irrigations of 60 mm (I_4). In all cases a pre-sowing irrigation has been given that was sufficient to bring the soil to field capacity. The plot size for each treatment is 50 m^2.

The pre-irrigation took place on 10 november 1985. On 18 november the watertable was measured at 96.5 cm below soil surface. The electrical conductivity of soil samples taken at different depths on the five plots on 18 november, measured in the 1 : 2 extract is given in table 7.

Table 7. Electrical conductivity of the soil water solution in the 1 : 2 extract in mmho.cm^{-1}

Depth	I_0	I_1	I_2	I_3	I_4	Average	At field capacity
0- 15	0.136	0.073	0.073	-	0.104	0.096	0.89
15- 30	0.146	0.101	0.073	-	0.093	0.104	0.98
30- 60	0.156	0.104	0.073	-	0.083	0.104	0.98
60- 90	0.083	0.114	0.167	-	0.093	0.114	1.07
90-120	0.083	0.083	0.230	-	0.093	0.122	1.15

Assuming transport in the unsaturated zone to take place at field capacity these figures have to be transformed to field capacity. In preparing a 1 : 2 extract a certain weight of oven-dry soil is mixed with twice the weight of distilled water. Assuming a dry bulk density of 1.43 kg.dm^{-3} this means that 70 cm^3 of soil is mixed with 200 cm^3 of water. At field capacity this quantity of soil would contain 21.35 cm^3 of water and consequently the electrical conductivity values measured in the laboratory have to be multiplied with a factor of 9.4 to estimate the electrical conductivity of the same sample at field capacity.

The electrical conductivity of the shallow groundwater was 1.00 mmho.cm^{-1}. The irrigation dates of the different treatments are given in table 8.

Table 8. Irrigation treatments in the reduced water application treatment for the wheat crop 1985/1986

Date	I_0	I_1	I_2	I_3	I_4
10-11-85		p r e i r r i g a t i o n			
10-12-85	-	60	60	60	60 mm
21- 1-86	-	-	-	-	60 mm
3- 2-86	-	-	-	60	- mm
26- 2-86	-	-	60	-	60 mm
11- 3-86	-	-	-	60	- mm

Using the initial soil salinity data given in table 7, the maximum evapotranspiration of wheat given in table 2 and including the precipitation rates given in table 6 the unsaturated salinity and evapotranspiration model has been used to calculate the course of the salinity of the upper 1 m of soil, the cumulative evapotranspiration and the depth of the groundwater table. The results are presented in fig. 11. The results on the watertable depth (fig.11a) indicate considerable differences in watertable depth on short distances (small plotsizes). In the field a difference of 35 cm at a distance of 5 to 10 m will be averaged out by lateral groundwaterflow. This has not been taken into account in the model. In fig. 11b the increase in salinity for the different treatments is given. Remarkable is that the salinity increases with increasing irrigation. This is due to the fact that for high watertables no effective leaching can take place and in fact more irrigation means adding more salts to the system. In fig. 11c the evapotranspiration results are presented. In the calculations a critical leafwater potential Ψ_c for wheat of 10 bar has been assumed. Due to the high initial watertable also the zero irrigation treatment still gives reasonable evapotranspiration (64% of the maximum). During the first 100 days of the growing season, untill the end of February there is hardly any difference between the treatments. The cumulative pan evaporation has been included in the figure for reference. During the first 75 days of the growing period pan evaporation over estimates and for the second 75 days the pan evaporation underestimates the potential evapotranspiration.

Because in the field local groundwaterflow will compensate for the difference between the treatments, it can be expected that the differences in crop yield between the treatments will be less than the 36% suggested by the difference in evapotranspiration . The implications for the soil salinity cannot be estimated. It is very well possible that in the high irrigation treatment effective leaching takes place through lateral outflow in the saturated system and it is most likely that more salinisation takes place in the low irrigation treatment through lateral inflow of saline groundwater.

For testing the above assumption it is necessary to continue the experiments on plots of greater sizes and to measure the groundwaterlevels not only inside the plots, but also outside to estimate gradients.

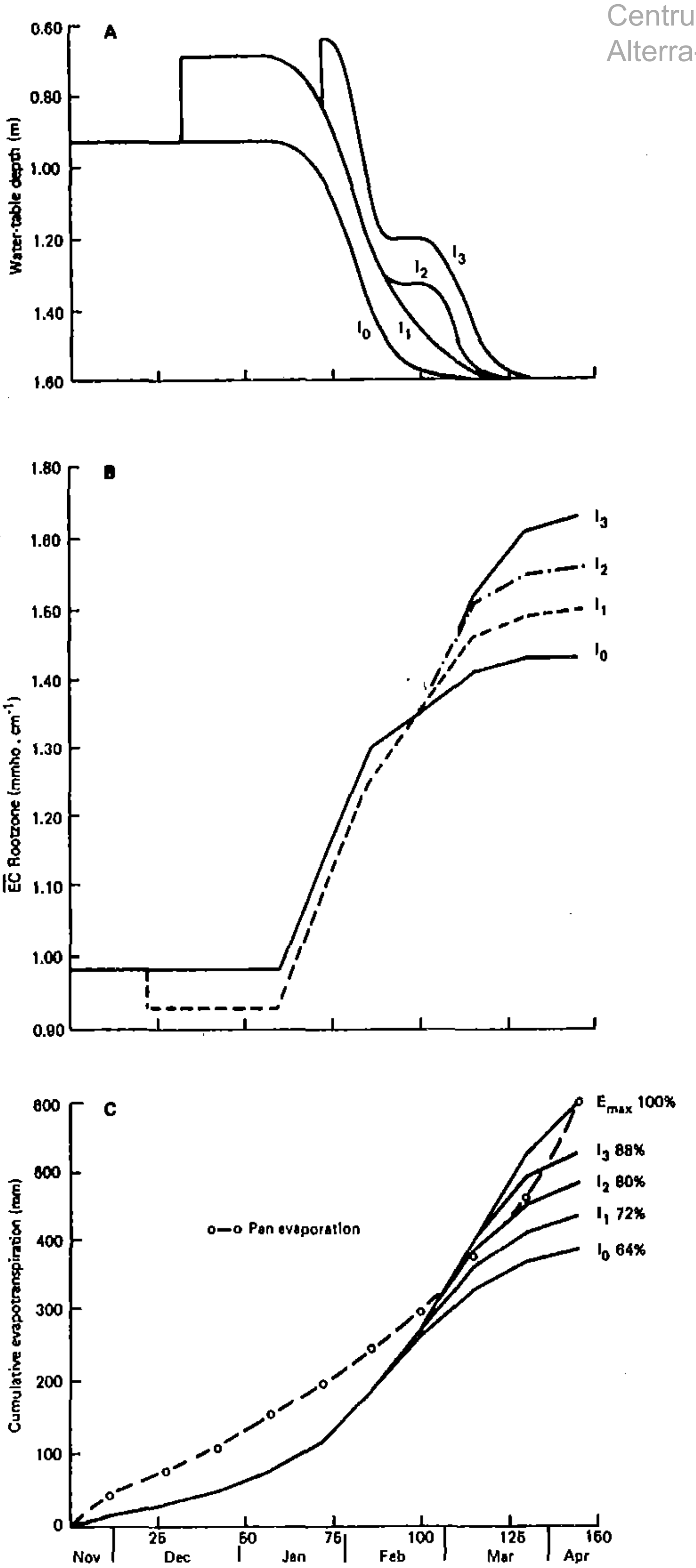

Fig. 11. Simulation results for the reduced water application experiment with wheat. a - watertable depth b - electrical conductivity rootzone c - cumulative evapotranspiration

When sufficient information is collected on the transmissivity of the shallow aquifer (untill the resistance clay layer) the lateral movement of water can be calculated. A second adventage of greater plot sizes is that it will become easier to accurately measure the exact irrigation water quantity to the plot. In this respect it should be mentioned that it is more important to know exactly how much water had been delivered than to exactly apply the 60 mm per irrigation mentioned in the project proposal. Also the inital and final soil moisture conditions in the profile after pre-irrigation and after harvest have to be measured accurately in order to have complete balance.

4.2. Experiment on conjunctive use of tubewell and canal irrigation water

The objectives of this experiment are to study the influence of salinity on crop yields under field conditions. The wintercrop studied is wheat and for summercrops cotton, bajra and maize are studied. The experiments are performed on plots of 1 acre. The pre-sowing irrigation is given with canal water and the subsequent irrigations are given with tubewell water from the deep aquifer having an electrical conductivity of 14 - 15 $mmho.cm^{-1}$.

Although it is the author's opinion that irrigation water with a salinity as high as 14 $mmho.cm^{-1}$ should not be used for regular irrigation it may give valuable information for testing simple models. It is therefore recommended to continue with these experiments and to supplement the monitoring programme with accurate measurements of the quantities of irrigation water delivered to the fields and with groundwater observations. The expected salinisation of the soil can be predicted by applying the model presented in chapter 3 for a number of consecutive years.

Because these experiments take place in the area that will be drained by the skimming well project it is recommended to concentrate these plots around one of the skimming wells and to exclude the drainage water of this particular skimming well from further reuse but to guide it to an evaporation pan for salt harvesting and/or fish culture.

Table 9. Irrigation schedule field crops. Gifts in mm

	Wheat	Raya	Cotton	Bajra
1 January	60			
15 January		60		
21 January	60			
15 February	60			
7 March	60			
15 May			200	
1 July				200
7 July			60	
1 August			60	
7 August				60
1 September			60	
7 September				60
21 September			60	
7 October		200		
7 November	200			
7 December	60			
21 December		60		
Total	500	320	440	320

Table 10. Results model calculations field crops

	Wheat	Raya	Cotton	Bajra
initial soil salinity	1.49	0.37	2.05	0.60
final soil salinity	1.34	0.57	1.49	0.37
relative evapotranspiration	0.74	0.73	0.71	0.62
drainage (mm)	46.7	34.2	75.4	206.2

4.3. Skimming well drainage experiment

With the skimming well drainage experiment the drainage of agricultural land with shallow wells will be tested on field scale. To this purpose shallow wells with a depth of 6 m and a diameter of 3 m have been constructed in a 120 ha area of the HAU experimental farm (fig. 12). A total of 24 skimming well have been constructed and by preliminary testing it appeared that 3 times daily 50 m^3 could be withdrawn from these wells. In order to estimate whether this yield of 3 $mm.d^{-1}$ can be sustained in the long turn calculations have been perfomed with the model described in chapter 3. The cropping pattern has been schematized as follows:
winter crops: 80% wheat and 20% raya
summer crops: 80% cotton and 20% bajra.

The critical leaf water potential Ψ_c has been assumed 13 bar for cotton, 10 bar for wheat and bajra and 7 bar for raya. Calculations have been perfomed using a low watertable and attributing any rise in watertable to drainage. The irrigation schedule used is presented in table 9. Assuming the cropping pattern as given above this means a yearly supply of irrigation water of 880 mm. The precipitation (11 year average) given in table 6 has been assumed to be distributed in two showers: 50% of the monthly total on the first day of the month and 50% of the monthly total on the fifteenth day of the month.

The results of the model calculations have been presented in table 10. According to the soil salinity figures the wheat-cotton rotation is not yet in equilibrium (EC = 2.00 at start of cotton season and 1,34 at end of wheat season). The soil salinity for the raya-bajra rotation is quite in equilibrium (EC = 0.60 at the start of bajra season and 0.57 at end of raya season). Given the crop rotation assumed above the average drainage rate in the skimming well area is about 146 mm yearly.

Given the total supply of 880 mm and the canal water salinity of 0,35 $mmho.cm^{-1}$ and the shallow groundwater salinity of 1 $mmho.cm^{-1}$ a total drainage of 308 mm would be expected. This can be explained by assuming a field application efficiency (including seepage losses) of 87%. The total field supply would then be 1030 mm. About 87% would be net irrigation gift (= 880 mm), 250 mm irrigation losses and 146 mm leaching, giving a total drainage of 396 mm.

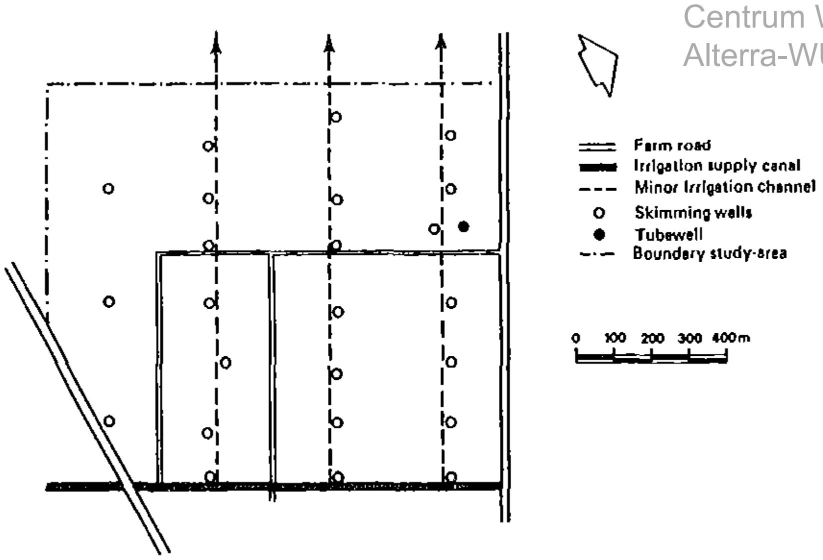

Fig. 12. Field layout of skimming well drainage experiment

Most probably the drainage rate will be between 0.40 and 1.1 mm.d^{-1}. Assuming a drainage rate of 0.75 m-.d^{-1} the skimming well can be operated one out of 4 days during the year. The objective of the experiment includes to reuse the drainage water within the experimental farm thereby postponing the salinity and waterlogging problems expected. A reduction of the waterduty to the skimming well area of 30% from 1030 mm to 755 mm (330,000 m^3) should therefore be applied and the drainage water should be pumped into the minor irrigation canals for downstream use.

The monitoring programme should include the observation of groundwater levels in the middle between skimming wells as well as close to these wells. A suggested configuration of observation wells in between 4 selected skimming wells is given in fig. 13. Due to the lowering of the watertable it is possible that seepage from the deep aquifer will occur. This can be tested by placing a piezometer in the centre of the area. The perforated filter should penetrate below the resistance clay layer. The water and salt balance of the skimming well area should be monitored. Measurements, preferably on a continuous basis should be performed on the three minor irrigation canals upon branching off from the supply canal and also on the location where they leave the skimming well area. The operation hours and capacity of the pumps pumping the drainage water into the minor canals should be monitored. Also the salinity of the drainage water should be regularly measured.

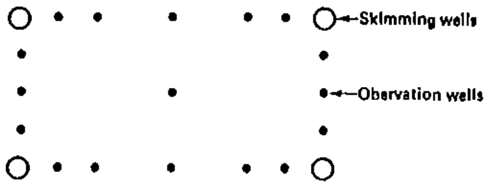

Fig. 13. Proposed layout of observation wells in between 4 selected skimming wells

Three skimming wells in the south-western part of the area are not located along a minor irrigation canal. The drainage water of these 3 wells could be used on the spot for irrigation. The size of individual plots should be small (say 400 m^2) in order to apply an irrigation gift of 60 mm.

The skimming well receiving the drainage water from the conjunctive use experiments should be excluded from the reuse of drainage water programme because it is expected that the salinity of this drainage water will deteriorate in the near future.

4.4. Subsurface drainage experiment

On the HAU experimental farm a drainage experiment is under construction. The total area of experiment is 10.36 ha, but 0.36 ha is excluded because a storage reservoir for water has been build. The area is cropped with vegetables needing a high irrigation frequency for which purpose this reservoir serves. With a nominal depth of 2,1 m the required water for an irrigation of 60 mm for the 10 ha can be stored. Field drains are installed at 2.5 m deep and at distances of 72 m , 48 m and 24 m respectively (see fig. 14). Because field drains have been installed also on the edges of the field the effectively drained area is not 10 but 12 ha. The laterals discharge into the collector drains through manholes that can be used for inspection and at the end of the collector drains sumps with a diameter of 5 m have been constructed. It is the intention to pump the drainage water from these sumps back into the irrigation system for downstream use.

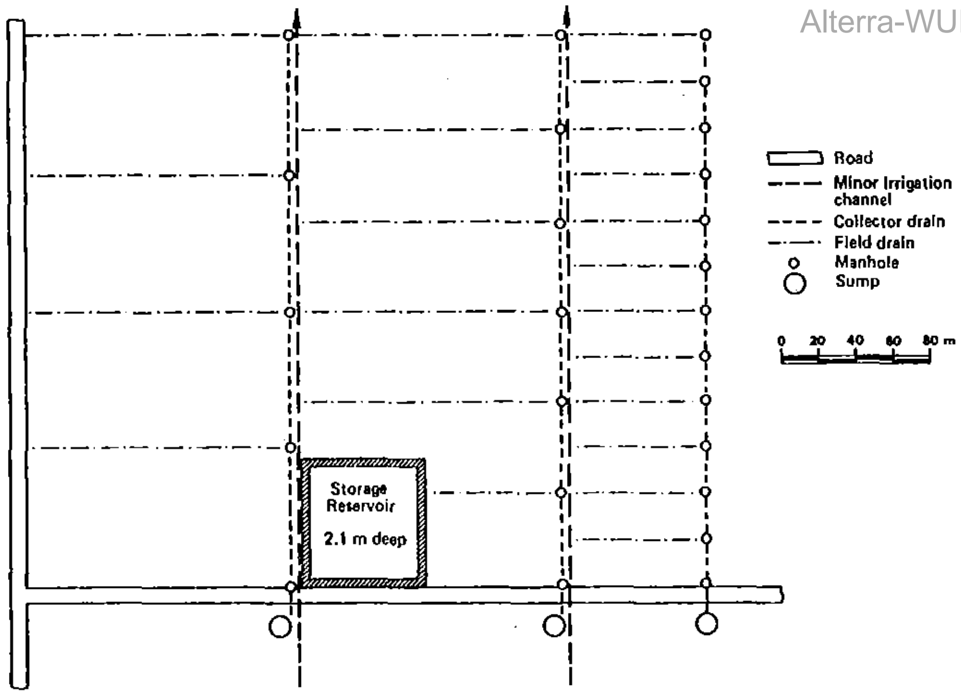

Fig. 14. Layout of the subsurface drainage experiment

In order to estimate the long term drainage rate from the vegetables cropped area calculations have been performed with the unsaturated salinity and evapotranspiration model. It has been assumed that on the average 80% of the area is cultivated with a uniform vegetable crop of average 30 cm high and a rooting depth of 30 cm. The critical leaf water potential is estimated at 4 bar. The irrigation interval has been assumed 7 days except during the winter months (December - February) with low evaporative demand. During these months the interval has been taken at 14 days. Assuming an irrigation gift of 40 mm each irrigation turn the total irrigation requirements have been estimated at 1295 mm. The average monthly rainfall has been assumed to be distributed in two equal showers at the beginning and at the middle of the month. Using the maximum evaporative demands calculated in table 4 the relative cumulative evaporation has been found 0.83 and the total drainage 689 mm. The course of the average drainage rate and the root zone salinity is presented in fig. 15. Assuming for the average 20% of area without crops medium dry soil conditions the evaporation surplus will be 160 mm on year basis and the net drainage rate of 520 mm on year basis can be calculated.

Based on the total irrigation water supply of 1295 mm with a salinity of 0.35 $mmho.cm^{-1}$ and a groundwater salinity of 1 $mmho.cm^{-1}$ a yearly drainage of 443 mm would be expected.

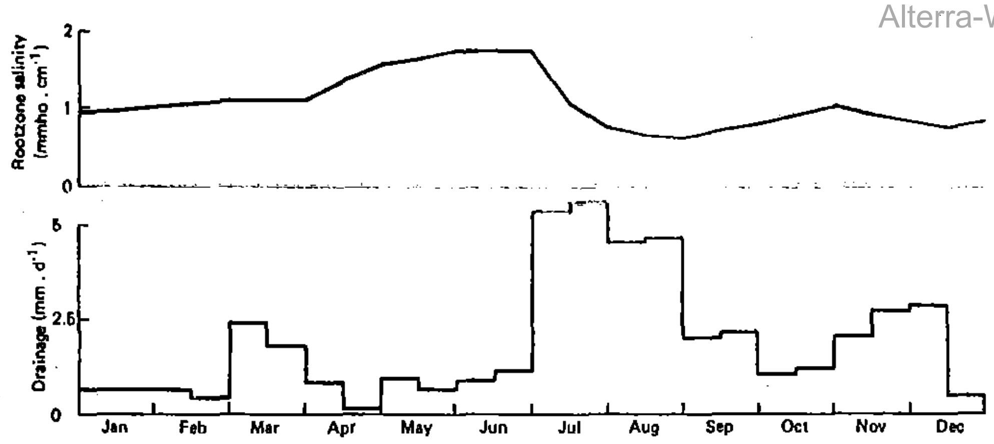

Fig. 15. Calculated drainage and root zone salinity vegetable area

Most probably the amount of irrigation applied has been overestimated and should have been 120 mm less (1175 mm). In this calculation it has been assumed that no losses will occur during irrigation. Most probably the drainage rate will be between 1.4 and 1,1 $mm.d^{-1}$ (520 and 400 mm on year basis). This means that the water supply to the canals running through the vegetable area can be reduced with about 460 mm on year basis (55,000 m^3) to 715 mm, assuming complete reuse of drainage water.

The monitoring programme should concentrate on the salt and water balance of the area and on the performance of the drainage system. The salt and water balance can be measured by recording the irrigation water quantity and salinity flowing into and out of the area. The quantity of water pumped from the sumps has to be monitored as well (capacity and operation hours of the pumps used). The piezometric head in the deep aquifer has to be measured to detect seepage or leakage conditions.

The drain performance can be studied by waterlevel observations midway between drains. On selected locations more shallow piezometers can be installed to measure the shape of the waterlevel between two drains. These drains could then be used to measure the individual drain-discharges in order to establish head-discharge relations. On a number of locations in the field soil sampling should be performed regularly (say twice per year) to detect salinisation/desalinisation trends:

On a limited scale some reuse experiments can be performed in the vicinity of the sumps. The watercontent of a sump being about 20 m^3 this restricts the individual plotsizes to 400 m^2, allowing an irrigation of about 50 mm per irrigation turn. For these plots the water and salt balances should be measured as accurate as possible to provide test data for model calculations.

5. RECOMMENDED FUTURE RESEARCH

The majority of the drainage water becomes available during the rainy season. This means that watertables will rise considerably during this period, and lowering of the watertable by pumping of the skimming wells or the drainage sumps may be immediately required. Reuse of this drainage water, however, will not be possible during this period of precipitation surplus.

During the ensuing dry periods following the rainy season drainage requirements will be low or absent due to the limited availability of irrigation water. Reuse of drainage water will be possible, but the availability will restrict it in practice. Obviously the soil has to be used as a subsurface storage reservoir to bridge the time period between the period of excess water and the period of water shortage. The amount of storage available depends on the depth of the drainage system installed and on the soil moisture characterisitcs.

Due to the fact that canal irrigation is applied, salts are added to the system. Eventually these salts also will have to be removed in order to prevent salinisation. The total canal watersupply to Haryana State being 10 billion m^3 yearly with an avarage electrical conductivity of 0.35 $mmho.cm^{-1}$ and considering arbitrarily a maximum permissible salinity of 3.5 $mmho.cm^{-1}$ under equilibrium conditions 1 billion m^3 yearly has to be removed from the soil system. Assuming a yearly net open water evaporation (evaporation minus precipitation) of 1.65 m a total area of 60,000 ha should be devoted to fish ponds and evaporation pans.

In this chapter research items that can contribute to the solution of the above mentioned problems will be suggested. Although part of this proposed research may be performed in the framework of the present cooperation project between HAU and ILRI, some of the work may be beyond the scope of this project due to limited funds and manpower.

5.1. Modelling

Although the preliminary calculation with the simple model presented in this report show promising results, it should be realised that proper testing on good quality input data and experimental results has not yet been done. The experiments under study for the Operational Research Project can be very useful for model validation if they are tuned to the requirements for testing the model. Also experiments performed in the past or reported by other research agencies could be used, however.

In order to become operational for the skimming well area and the subsurface drainage area the model had to be extended with a drainage model. This has not yet been implemented due to the limited computer facilities at HAU (the present model is operational on a HP41CV calculator, using almost its complete capacity). The experimental data to calibrate such a drainage model should be provided for by the results of the skimming well and subsurface drainage performance investigations.

The calculations performed for the field crops indicate that irrigation losses may occur. For practical application of the model an irrigation efficiency model will therefore be required, in order to calculate the inevitable leaching taking place during irrigation. For testing such a submodel additional field research will be required.

5.2. Optimal irrigation and drainage water management

Considering a soil-water-plant system provided with a drainage system at a certain drainage depth, the operation of such a system with respect to irrigation and drainage has to be optimized. Due to the variability in the rainfall distribution within the rainy season but also from year to year it is not sufficient to calculate with the average hydrological years.

In broad lines a good water (and salt) management system should be as follows. At the start of the rainy season the phreatic waterlevel should be as deep as possible in order to allow the storage of as much precipitation as possible. If the phreatic waterlevel, due to excessive rainfall approaches the crop root zone, the drainage system should be operated and the drainage water conveyed to the evaporation pans. At the end of the rainy season the phreatic waterlevel should still be as high as possible, but beyond the crop root zone.
By capillary rise part of the stored precipitation will become

available during the remaining part of the growing period of the summer crops. Depending on the availability of good quality canal water and the drainage depth part of the soil water can be reused for the winter crops. Before the next rainy season the waterlevel should be reduced to drainlevel and the drainage water conveyed to the evaporation pan in order to allow the storage of excess precipitation.

The above metioned watermanagement strategy allows a maximum utilization of the available waterresources and offers a possibility to maintain a suitable salt balance in the soil. To quantify such a watermanagement strategy in terms of 'operation rules' and desired drainage depth in relation to cropping pattern and permissible soil salinity levels and variation requires a complete analysis of the system. The model described in chapter 3 extended with the modules described before offers such a possibility. Several alternatives with respect to drainage depth and operation rules can be evaluated using a number of hydrological years with respect to drainage rates, soil salinity and crop water use.

After selection of the most suitable strategy the input for the fish culture and evaporation ponds will also be known in terms of salinity and distribution of drainage throughout the year and from year to year. By constructing fish ponds as a cascade system, each pond discharging into the next pond, several levels of salinity can be maintained depending on the individual requirements of each species. The last pond in such a cascade will contain brines and could be designed in such a way that it falls dry from time to time to harvest the accumulated salts.

Once the irrigation and drainage water management has been simulated the drainage experimental fields (both by skimming wells as well as by subsurface drainage) can be used to verify the operational rules established by model calculations. In this respect it can be expected that the subsurface drainage system will be easier to manage than the skimming wells because a greater catchment (up to 80 ha) can be drained by one drainage outlet by constructing a composite system of collector drains, subcollector drains and lateral drains.

Since the HAU experimental farm starts to suffer at present from waterlogging with salinisation to follow in due time, the whole farm could form a pilot scheme on water management by providing a subsurface drainage system and well-designed fish ponds and evaporation lake and operating it at the established 'operating rules'. This solution obviously serves a dual purpose: for the State it serves as a pilot scheme; for the university it is a mere necessity to maintain a favourable salt balance as a boundary condition for all other agricultural activities on the farm.

5.3. Extrapolation of results

The irrigation and drainage water management that is most suitable depends on the evaporative demand of the crops, the amount and distribution of rainfall and on the soil and hydrological circumstances.
By collecting these data throughout Haryana State the solutions found at Hissar can be extended to other parts of the State. Such an approach could very well provide clues to change the water distribution between the different parts of Haryana State, or to adapt the croppping pattern, thereby increasing the total agricultural production.

6. PROSPECTS OF ATTACHMENT TRAINING

The checking of the model presented in this report and the extension of this model with a drainage module provide suitable material for attachment training at the Institute for Land and Water Mangement Research (ICW) in Wageningen. A period of 2 months for 2 HAU researchers familiar with the FORTRAN programming language should be sufficient for the above mentioned objectives.

Additional to model development attention could be paid to the use and operation of other hydrological and water quality models that are operational at ICW. In this respect models such as "SWATRE", "WATBAL" "COMPLEX", and the models developed in the framework of the 'Reuse of Drainage Water Project in Egypt' can be mentioned.

Two prerequisites should be mentioned with respect to this training period:
- a suitable personal computer with sufficient capacity and capability should become available at HAU, Hissar, in order to use the models developed
- for model validation sufficient input and testing data should be collected and brought along to the Netherlands.

7. LITERATURE

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RAO, K.V.G.K., O.P. SINGH, R.K. GUPTA, S.K. KAMRA, R.S. PANDEY, P.S. KUMBHARE and I.P. ABROL, 1986. Drainage investigations for salinity control in Haryana. CSSRI, Karnal.

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RIJTEMA, P.E. and A. ABOUKHALED, 1975. Crop water use. In: Research on crop water use, salt affected soils and drainage in the Arabic Republic of Egypt. ABOUKHALED ET AL., FAO, Rome.

8. ITENARY

date	activity
1-3	Departure to India
2-3	Arrival at Delhi; discussions with ir. J.G. van Alphen.
3-3-morning	Meeting dr. M.C. Agarwal in Delhi and travel to Hissar. Visit of the Agricultural Extension Service in Rohtak.
-afternoon	Meeting several scientists at soil department of HAU. Tour of the University Campus.
4-3-morning	Meeting dr. R.P.S. Tyagi, Director of Research. Field visit to HAU experimental farm with dr. M.C. Agarwal, eng. R. Kumar, and eng. J. Singh.
-afternoon	Discussion with eng. J. Sing and eng. R. Kumar on skimming well and horizontal drainage experiments. Discussion with dr. M.C. Agarwal on terms of reference and work programme.
5-3	Office work.
6-3-morning	Office work.
-afternoon	Field visit to nearby village with eng. R. Kumar and eng. J. Singh. Discussion with farmers on crop yields in relation to irrigation.
7-3	Departure to the Central Soil Salinity Research Institute (CSSRI) with dr. S.S. Khanna, eng. J. Singh and eng. R. Kumar. Meeting with dr. I.P. Abrol, Director. Discussions and field visits with several CSSRI scientists. Visit to the HAU Research station in Karnal.
8-3	Departure from Karnal to the Mundlana and Sampla drainage pilot areas of CSSRI with dr. K.V.G.K. Roa, dr. S.S. Khanna, eng. R. Kumar and eng. J. Singh. Explanation at Mundlana and Sampla pilot areas by dr. K.V.G.K. Roa on results, problems and future planned research.
9-3	Official holiday.
10-3-morning	Discussions with dr. S.P. Garg on the reduced water application experiments.
-afternoon	Discussions with dr. Sihag and dr. Kumar on the conjunctive use of canal and saline water experiments.
11-3	Office work.

12-3		Office work.
	-evening	Dinner at the residence of eng. J. Singh.
13-3		Office work. Discussions with dr. Raj Pal on the available computer facilities.
14-3	-morning	Office work.
	-afternoon	Field visit to the HAU meteorological station with eng. J. Singh and eng. R.Kumar. Visit to the annual farmers exhibition at the HAU university.
15-3		Office work. Discussions with eng. R. Kumar on the unsaturated salinity and evapotranspiration model.
16-3		Official holiday.
	-afternoon	Lunch at the residence of dr. M.C. Agarwal.
	-evening	Dinner at the residence of eng. R. Kumar.
17-3	-morning	Discussion with dr. S.P. Garg and dr. P. Singh.
	-afternoon	Office work and lecture on "Modelling aspects of the Reuse of Drainage Water Project in Egypt".
	-evening	Dinner at the Engineers Club on invitation of dr. L.D. Kataria, Vice Chancelor of HAU.
18-3	-morning	Office work.
	-afternoon	Discussions with eng. G.S. Tandon, HAU Chief Engineer, on problems and achievements with drainage implementation at the HAU experimental farm. Discussions with dr. L.D. Kataria, HAU Vice Chancelor on the water management and salinity problems in Haryana State and the consequences for water management research at HAU.
19-3		Departure to the Netherlands.

ANNEX 1

TERMS OF REFERENCE WATER MANAGEMENT CONSULTANT

The consultant will, in collaboration with the staff of HAU - Hissar.

- Appraise the research programmes on (i) reduced water application and (ii) the conjunctive use of good quality canal water and poor quality drainage water.
- Assist in developing techniques for measuring and monitoring the various in- and output factors of the water and salt balance.
- Assist in adapting the aforementioned research programmes if, for implementation reasons, found necessary.
- Assist in the write-up of a programme on monitoring farm irrigation practices and constraints on a limited number of farms in the region.
- Assist in the evaluation of long-term changes in the physico-chemical properties and crop performance using poor quality irrigation water and contribute into the formulation of predicitive models on these physico-chemical phenomena.
- Assist in the formulation of experiments on the reuse of drainage water.
- Finalize, as required, the list of equipment to be purchased in The Netherlands and India.
- Explore the possibility for further attachment training in The Netherlands.
- Prepare a mission report.

The consultant will stay at HAU - Hissar for a period of 3 - 4 weeks, preferably in the period of February - April 1986.

ANNEX 2

HP41CV PROGRAMME LISTING

```
01♦LBL "SALT"
02 0
03 STO 42
04 STO 43
05 "NULAYERS?"
06 PROMPT
07 STO 07
08 "THETAL?"
09 PROMPT
10 STO 08
11 "  L  ?"
12 PROMPT
13 STO 15
14 "WLEVEL ?"
15 PROMPT
16 STO 17
17 "MOIAVAI?"
18 PROMPT
19 STO 27
20 "DRAINPOR?"
21 PROMPT
22 STO 28
23 "CRIT D ?"
24 PROMPT
25 STO 29
26 "CSTOR ?"
27 PROMPT
28 STO 25
29 "VSTOR ?"
30 PROMPT
31 STO 26
32♦LBL 03
33 0
34 STO 09
35 "IRRIG ?"
36 PROMPT
37 1 E3
38 /
39 STO 13
40 "CIRR ?"
41 PROMPT
42 STO 05
43 "DROOT ?"
44 PROMPT
45 STO 16
46 RCL 15
47 /
48 ,5
49 +
50 INT
51 X=0?
52 1
53 STO 18
54 XEQ "NU"
55 STO 22
56 50
57 +
58 STO 23
59♦LBL 31
60 RCL IND 23
61 ST+ 09
62 1
63 ST- 23
64 DSE 22
65 GTO 31
66 XEQ "DELT"
67♦LBL 04
68 XEQ "MDH"
69 STO IND 23
70 1
71 ST- 23
72 DSE 22
73 GTO 04
74 1
75 STO 22
76 51
77 STO 23
78 71
79 STO 24
80♦LBL 07
81 RCL 13
82 X=0?
83 GTO 11
84 RCL IND 23
85 -
86 0
87 X<=Y?
88 GTO 08
89 RCL 13
90 RCL 08
91 /
92 STO 06
93 RCL IND 23
94 RCL 13
95 -
96 STO IND 23
97 0
98 STO 13
99 GTO 09
100♦LBL 08
101 RCL IND 23
102 X=0?
103 GTO 11
104 RCL 08
105 /
106 STO 06
107 RCL IND 23
108 ST- 13
109 0
110 STO IND 23
111♦LBL 09
112 RCL 06
113 RCL 05
114 *
```

```
115 STO 21
116 1
117 RCL 22
118 X=Y?
119 GTO 10
120 1
121 -
122 STO 01
123 XEQ "LEACH"
124 RCL 10
125 RCL 11
126 -
127 ST+ 21
128♦LBL 10
129 RCL 21
130 ST+ IND 24
131♦LBL 11
132 0
133 STO 39
134 1
135 ST+ 22
136 ST+ 23
137 ST+ 24
138 RCL 07
139 RCL 22
140 X<=Y?
141 GTO 07
142 RCL 13
143 X=0?
144 GTO 12
145 RCL 08
146 /
147 STO 06
148 RCL 07
149 STO 01
150 XEQ "LEACH"
151 RCL 13
152 RCL 05
153 *
154 RCL 10
155 RCL 11
156 -
157 RCL 08
158 *
159 +
160 RCL 25
161 RCL 26
162 *
163 +
164 RCL 26
165 RCL 13
166 +
167 /
168 STO 25
169 RCL 13
170 ST+ 26
171 RCL 28
172 /
173 ST- 17
174♦LBL 12
175 RCL 18
176 STO 22
177 70
178 +
179 STO 24
180♦LBL 20
181 RCL IND 24
182 ST+ 39
183 1
184 ST- 24
185 DSE 22
186 GTO 20
187 RCL 39
188 RCL 18
189 /
190 STO 39
191 0
192 STO 09
193 RCL 19
194 STO 22
195 50
196 +
197 STO 23
198♦LBL 13
199 RCL IND 23
200 ST+ 09
201 1
202 ST- 23
203 DSE 22
204 GTO 13
205 XEQ "EVAP"
206 XEQ "REDIS"
207 "  INTERVAL"
208 PRA
209 RCL 44
210 PRX
211 "WATERDEPTH"
212 PRA
213 RCL 17
214 PRX
215 "      EMAX"
216 PRA
217 RCL 31
218 1 E3
219 *
220 PRX
221 "     EREAL"
222 PRA
223 RCL 33
224 RCL 44
225 /
226 1 E3
227 *
228 PRX
```

```
229 "      HOEF"
230 PRA
231 RCL 45
232 1 E3
233 *
234 PRX
235 "   SOIL EC"
236 PRA
237 1
238 STO 22
239 71
240 STO 24
241*LBL 24
242 RCL IND 24
243 PRX
244 1
245 ST+ 22
246 ST+ 24
247 RCL 07
248 RCL 22
249 X<=Y?
250 GTO 24
251 "RELATIVE E"
252 PRA
253 RCL 42
254 RCL 43
255 /
256 PRX
257 GTO 03
258 END
```

```
01*LBL 'NU'
02 RCL 16
03 RCL 29
04 +
05 RCL 17
06 X>Y?
07 X<>Y
08 RCL 15
09 /
10 ,5
11 +
12 INT
13 STO 19
14 END
```

```
01*LBL "DELT"
02 RCL 19
03 RCL 18
04 +
05 RCL 15
06 *
07 RCL 09
08 2
09 *
10 X<>Y
11 /
12 STO 20
13 RCL 19
14 STO 22
15 50
16 +
17 STO 23
18 10
19 +
20 STO 46
21 END
```

```
01♦LBL "MDN
02 RCL 18
03 RCL 22
04 X>Y?
05 GTO 05
06 RCL 15
07 RCL 20
08 *
09 GTO 06
10♦LBL 05
11 RCL 19
12 X<>Y
13 -
14 ,5
15 +
16 RCL 19
17 RCL 18
18 -
19 X=0?
20 GTO 28
21 /
22 RCL 20
23 *
24 RCL 15
25 *
26 GTO 06
27♦LBL 28
28 0
29♦LBL 06
30 END
```

```
01♦LBL "LEACH"
02 0
03 STO 10
04 STO 11
05 RCL 01
06 STO 02
07♦LBL 01
08 0
09 STO 12
10 RCL 02
11 STO 03
12 70
13 +
14 STO 04
15 RCL IND 04
16 ST+ 10
17♦LBL 02
18 RCL IND 04
19 RCL 05
20 -
21 RCL 06
22 RCL 02
23 RCL 03
24 -
25 Y↑X
26 *
27 RCL 02
28 RCL 03
29 -
30 FACT
31 /
32 ST+ 12
33 1
34 ST- 04
35 DSE 03
36 GTO 02
37 RCL 12
38 RCL 06
39 CHS
40 E↑X
41 *
42 RCL 05
43 +
44 ST+ 11
45 RCL 02
46 70
47 +
48 STO 04
49 RDN
50 STO IND 04
51 DSE 02
52 GTO 01
53 END
```

```
LBL "EVAP"
RCL 39
STOP
"AFACT ?"
PROMPT
STO 30
"EMAX ?"
PROMPT
1 E3
/
STO 31
"TINT ?"
PROMPT
STO 32
STO 44
0
STO 33
STO 38
RCL 16
RCL 27
*
RCL 29
RCL 27
*
2
/
+
STO 34
STO 35
RCL 30
*
STO 30
RCL 19
STO 22
50
+
STO 23
LBL 14
RCL IND 23
ST- 35
1
ST- 23
DSE 22
GTO 14
RCL 35
0
X>Y?
GTO 19
RCL 17
RCL 16
-
RCL 29
-
RCL 28
*
CHS
X>Y?
ST+ 35
RCL 35
RCL 30
X>Y?
GTO 16
-
RCL 31
/
STO 36
RCL 32
X<=Y?
GTO 15
RCL 35
RCL 30
-
ST+ 33
RCL 30
STO 35
RCL 36
ST- 32
GTO 16
LBL 15
RCL 31
*
ST+ 33
ST- 35
GTO 17
LBL 16
RCL 31
RCL 30
/
RCL 32
*
CHS
E↑X
CHS
1
+
RCL 35
*
ST+ 33
ST- 35
LBL 17
RCL 34
RCL 35
-
STO 09
0
X>Y?
GTO 29
RCL 16
RCL 29
+
RCL 17
-
RCL 28
*
```

```
115 X>Y?
116 ST+ 09
117 RCL 09
118 2
119 *
120 RCL 16
121 RCL 29
122 +
123 /
124 RCL 27
125 /
126 RCL 29
127 *
128 RCL 16
129 +
130 STO 37
131 RCL 17
132 RCL 16
133 RCL 29
134 +
135 X<=Y?
136 GTO 19
137 X<>Y
138 RCL 37
139 X<=Y?
140 GTO 19
141 RCL 16
142 RCL 29
143 +
144 X<=Y?
145 STO 37
146 RCL 37
147 RCL 17
148 -
149 RCL 28
150 *
151 STO 38
152 ST- 26
153 ST- 09
154 RCL 37
155 STO 17
156 GTO 19
157♦LBL 29
158 RCL 16
159 RCL 29
160 +
161 RCL 09
162 RCL 28
163 /
164 +
165 STO 37
166 0
167 STO 09
168 RCL 37
169 RCL 17
170 -
171 RCL 28
172 *
173 STO 38
174 RCL 37
175 STO 17
176 RCL 38
177 ST- 26
178♦LBL 19
179 RCL 33
180 ST+ 42
181 RCL 31
182 RCL 44
183 *
184 ST+ 43
185 RCL 19
186 1
187 +
188 STO 22
189 50
190 +
191 STO 23
192 RCL 09
193 STO 45
194♦LBL 22
195 RCL IND 23
196 ST+ 45
197 1
198 ST+ 22
199 ST+ 23
200 RCL 07
201 RCL 22
202 X<=Y?
203 GTO 22
204 END
```

```
♦LBL "REDIS"
XEQ "NO"
XEQ "DELT"
♦LBL 21
XEQ "MDN"
RCL IND 23
X<>Y
STO IND 23
X<>Y
-
STO IND 46
1
ST- 23
ST- 46
DSE 22
GTO 21
RCL 19
STO 22
70
+
STO 24
10
-
STO 46
RCL 38
STO 13
RCL 25
STO 05
♦LBL 24
RCL 13
RCL 08
/
STO 06
CHS
E↑X
RCL IND 24
RCL 05
-
STO 40
*
RCL 05
+
STO IND 24
RCL 06
CHS
E↑X
CHS
1
+
RCL 40
*
RCL 06
X=0?
GTO 25
/
ST+ 05
GTO 26
♦LBL 25
RCL IND 24
STO 05
♦LBL 26
RCL IND 46
ST+ 13
RCL 08
/
RCL 05
*
ST- IND 24
1
ST- 22
ST- 46
ST- 24
RCL 18
RCL 22
X>Y?
GTO 24
RCL 13
RCL 08
/
RCL 05
*
ST+ IND 24
END
```