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APPLICATION OF 'SHE' FOR IRRIGATION COMMAND AREA STUDIES

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PREFACE

There have been significant developments in the sectors of agriculture and irrigation in our country since independnece. The gross irrigated area in the country was reported as 22.6 m.ha. in 1950-51 and reliable estimates indicate that by the end of Seventh Plan, an irrigation potential of the order of 77 m.ha. has been created. The Eighth Five Year Plan envisages creating additional potential of about 20 m.ha. With the vast developments in the irrigation sector, some major commands have experienced problems of water logging and drainage. Besides, the problems of uneven distribution of water along the irrigation canals, large amounts of water losses in conveyance of water and absence of proper irrigation and scheduling techniques are contributing to lowering the overall efficiencies of irrigation projects. In order to properly understand and evaluate these aspects, detailed hydrologic modelling using distributed approach is quite relevant and useful.

Under an agreement (ALA 86/19) signed between the Commission of the European Committees (CEC) and the Govt. of India, the 'System Hydrologique European' (SHE) hydrological modelling system was transferred to the National Institute of Hydrology at Roorkee. The project is funded by the EEC and is intended to increase India's capabilities for formulating water and land resources development strategies through numerical modelling. As part of the field application of the SHE Model, it was applied for irrigation command studies. The command of Barna Project in Madhya Pradesh was chosen for such application. Since modelling of the entire command was an unrealistic task in view of time and data required, hypothetical set up of irrigation fields were used in three different scales. The model could be successfully used for modelling processes involved in irrigation including moisture advancement part, vertical movement of moisture in the soil column and effects of changed vegetation parameters on irrigation requirements.

The study has been carried out by Mr. V K Lohani, Scientist 'C' of the Institute. A team of Consultants including Mr. Thomas Clausen, Mr. Marek Erlich, Mr. G H Jorgensen, and Mr. Borge Storm were involved in the study from Consultants side. Dr S M Seth, Sc.'F' as the Project Coordinator from NIH side and Mr. J C Refsgaard as Project Manager from Consultants side provided useful suggestions and interaction for the study.

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Abstract

Irrigation development has been accepted as a major factor in increasing agricultural production in our country. The irrigation potential is estimated to have increased to a value of about 77.0 M.ha upto the end of VII five year plan while in 1950-51, the gross irrigated area in the country was of the order of 22.6 M.ha. As per reliable estimates, the VIII five year plan envisages creating additonal irrigation potential of 10 M.ha. from surface water and another 10 M.ha. from ground water. With the vast developments in the irrigation sector, some problems have also cropped up in irrigation commands. Among these problems of water logging and soil salinity are the major ones. Estimates made on the basis of the report of the working group of the then Ministry of Irrigation (now Ministry of Water Resources) indicate that in 41 major and medium commands, an area of 0.743 M.ha. area has been affected by water logging and 0.718 M.ha. by soil salinity and alkalinity.

As per the activity schedule of the EEC funded project ALA/86/19 on hydrological computerised modelling system, SHE model was transferred to the National Institute of Hydrology, Roorkee. As a part of its field application, the model was applied for irrigation studies. The Command of Barna project in Madhya Pradesh was chosen for irrigation application study. Since modelling of entire command was an unrealistic task in view of time and data required, hypothetical set up of irrigation field in three different scales were used for simulation studies.

The results indicate that the model has capability to successfully model the processes involved with irrigation including moisture advancement front, vertical movement of moisture in the soil column and effects of changed vegetation parameters on irrigation requirements. The studies can be extended with more efforts to make estimates of irrigation return flow. The schedules of irrigation based on soil moisture status in the root zone will be most economic but may not be very practical. The extensive data requirement and need of sophisticated computing system are major limitations of SHE model applications. However, with the availability of resources pilot studies using SHE can be undertaken to find solutions of major problems of irrigation commands like water logging and drainage.

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1.0 INTRODUCTION

Irrigation development has been accepted as a major factor in increasing agricultural production in India. The irrigation potential has been increased by more than three times since 1950s and agricultural productivity has also substantially increased. However, there remains a big gap between the irrigation potential created and utilised. Estimates indicate that during seventh plan period (1985-90) 79% of the targetted potential to be created (about 24.6 mha) will be utilised. The chief cause for the mismatch between creation of potential and its utilisation stems from a partial implementation of the management with special reference to micro level irrigation and drainage networks, in the commands of irrigation outlets. Problems of water logging and drainage are being experienced in a number of irrigation commands. Reliable sources indicate that in 41 major and medium canal commands, an area of 7.43 lakh ha. has been affected by water logging and 7.18 lakh ha. by soil salinity and alkalinity, (Working Group Report 84).

As per the activity schedule of project ALA/86/19 on hydrological computerised modelling system, SHE model is to be applied for modelling of irrigation schemes. The goal of such an application is to demonstrate the SHE capability to represent an irrigation scheme and consequently to simulate the typical problems encountered within the command areas. Since SHE is a physically based distributed model, it requires realistic information about the various subsystems representing land phase of hydrological cycle. Since consideration of a real irrigation command was almost impossible within the available time (in view of enormous efforts and large amount of data needed), as a first step in this direction, hypothetical set up of irrigation areas have been studied. This note describes the application of the SHE model to hypodthetical irrigation schemes or their component parts. Data used in the model set up are based on measurements made in the Barna Command Area in the Narmada Valley in M.P. in January 1990.

2.0 IRRIGATION - SOME KEY ISSUES

Some important issues concerning irrigation projects include time/cost overruns, under utilisation of irrigation potential, water logging and soil salinity hazards, water use efficiency and socio-environmental concerns. Reliable sources indicate that about 246 major surface irrigation projects taken up for construction since the first five year plan, only 25% have been completed by sixth plan period and remaining have spilled to subsequent plans for completion. Due to these delays, such major irrigation projects which are highly capital intensive become unusually expensive even to the extent that their viability gets jeopardised. There is a gap between creation of irrigation potential and its utilisation. At the end of 6th Plan period utilisation figures were estimated as 77% of the created potential and in the seventh plan target utilization has been estimated as 79% of the created potential. In the commands of surface irrigation projects, problems of water logging and soil salinity have been steadily increasing. Reliable sources indicate that in 41 major and medium canal commands, an area of 0.743 m.ha. has been affected by water logging and 0.718 m. ha. by soil salinity and alkalinity. This aspect which has been much studied and discussed needs to be tackled with extreme urgency and all out efforts are needed to imporve the situation. Irrigation water use efficiency can be increased by careful planning of conjunctive use of ground and surface water resources Lining of canals, distributories and water cources is increasingly being recommended for controlling losses in transmission systems of irrigation projects, thereby improving irrigation efficiency. However, lining of a part on the entire system should be carefully examined from considerations of costs and benefits, particularly in existing systems where conjunctive use has already got well established. The field application efficiency needs closer examination and can be substantially improved if proper calculations of amount of irrigation water required are done taking soil moisture status and crop water needs into account. Socio-environmental concerns of irrigation water projects **are** important **issues** of consideration. The aspects of groundwater pollution as a result of leaching of fertilisers in irrigated areas are also issues of concern in times to come. Peoples participation in the development and management of water is being accorded due priority due to its prime role. Farmers can be involved, through cooperative societies, in irrigation water management for better utilisation of water resources allocated for irrigation. Besides, training of professionals in various aspects of irrigation water management is another key issue which needs consideration at the present juncture.

3.0 IRRIGATION SCHEDULING TECHNIQUES

Irrigation scheduling is a decision making process of irrigating a field depending upon the water needs of the crop. The scheduling of irrigation requires knowledge of soils, crops, climate, water supplies, irrigation system facilities, system layout, soil and economic factors and other constraints of the system. The rising rate of problems of Water Logging & Drainage in the irrigation commands can be easily controlled by properly scheduling the irrigation which will result not only in better crop yields but also saving of water, energy and labour. Generally, there is a feeling that the more amount of water one applies to the crop, more crop yield will be expected. This opinion is not at all correct and with the advancement of technology, proper determination of time and amount of irrigation are essential for making judicious use of irrigation water. Several techniques have been developed for scheduling irrigation based on a number of criteria like plant water status, soil water status, stress index etc. The technique using soil water status is perhaps most convenient and can be implemented rather easily as compared to other criteria.

The F.A.O. paper on crop water requirements (No.24) gives a technique of scheduling irrigation based on soil water balance. In this method, the entire soil moisture regime of root zone is calculated based on stored soil moisture in the rooting zone + ground water contribution in the root zone - evapotranspiration and deep percolation loss. The water availability in the root zone for crop growth increases with the growth of crops as the root zone depths increase. The available moisture in the root zone for crop yields is considered as the difference between the field capacity and wilting point. It has generally been observed that in order to get better crop response, the soil moisture level should remain above permanent wilting point. At this stage, the crops are not able to extract water for their growth. However, they do survive. Therefore, a particular fraction of water between field capacity and PWP needs to be utilised by the crops before watering is done to recoup moisture upto field capacity. Therefore, in this process of scheduling irrigations, a particular fraction of soil moisture (p) available (field capacity to PWP) is decided and once the moisture level comes upto the threshold value, the watering is done.

The time of irrigation also depends on the growing stage of crops. Generally the crops undergo 3-4 growth stages namely initial stage, vegetative stage, fruiting and flowering stage and harvesting stage. Out of all these stages, the fruiting and flowering stage is considered to be most sensitive to moisture stress in the root zone. Using this criterion, the fraction of available water (p) which is used for scheduling irrigation can also be taken as a variable depending upon crop growth stages for irrigation scheduling. Therefore, there can be following two approaches which can be used for irrigation scheduling:

i) taking a constant fraction, let us say 50% of depletion level for irrigation scheduling

ii) taking variable fraction during growth stages as per following description:

Initial stage 60%; vegetative stage 50%; fruiting and flowering stage 40%; harvesting stage 70%.

The scheduling of irrigation should also take into account the availability of water for applying irrigation. The above proposed scheduling procedure can be therefore modified in view of the actual soil moisture depletion at the time of water release to the field. Since there are chances that the actual time when crops need irrigation and the time when the water is available for irrigation may have some time-lag of two to three days depending on the irrigation distribution system, provision may be made to incorporate this aspect of the irrigation system.

4.0 SHE MODEL APPLICATION FOR IRRIGATION STUDIES

4.1 General

The introduction of SHE applications for the purpose of modelling of irrigation schemes is planned in SHE application studies. The objective of such an application is to demonstrate the SHE capability to represent an irrigation scheme and consequently to simulate the typical problems encountered within command areas.

4.2 Methodology

The SHE model has capability to model soil moisture movement in the unsaturated zone. The model only considers the vertical flow in the unsaturated zone and the flow is expressed by Darcy's law as below:

$$q = k(Q) \text{ gradient } (h) \qquad \ldots \text{ (i)}$$

where:

k (Q) is the unsaturated hydraulic conductivity (m/sec); and gradient (h) is the change of head in the flow direction.

The equation (i) yields in conjuction with a continuity equation the governing equation for the vertical flow in the unsaturated zone, usually called the Richards equation. The SHE model incorporates solution of Richards equation by finite difference technique and the solution provides a value of the pressure head and moisture content at each nodal point, and the flow between the nodal points including the flow exchange between the soil and atmosphere and the reacharge to the ground water table. The capability of SHE to model the variation in soil moisture status has been used for application of model in irrigation studies. The status of soil moisture in the root zone has been used as a criterion for finding data and amount of irrigation for different crops. In the algorithm a check is done if the calculated effective soil moisture content is kept at a sufficiently high level required for normal crop growth

or;

$$\text{theta - eff.} > \text{THMIN}$$

where; theta_eff is the effective water content in the root zone (with included distribution of roots)

THMIN is the user defined threshold minimum of the effective soil moisture content for actual crop type.

The above test is used as a mechanism to initiate irrigation when the effective water content in the root zone gets below THMIN value. The amount of water required for irrigation is then calculated as:

$$\text{QIR} = (\text{THMAX} - \text{theta-act}) * \text{root depth} \quad \text{......(ii)}$$

where;

THMAX is the upper limit of moisture content to which irrigation should be applied and is generally taken as field capacity of the soil.

theta-act is the actual moisture content in the root zone.

Two approaches of scheduling irrigations were tried in the irrigation module developed for SHE application. In the first approach, which was called as 'automatic', the irrigation was scheduled based on soil moisture status in the root zone. In the second approach known as 'Pre-specified', the dates and amount of irrigations were specified in advance. The schedules were compared by changing the parameter values in various runs. The 'SHE model irrigation module' requires two additional data files besides the usual data files of frame component, unsaturated zone, saturated zone, evaporation, vegetation and rainfall. These files include description of policy of irrigation and field set up.

4.3 Concept of Different Scales

The irrigation application studies have been carried out in different scales starting from a plot (of few square metres) and extending it to row of plots and number of such rows. The soil moisture conditions have been simulated as a function of time varying rainfall, irrigation and evaporation. The description of various scales is given in following sections:

4.3.1 One dimensional plot model (Scale I)

In this case, modelling is carried out for one single, vertical soil column. The soil and crop parameter values as have been obtained from field investigation visits have been used. A schematic representation of plot model is as shown in Figure 1. The crop and soil parameters can be changed to see the effects on simulation results. Since there is no overland flow consideration in plot model, uniformity of irrigation can not be judged in this scale. However, the effects of change in crop/soil parameters on components of water balance can be studied at this scale of modelling.

Two policies of scheduling irrigations namely, prespecified and automatic are used to study the effects of change in crop/ soil parameter values on simulation results.

4.3.2 Two Dimensional Vertical Field Model (Scale II)

In this scale, the modelling excercise is performed on a row of adjacent unsaturated zone columns representing a vertical cross-section of a field with a typical length scale of 100-200 m (Fig. 2). The irrigation water is delivered at the head end of the field and it runs over the field in the direction of slope. The collector drain at the tail end collects the waste water and catches the return flow. In this case overland flow computations are also done besides the ones performed in scale one. Therefore, the propagation of irrigation water front on the surface and in the soil can be simulated in this scale of modelling. The distribution of water over a length of field when irrigated from one end can be studied in this scale of modelling. The effects on overland flow by changing distances of top two nodes in unsaturated zone computations can be studied in this scale of modelling. The effects of deepening the collector drain at the tail end of the field can also be modelled in this scale of modelling.

4.3.3 Small Irrigation System (Scale III)

The extension of scale II simulation studies to cover a number of fields along an irrigation canal is modelled in scale III simulation exercise. The schematic representation of Scale III set up is shown in Figure 3. As can be seen

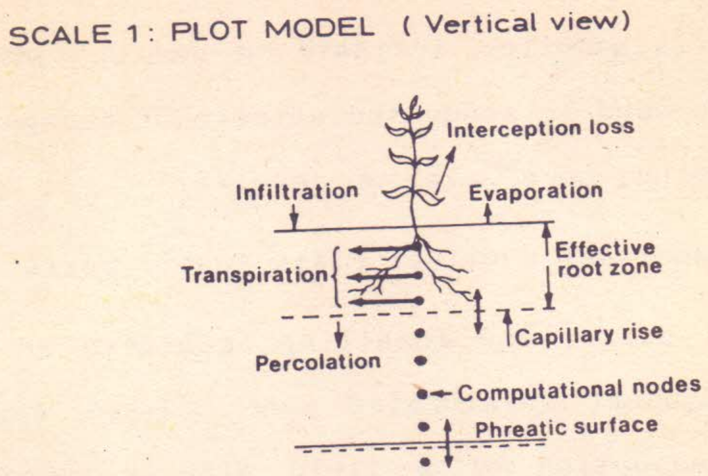


Fig.1. Schematic Representation of Plot Model (Scale I)

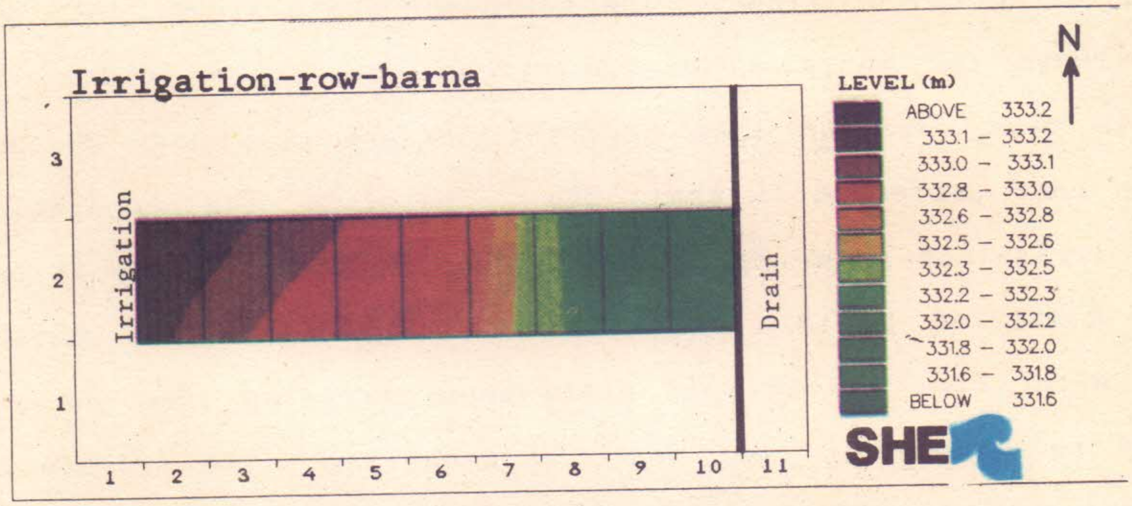


Fig.2. Two dimensional vertical field model (Scale II)

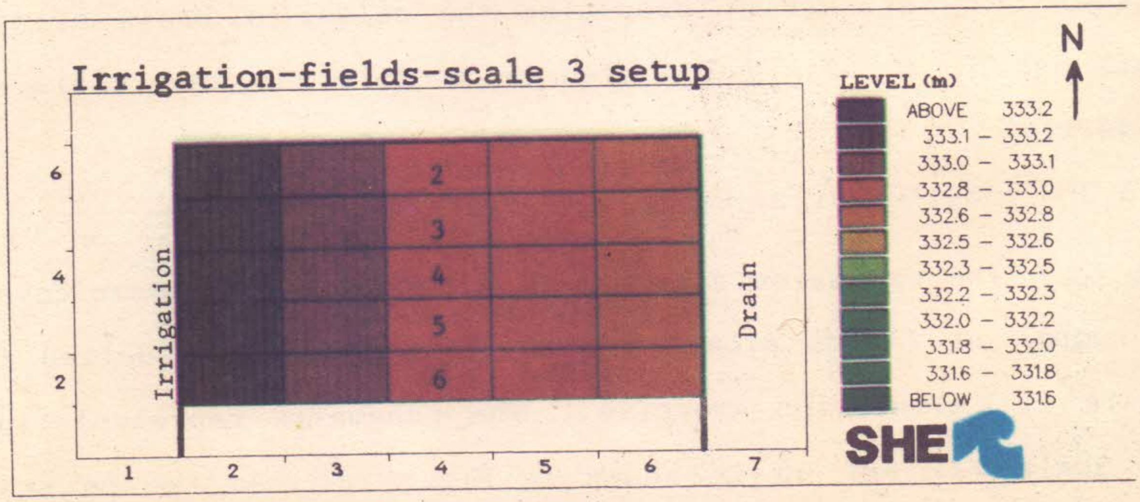


Fig. 3 : Schematic Representation of Scale III Setup

from Figure 3, the irrigation canal runs from north to south and the fields are laid east to west. The scale III modelling exercise can yield effects of changed cropping pattern on irrigation applications. Also scheduling of irrigations and assignment of priority to a particular irrigation field can be modelled in this scale of modelling. Also, the moisture distribution pattern of the field located at the tail end of canal can be visualised in scale III modelling. The conditions of short supply of water in the canal for adjusting water delivery to the fields can also be simulated in Scale III simulation exercise.

5.0 CASE STUDY OF BARNA COMMAND

In order to demonstrate the ability of the SHE model, the simulation exercise has been performed for a hypothetical irrigation system. The data of Barna project has been used for the study and the field investigations have been carried out in the command area of Barna project in Madhya Pradesh. The selection of the command for SHE model applications for irrigation studies has been done because in earlier studies the catchment modelling for Barna has been done using the SHE model. Therefore, the data required for application of SHE in the command were available. Moreover, at Bari, a research station of Jabalpur Agriculture university is carrying out detailed investigations on soils, crops etc. in Barna command and the data which are required for SHE application were readily available with this research station. Also, the irrigation system in the Barna command is in active stage of operation.

5.1 Barna Command Area

The Barna Command Area incorporates 198 villages (156 in Raisen and 42 in Sehore districts) of Madhya Pradesh on both banks of Barna river upto Narmada river extending upto Ikyawan river on left and Dohi river on right bank with a population of 0.1 million. The Barna project has a gross command area of 720 km^2 with a cultural command area of 479 km^2. The command area is bounded by Vindhyan ranges in the north and Narmada river in the south. About 50% of the command area has a slope range of 0-1%. The town of Bari lies in the Barna Command area which is accessible by national highway

No.12 and is situated at 96 kms. away from Bhopal. The climate of the command area is dry, sub-tropical with three well defined seasons. The average annual precipitation reported at Barna is 1165 mm of which 90% occurs in the rainy season. The mean daily temperature varies between 40^{0} C in May to 10^{0} C in January. The command area is rich in agricultural resources and is predominantly rabi growing with 50% of the area being under local varieties of wheat. The crop of paddy is virtually non-existent in the command. The main Kharif crops are Soyabean, Jowar & Arhar and the prominent rabi crops are wheat, gram and lentil. A brief description of crops grown before and after the project operation in given in Table 1. It has been observed that after introduction of irrigation, soyabean cultivation has been added to a considerable extent under Kharif season.

Table 1: Description of major cropped Area of various crops under Barna Command before and after project operation. (Area in Sq. Kms.)

Sl.No.	Season	Name of crops	1974-75 (before the project)	1987-88 (after the project)	1988-89
1.	Kharif	Soyabean	1.5	120.0	135.0
		Jowar	30.0	25.0	27.0
		Arhar	-	50.0	55.0
2.	Rabi	Wheat	115.0	235.0	250.0
		Gram	126.0	150.0	140.0
		Lentil	30.0	20.0	20.0
		Linseed	16.0	8.0	9.0
		Pea	5.0	10.0	10.0

Source: The S.D.O. Agriculture Office,Bari

The revenue records of year 1984 indicate that the per capita income of Barna was Rs. 834. The records of year

1980 show that about 33.6% of agricultural holding size ranges from 0.02-0.05 sq.km. There are only about 0.4% holding size ranging about 0.3 sq.km. in the command. The agriculture department of Madhya Pradesh Govt. carried out reconnaissance soil survey of the command area during 1974 and 1975. The survey indicated that the soils in the command area are deep to very deep and belong to black cotton group with major percentage of clay. The studies done by J.N. Agriculture University in the command indicate that the soil starta consists of top black soil underlaid by hard yellow clay soil followed by murram, kankar, sand, gravel and finally bedrock. The depth of top black soil in three typical profiles ranged from 2-4 metres while the total depth of soil column above the impermeable bed ranged from 19-29 m.

The heavy black soil of the command need an efficient drainage system. The groundwater level is reported to be about 4-10 m from the ground surface in the command area. Since introduction of irrigation, the water table has been rising in the command area and in some areas the water table is within 1 m of ground level. During a measurement in 3rd week of January 1990, the water table was found at a depth of 32 cm. in a plot located in the command of left bank canal. Besides losses from irrigation water, the seepage losses from unlined distribution system also contribute to the drainage problem. The studies on measurement of seepage losses have indicated the seepage rate as 1.2 cumec/million sq.m. of wetted area which is 1.5 times higher than the designed value of

0.81. This under-estimation of seepage loss has also led to increasing incidences of water logging and drainage. The University of Sagar in M.P. has carried out studies on conjunctive use of waters in Barna command area in year 1978 and has found that the whole area is occupied by basaltic rocks and vindyan formations and alluvium deposited by the river Barna and other tributories of Barna. According to the studies very large ground water reserves of the order of 950 Mm^3 are accumulated in different aquifers in the Raisen part of the command area.

Application of irrigation water in a most suitable manner is an important factor for obtaining better crop yields Irrigation within the field is done by the following methods.

(I) Fields are divided up into smaller pieces by narrow high bunds and the area is flooded

(II) Fields are divided up into smaller squares by banks only 4 or 5" high constructed after sowing and the area is flooded.

(III) On land which has never been levelled, a network of small channels like veins are made and the intervening areas are flooded. In case of larger fields a small channel is made right in the middle of the field and the water is applied through this channel to the farther areas which do not get water easily from head end of the field.

5.2 Data Requirement, Availability And Investigations

The application of SHE model for simulation of irrigation system requires a variety of data. The following specific data from an irrigation command area are required for the studies:

- Time series of rainfall
- Time series of potential evaporation
- Soil data
- Vegetation data
- Topography
- Geometry of canal systems
- Groundwater abstraction records
- Irrigation practices and water requirements

The hourly rainfall data as recorded at Bari station were used for simulation exercise. The simulation was done for a period of two years i.e. 1st May, 1987 to April 1989. The daily evaporation data as recorded at the Powerkheda station which is near to the command area were used for the simulation exercise.

As per plans laid out for SHE application to irrigation studies, a plot/field was to be selected in the command area of Bama project. Accordingly, visits were made in the month of January 90 to command areas of left bank and right bank main canals and finally a plot was selected in the command of Dhansari minor in the Bari village. This minor takes off from left bank main canal. The selected field had wheat crop in the rabi season and soyabean in Kharif season. At the head end of the field watering is done and at the tail end natural drain runs to collect excess water. For various scales of simulation , various sizes of fields were chosen from this selected field. A field survey to get the elevations at the grid (30m x 30m) nodes was done in the field. The soil data concerning the soil moisture constants, hydraulic conductivity, soil moisture retention curves were derived from literature available from Agriculture research station as also field investigations were carried out near the selected plot of land in the command area. A brief description of field investigation for soil data is given in following section:

5.2.1 Infiltration test:

Infiltration tests were carried out using double ring infiltrometer at two sites, one close to the plot selected for study and another about 300m away from the plot. Since the irrigation season was on during the period of experiments, the water table was observed about 32cm from the ground surface. The results of the test are shown in figure 4. As can be seen the basic infiltration rate was observed to be about 0.4 cm/hr.

5.2.2 Soil moisture profile:

The records of soil moisture profile in the root zone are very rare. Therefore, soil moisture observations were made upto 1m depth of soil on the plot on 22nd Jan. 90. The soil moisture was determined by both gravemetric method and infrared moisture meter. The plot of soil moisture profile upto 1m depth in the plot chosen for study is shown in figure 5.

5.2.3 Auger Hole Test:

The auger hole method is a quick and simple field technique with minimal equipment requirments for determining hydraulic conductivity of porous strata below a water table and measuring how quickly the hole refills. The relationship between the observed rate of rise of water in the auger hole

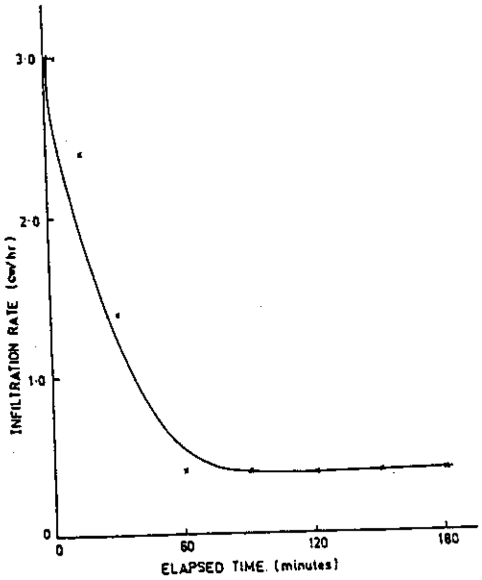


Fig. 4 : Infiltration test carried out in the command of Dhanasari minor in Barna command on Jan. 23, 1990.

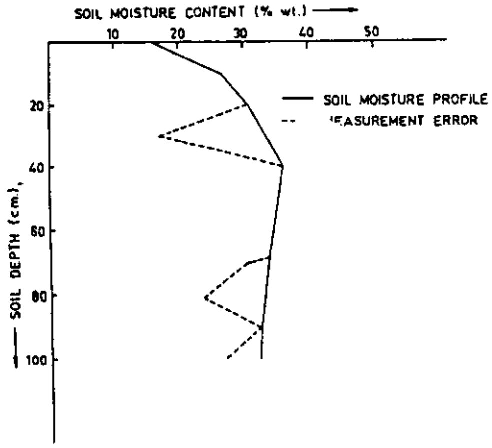


Fig. 5 : Soil moisture profile upto 1 m depth of soil in the command of Dhanasari minor in Barna command as on Jan.22, 1990.

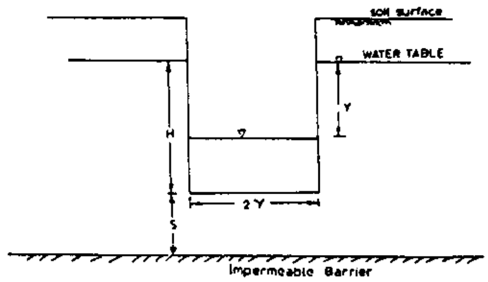


FIG. 6 - REQUIRED DIMENSIONAL PARAMETERS FOR AUGER HOLE TEST

and the hydraulic conductivity is expressed by:

$$K = \frac{C}{864} \, dy/dt$$

Where c is the shape factor C=f(H/r, Y/H, S/H) of the auger hole, dy is the change in water height in the anger hole (cm) that occurs is time dt(sec) and K is the hydraulic conductivity in cm/sec. The constant 864 is a conversion factor. The required dimensional parameters for auger hole test are shown in figure 6.

The auger hole tests were carried out at two locations using anger holes of about 110cm depth. The dimensional parameters for the field tests were as below:

r=5cm
H=110 cm
Initial depth of water table = 32 cm.

During the two observations, a typical measurement indicated dy/dt = 0.4cm/30sec.. Using the table for values of 'c' given by Boast and Kirkham, 1971, for s=o and , the c values range from 7-8. Therefore, the hydraulic conductivity will be:

$$K = \frac{8.0}{864} \times \frac{.4}{30} = 0.106 m/day$$

5.2.4 Soil Moisture Retention Curve:

The moisture retention characteristics of the soil can be expressed in the form of a retention curve showing relationship between soil moisture content and corresponding tension values. In the retention curve two regions are of special interest to agriculturists, the field capacity or residual saturation and the permanent wilting point. In order to derive the retention curve, moisture measurements are made at various levels of tension. The retention curve developed for soil in the Barna command by Agriculture Drainage research centre at Bari has been used for the purpose of studies. The retention curve so obtained is as shown in fig. 6(a).

5.2.5 Vegetation Parameters:

The SHE Model requires values of vegetation parameters like root zone depth, leaf area index etc. for the crops/ trees in the area of interest. After the field visit, it was found that enough information about such parameters is not readily available. Discussions to this effect were held with the scientists of Agriculture Drainage research project, Bari. Based on experience and published literature, the values of leaf area index and root zone were derived. The variation of leaf area index and root zone values for wheat and soyabean crops is shown in figure 7.

During its growth and developmenat a crop undergoes a number of stages including initial stage, vegetative stage flowering and fruiting stage and harvesting stage. Based on the information obtained, the length of growing stages of two crops, namely wheat and soyabean were assumed as follows:

Stage	Wheat	Soyabean
Initial	20 days	7 days
Vegetative	40 days	30 days
Fruiting(flowering)	40 days	40 days
Harvesting	20 days	30 days

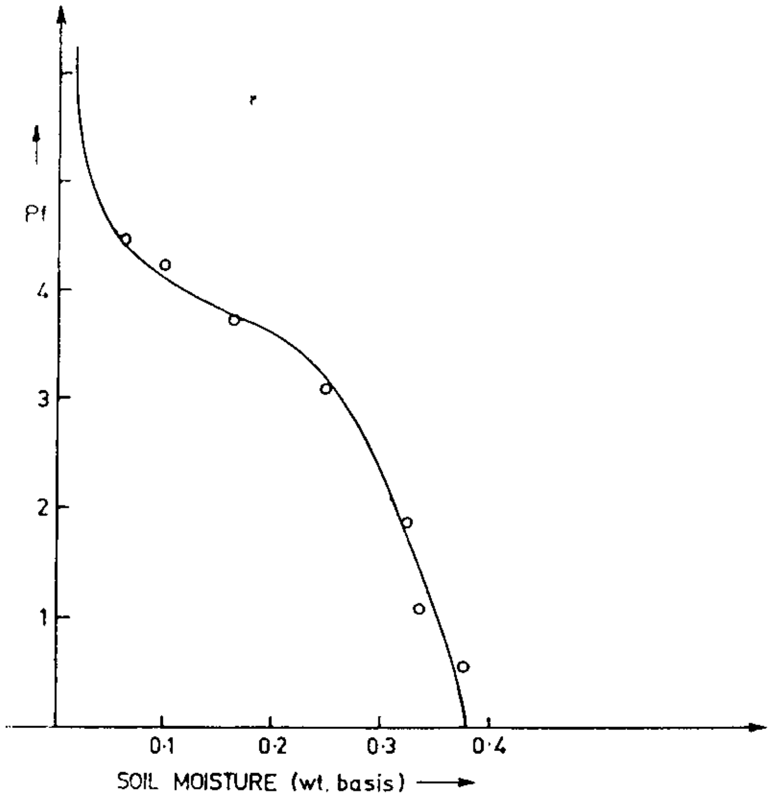


Fig. 6(a) : Soil moisture retention curve (Pers.Comm.Mr.Kool)

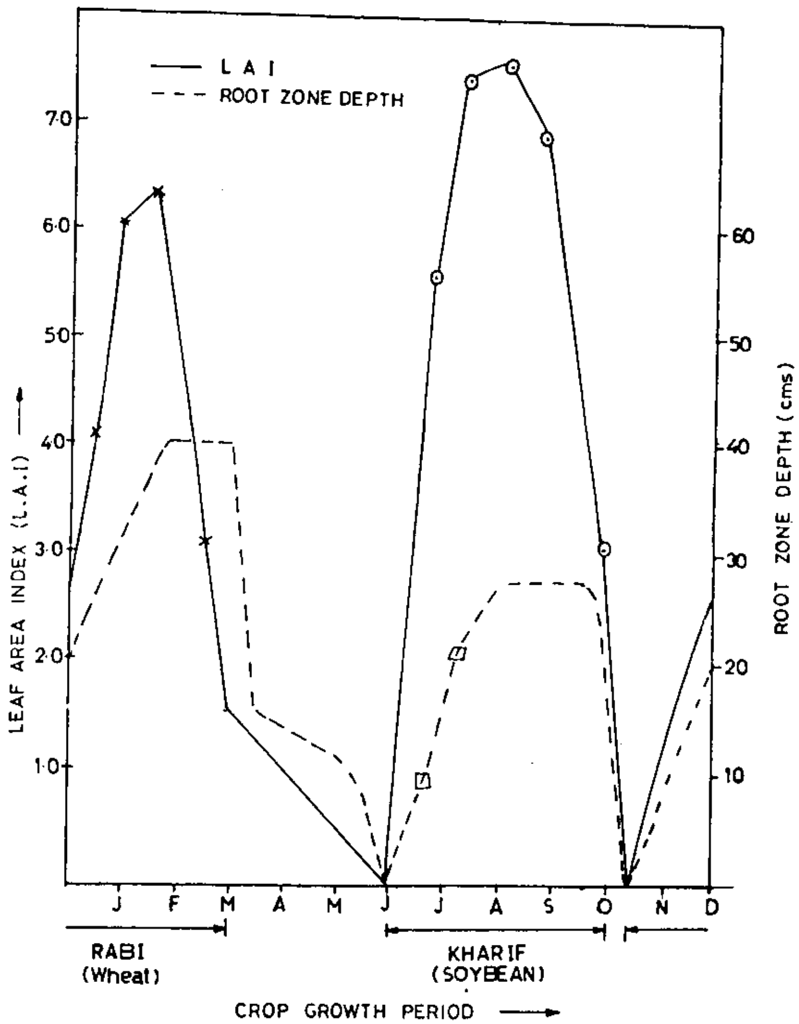


FIG.7 — VEGETATION PARAMETERS-MONTHLY VARIATION

Table 2 gives idea about the date of sowing, duration of crops, water requirements, harvesting date and yield of various crops in the command.

Table 2 : Sowing Date, Duration, Water requirement, Harvesting Date & Yield of Different Crops in Barna Command

Name of crop	Date of sowing	Duration (days)	Water requi-rement (cm)	Harvesting date	Yield (q/ha)
KHARIF					
Soyabean	2nd July	108	25	16 Oct.	15.0
Paddy	28 June	120	57	1 Nov.	30.0
Maize	2nd July	90	15	28 Sept.	25.0
RABI					
Wheat	15 Nov.	125	55	28 March	20.0
Gram	15 Nov.	115	15	26 Feb.	12.0
Linseed	15 Oct.	120	7	26 Feb.- 7 March	8.0
Lentil	15 Oct.	108	15	15 Feb.	10.0

Source: Information supplied by J.N. Krishi Vishva Vidhyalaya Centre, Bari, M.P.

Note: In Tables 3 to 18, the description of symbols is as below:

yymmdd = year month date
thuz = unsaturated zone moisture content
h-ovl = overland storage
q-riv = river flow
csto = canopy storage
ac.p = accumulated ppt
szb = saturated zone flow
ac.ep = accumulated evaporation
qirr = irrigation
h-riv = river storage

All the values are in mm.

5.3 SHE Model Application

As has been discussed in previous section, SHE model was used for irrigation studies in three different scales. The model set up, data files, description of simulation & sensitivity runs and analysis of results for different scales of simulation are given in following sections :

5.3.1 Single Column (Plot Model) or Scale I Simulation

The basic concept of different scales of modelling has been described in previous section. A single column (30 x 30 m) was set up to apply SHE model (Fig.1.). Two types of policies of irrigation were used for simulation exercise. In case of 'Pre-specified' policy the date and amount of irrigations were provided as an input to simulation exercise and in case of 'automatic' policy the irrigation scheduling was done based on soil moisture status. The parameter values used for the simulation exercise are given as below :

Soil conductivity (unsaturated) = 0.096m/day

Soil conductivity (saturated) = 0.0

Impermeable bed depth = 6.0 m

Averjanov constant =14.0

The simulation results have been discussed in following sections :

A. Pre-specified Scheduling Policy

(a) Reference Run

A run of plot model for the period 1st May '87 - April '89 was taken with the parameter values as given above. The results have been analysed in terms of carrying out monthly water balance during the perid of simulation. The various components of water balance for the run were computed. The water balance figures indicate poorest moisture status in soil during the months of April and May (Table 3). The moisture condition

TABLE 3 : WATER BALANCE COMPONENTS (MONTHLY BASIS), SCALE I, PRE-SPECIFIED (REFERENCE RUN).

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-147	0	0	0
87 6 1	4	102	0	0	0	0	0	-244	0	0	0
87 7 1	7	39	0	0	0	0	0	-276	0	0	0
87 8 1	134	96	0	0	0	0	3	-243	0	0	0
87 9 1	541	101	2	0	0	0	253	-52	0	0	0
8710 1	139	89	0	0	0	0	95	-93	0	0	0
8711 1	69	121	0	0	0	0	9	-153	0	0	0
8712 1	3	86	0	0	0	0	39	-201	70	0	0
88 1 1	23	51	0	0	0.	0	36	-207	60	0	0
88 2 1	0	73	0	0	0	0	30	-246	60	0	0
88 3 1	0	77	0	0	0	0	23	-284	60	0	0
88 4 1	0	64	0	0	0	0	0	-348	0	0	0
88 5 1	6	23	0	0	0	0	0	-365	0	0	0
88 6 1	3	16	0	0	0	0	0	-381	0	0	0
88 7 1	132	50	0	0	0	0	10	-307	0	0	0
88 8 1	266	97	2	0	0	0	31	-173	0	0	0
88 9 1	254	101	0	0	0	0	47	-60	0	0	0
8810 1	80	89	0	0	0	0	11	-81	0	0	0
8811 1	18	120	0	0	0	0	0	-181	0	0	0
8812 1	5	83	0	0	0	0	33	-222	70	0	0
89 1 1	0	49	0	0	0	0	31	-240	60	0	0
89 2 1	0	73	0	0	0	0	27	-276	60	0	0
89 3 1	0	71	0	0	0	0	21	-308	60	0	0
89 4 1	13	73	0	0	0	0	0	-369	0	0	0
89 5 1	0	18	0	0	0	0	0	-386	0	0	0

TABLE 4 : WATER BALANCE COMPONENTS (MONTHLY BASIS), SCALE I, PRE-SPECIFIED, CHANGE OF AVERJANOV CONSTANT FROM 14 TO 10.

yymmdd	ac.p	ac ·p	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-147	0	0	0
87 6 1	4	174	0	0	0	0	0	-315	0	0	0
87 7 1	7	73	0	0	0	0	0	-382	0	0	0
87 8 1	134	96	0	0	0	0	1	-345	0	0	0
87 9 1	541	101	2	0	0	0	221	-126	0	0	0
8710 1	139	89	0	0	0	0	28	-98	0	0	0
8711 1	69	121	0	0	0	0	5	-156	0	0	0
8712 1	3	86	0	0	0	0	40	-208	70	0	0
88 1 1	23	52	0	0	0	0	33	-208	60	0	0
88 2 1	0	73	0	0	0	0	30	-248	60	0	0
88 3 1	0	81	0	0	0	0	28	-295	60	0	0
88 4 1	0	133	0	0	0	0	0	-430	0	0	0
88 5 1	6	92	0	0	0	0	0	-514	0	0	0
88 6 1	3	68	0	0	0	0	0	-579	0	0	0
88 7 1	132	57	0	0	0	0	2	-506	0	0	0
88 8 1	266	97	2	0	0	0	16	-354	0	0	0
88 9 1	254	101	0	0	0	0	19	-221	0	0	0
8810 1	80	89	0	0	0	0	0	-230	0	0	0
8811 1	18	119	0	0	0	0	0	-330	0	0	0
8812 1	5	86	0	0	0	0	34	-372	70	0	0
89 1 1	0	49	0	0	0	0	27	-388	60	0	0
89 2 1	0	73	0	0	0	0	26	-424	60	0	0
89 3 1	0	77	0	0	0	0	24	-464	60	0	0
89 4 1	13	113	0	0	0	0	0	-563	0	0	0
89 5 1	0	50	0	0	0	0	0	-614	0	0	0

of root zone was best in the months of August in both the years during rainy season. The moisture stress was found increasing during February-March months. The plot showing variation of evaporation, transpiration, leaf area index and root zone values and uz water content is given as in Figure 8.

(b) Change of Averjanov constant from 14 to 10.

A run was taken by changing the value of Averjanov constant from 14 to 10. The remaining parameters were kept as in the reference run. It can be observed from the following relationship that by reducing value of Averjanov constant, the soil conductivity at a given (unsaturated) moisture content will get increased except at saturation :

$$Kr\ (Q) = \left[\frac{(Q - Qr)}{(Qs - Qr)} \right]^{n} \qquad \text{....(iii)}$$

where : n = Averjanov constant

Qs = saturated moisture content

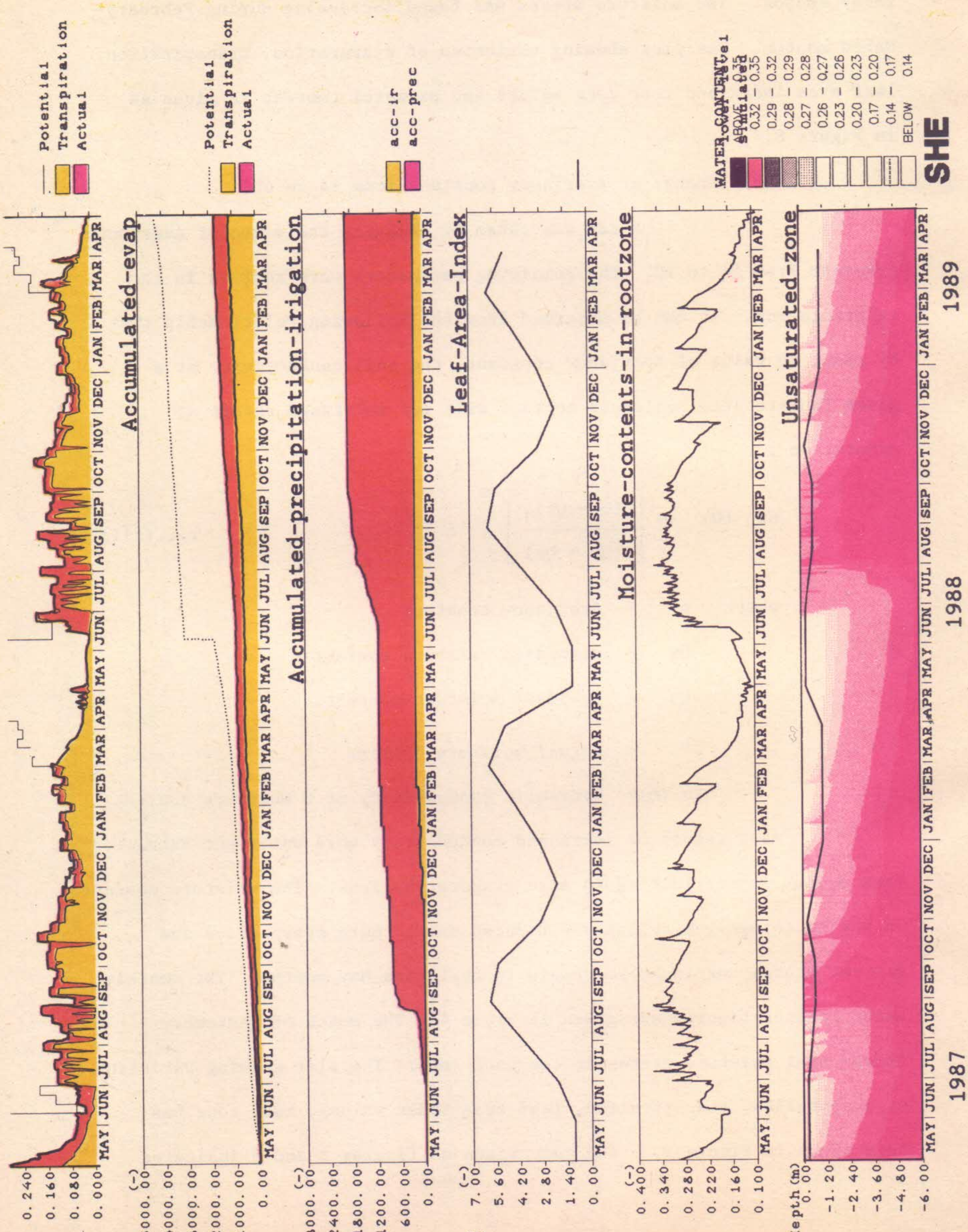
Qr = residual moisture content

Q = actual moisture content

Kr (Q)= hydraulic conductivity at Q moisture content

As a result of increased conductivity more water got extracted from deeper layers leading to more evaporation loss. The moisture content in the uz column got relatively reduced due to more evaporation and poorest status continued to remain in April and May months. The monthly water balance figures are given in Table 4. The month of September showed best moisture status in the root zone. The plot showing variation of evaporation, transpiration, leaf area index values, root zone has been shown in figure 9. The comparison of figures 8 and 9 indicates

FIG. 8 : VARIATION OF WATER BALANCE COMPONENTS DURING SIMULATION PERIOD, SCALE I, PRE-SPECIFIED (REFERENCE RUN)



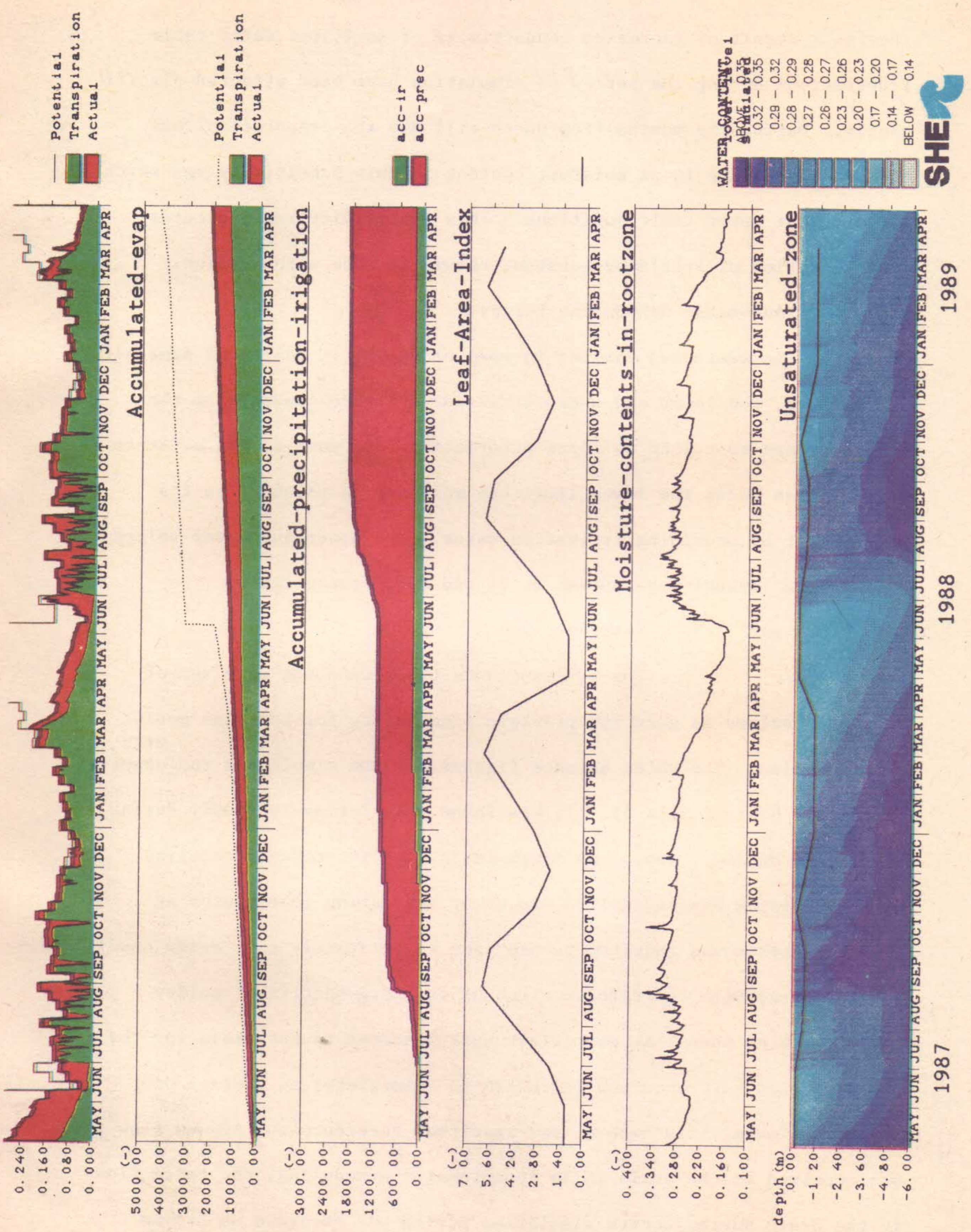


FIG. 9 : VARIATION OF WATER BALANCE COMPONENTS DURING SIMULATION PERIOD, SCALE I, PRE-SPECIFIED (CHANGE OF AVERJANOV CONSTANT FROM 14 TO 10

that as a result of increased conductivity of soil, the water table fluctuations during the period of simulation have been affected significantly. During the months from March till May the evaporation loss has caused decline in uz moisture content in this sensitivity run which affected the water table positions. This sensitivity run indicates that selection of Averjanov constant should be done with caution.

B. Automatic Scheduling Policy

As mentioned earlier in case of automatic policy of scheduling irrigations, the lower and upper limits of moisture contents in the root zone are specified as input information. As soon as the moisture content goes below the lower limit the moisture is recouped to the upper limit by providing irrigation water. The upper and lower values of moisture content were chosen as 31 and 20%, respectively.

(a) Reference Run

The reference run was taken with the same set of parameter values as used for pre-specified policy for the same period of simulation. The water balance figures for the simulation run were observed on monthly basis (Table 5). It was found that during 1988 only during the months of Jan., Feb., and March irrigation inputs were required for maintaining desired moisture content but during four months in 1989 irrigation was required perhaps due to relatively more drier conditions. When compared with the reference run of the 'pre-specified' policy run, it can be seen that more flows were observed in the drain for the pre-specified reference run which can be interpreted as wastage of irrigation water. In case of pre-specified reference run 699 mm flow was received in the drain while in automatic scheduling, the total flow in the drain during entire simulation period was recorded as 545 mm in the reference run. This indicates that the better the irrigation

TABLE 5 : WATER BALANCE COMPONENTS (MONTHLY BASIS), SCALE I, AUTOMATIC (REFERENCE RUN)

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-147	0	0	0
87 6 1	4	121	0	0	0	0	0	-237	26	0	0
87 7 1	7	52	0	0	0	0	0	-271	11	0	0
87 8 1	134	96	0	0	0	0	4	-239	0	0	0
87 9 1	541	101	2	0	0	0	253	-49	0	0	0
8710 1	139	89	0	0	0	0	98	-93	0	0	0
8711 1	69	121	0	0	0	0	9	-152	0	0	0
8712 1	3	85	0	0	0	0	0	-224	11	0	0
88 1 1	23	49	0	0	0	0	0	-250	0	0	0
88 2 1	0	71	0	0	0	0	1	-297	25	0	0
88 3 1	0	77	0	0	0	0	7	-316	64	0	0
88 4 1	0	133	0	0	0	0	24	-324	148	0	0
88 5 1	6	114	0	0	0	0	6	-343	95	0	0
88 6 1	3	109	0	0	0	0	1	-369	83	0	0
88 7 1	132	78	0	0	0	0	10	-299	23	0	0
88 8 1	266	97	2	0	0	0	31	-165	0	0	0
88 9 1	254	101	0	0	0	0	52	-58	0	0	0
8810 1	80	89	0	0	0	0	11	-81	0	0	0
8811 1	18	120	0	0	0	0	0	-181	0	0	0
8812 1	5	83	0	0	0	0	0	-234	26	0	0
89 1 1	0	47	0	0	0	0	0	-280	0	0	0
89 2 1	0	71	0	0	0	0	2	-306	47	0	0
89 3 1	0	75	0	0	0	0	8	-325	67	0	0
89 4 1	13	135	0	0	0	0	18	-351	112	0	0
89 5 1	0	116	0	0	0	0	10	-352	127	0	0

TABLE 6 : WATER BALANCE COMPONENTS (MONTHLY BASIS), SCALE I, AUTOMATIC (CHANGE IN CROP TYPE FROM WHEAT TO GRAM).

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-147	0	0	0
87 6 1	4	121	0	0	0	0	0	-237	26	0	0
87 7 1	7	52	0	0	0	0	0	-271	11	0	0
87 8 1	134	90	0	0	0	0	4	-235	0	0	0
87 9 1	541	101	0	0	0	0	256	-43	0	0	0
8710 1	139	89	0	0	0	0	102	-93	0	0	0
8711 1	69	121	0	0	0	0	9	-154	0	0	0
8712 1	3	60	0	0	0	0	0	-211	0	0	0
88 1 1	23	44	0	0	0	0	0	-231	0	0	0
88 2 1	0	68	0	0	0	0	4	-271	33	0	0
88 3 1	0	78	0	0	0	0	7	-316	38	0	0
88 4 1	0	114	0	0	0	0	8	-333	107	0	0
88 5 1	6	112	0	0	0	0	8	-341	104	0	0
88 6 1	3	110	0	0	0	0	1	-356	96	0	0
88 7 1	132	75	0	0	0	0	10	-294	12	0	0
88 8 1	266	94	0	0	0	0	34	-157	0	0	0
88 9 1	254	101	0	0	0	0	59	-60	0	0	0
8810 1	80	89	0	0	0	0	12	-82	0	0	0
8811 1	18	120	0	0	0	0	0	-182	0	0	0
8812 1	5	54	0	0	0	0	0	-231	0	0	0
89 1 1	0	39	0	0	0	0	0	-270	0	0	0
89 2 1	0	67	0	0	0	0	2	-313	26	0	0
89 3 1	0	74	0	0	0	0	14	-324	77	0	0
89 4 1	13	117	0	0	0	0	4	-349	80	0	0
89 5 1	0	116	0	0	0	0	10	-352	125	0	0

scheduling criterion the less will be loss of irrigation water. The total water balance components for the run are as shown in figure 10. The comparison of figures 8, and 10 indicates more frequent irrigations in the present simulation run due to more precise calculations of irrigation demand.

(b) Change in crop type from wheat to gram

In order to see the effects of changes in vegetation type, it was attempted to replace wheat crop by gram. For this purpose the leaf area index and root zone depth values were changed according to the gram crop. The maximum values of leaf area index and root zone depth were lower than the wheat crop. The water balance figures were observed and their plot is shown in Figure 11. It was observed that relatively less no. of irrigations are required for gram crop as compared to the reference run. The comparison of figures 10 and 11 also shows higher transpiration loss in case of wheat crop as compared to gram crop which is coherent with the reality. This indicates correct representation of vegetation parameters in the modelling process. The water table conditions did not show major differences as compared with the reference run. The water balance figures for the entire period of simulation are given in Table 6. It can be seen that the drain flow picture did not change as a result of change in crop type. However, the evaporation values got affected during the months of irrigation. The uz column showed better storage of moisture by the end of irrigation season due to less requirements of the crop. This sensitivity run has demonstrated capability of SHE model to consider effects of vegetation changes on irrigation requirements.

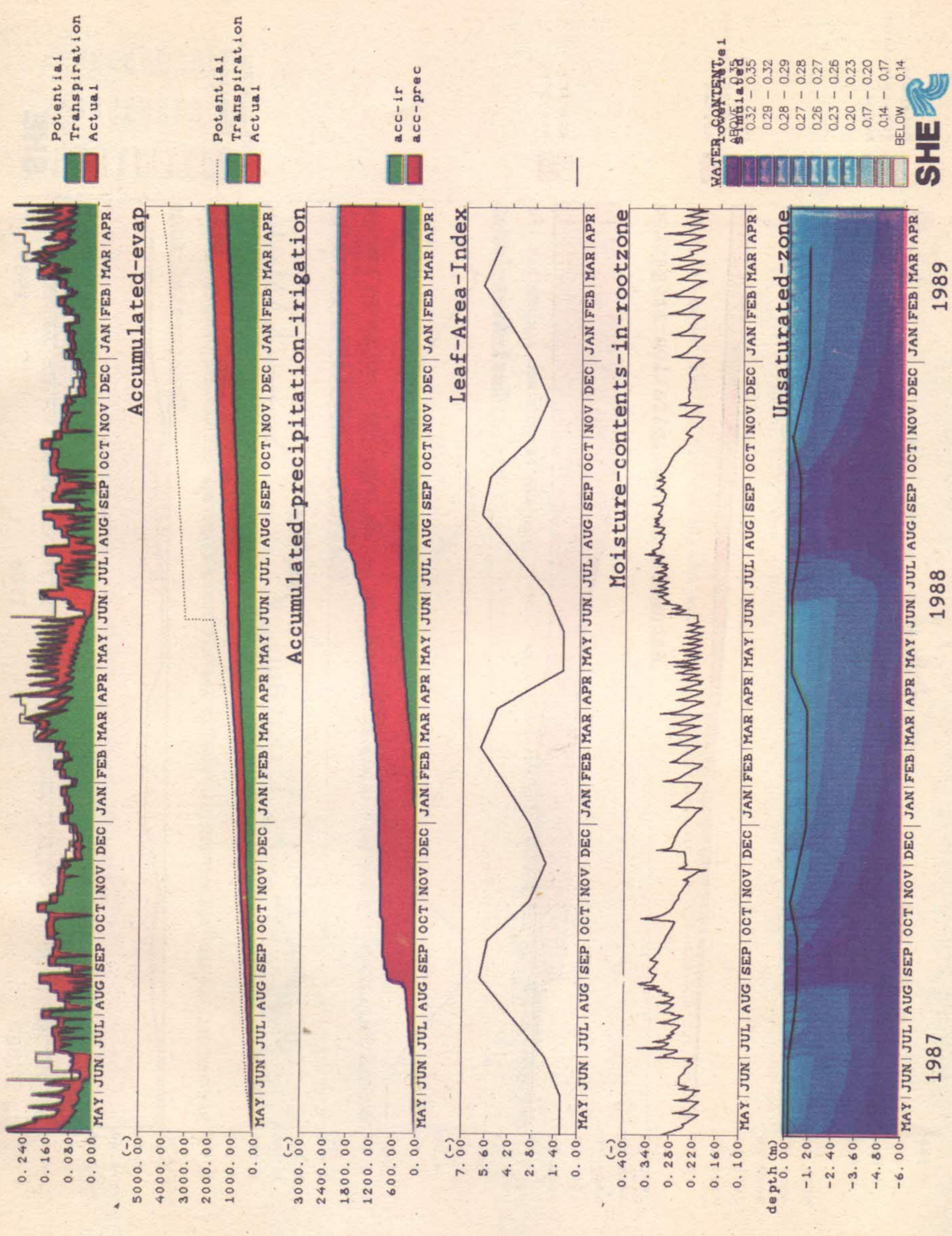


FIG. 10 : VARIATION OF WATER BALANCE COMPONENTS DURING SIMULATION PERIOD, SCALE I, AUTOMATIC (REFERENCE)

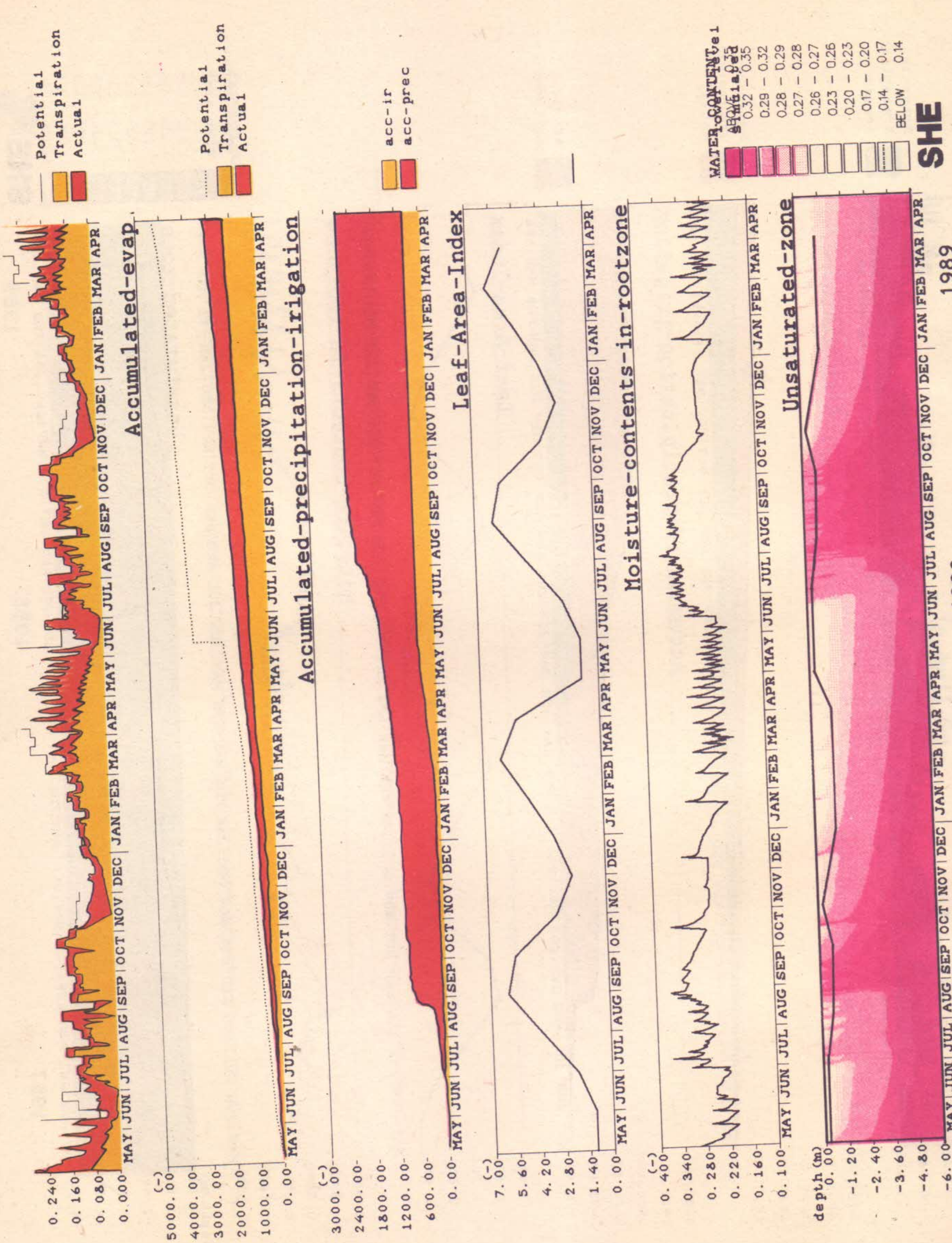


FIG.11 : VARIATION OF WATER BALANCE COMPONENTS DURING SIMULATION PERIOD, SCALE I, AUTOMATIC (CHANGE IN CROP TYPE FROM WHEAT TO GRAM)

5.3.2 Field Model (Scale II) Simulation

The modelling exercise in case of Scale II simulations is carried out for a row of columns representing a field (Fig.2). The irrigation is applied at the head end of the field and the overland flow takes place along the field. The collector drain at the tail end collects the waste water from overland flow or catches the return flow from irrigation. As in the case of Scale I, two kinds of irrigation policies are adopted for simulation studies. In case of pre-specified policy, the date and amount of irrigation to be applied during irrigation season is supplied as an input to the simulation. The irrigation water is presumed to be applied to the first grid in the row of columns and depending upon the slope and surface roughness it travels overland and irrigates other fields subsequently. In case of automatic policy the date and amount of irrigation is controlled through soil moisture status and crop water requirements. The parameter values which were used for soil and computational values are as given below :

A. Soil Parameters

Saturated conductivity uz = 0.096 m/d

Saturated conductivity sz = 0.100 m/d

Strickler Coeff.(Overland)= 5.0

Averjanov Constant =14.0

Depth to Imp. bed = 6.0 m

B. Other Computational Values

Initial water table depth = 4.0 m

Pmax = 2.5

Tmax = 2.0

Distance of top two nodes in uz computations = 2 cm

The simulation covers the period from 1st May '87 to 1st May '89. The simulation results are discussed in following section :

A. Pre-specified Scheduling Policy

(a) Reference Run

In case of pre-specified policy the date and amount of irrigation are pre-determined and are given as input. The irrigations are given in the months of November through February. The drain flow can be interpreted as an estimate of the wastage of irrigation water within described field. The change in water balance components throughout the simulation period is given in Table 7. As can be observed during the entire period of simulation a total of 521 mm water was observed as drain flow. A major part of it was observed during rainy period. During non-rainy period 61 mm flow was observed in the drain from Oct.'87 - Feb. '88 and 33 mm was observed from Oct. '88 - Feb.'89. The soil moisture status of three columns representing wettest, central and driest portions of field has been shown in Fig.12. It has been observed that the wettest column shows the irrigation application prominently while the driest column have less prominent irrigations resulting in poor soil moisture status. It is also evident from Fig.12 that the application of irrigation seems to have fluctuated water table prominently in case of the field nearest to the irrigation source which is the wettest column. However, for the last column (driest) the fluctuations are marginal. In order to see the soil moisture movement front, the cross section of the field at three different times (± 48 hours of irrigation time) were plotted and are shown in figure 13. It can be seen that within 48 hours the moisture profile gets changed significantly.

TABLE 7 : WATER BALANCE COMPONENTS (10 DAYS BASIS), SCALE II, PRE-SPECIFIED (REFERENCE).

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-148	0	0	0
87 511	4	56	0	0	0	0	0	-201	0	0	0
87 521	0	27	0	0	0	0	0	-226	0	0	0
87 531	0	17	0	0	0	0	0	-244	0	0	0
87 610	4	15	0	0	0	0	0	-254	0	0	0
87 620	1	10	0	0	0	0	0	-265	0	0	0
87 630	1	14	0	0	0	0	0	-275	0	0	0
87 710	77	27	0	0	0	0	3	-228	0	0	0
87 720	27	32	0	0	0	0	1	-234	0	0	0
87 730	29	30	0	0	0	0	0	-235	0	0	0
87 8 9	32	33	0	0	0	0	0	-235	0	0	0
87 819	21	26	1	0	0	0	0	-240	0	0	0
87 829	407	37	3	0	6	0	231	-96	0	0	0
87 9 8	155	27	2	0	0	0	59	-9	0	0	0
87 918	65	34	1	0	0	0	30	-2	0	0	0
87 928	0	32	0	0	0	0	0	-31	0	0	0
8710 8	0	36	0	0	0	0	0	-67	0	0	0
871018	28	38	2	0	0	0	0	-80	0	0	0
871028	40	43	0	0	0	0	13	-90	0	0	0
8711 7	0	33	0	0	0	0	0	-124	0	0	0
871117	0	29	0	0	0	0	0	-153	0	0	0
871127	3	28	0	0	0	0	18	-124	70	0	0
8712 7	0	21	0	0	0	0	0	-143	0	0	0
871217	23	17	0	0	0	0	14	-91	60	0	0
871227	0	15	0	0	0	0	0	-105	0	0	0
88 1 6	0	23	0	0	0	0	0	-128	0	0	0
88 116	0	22	0	0	0	0	8	-100	60	0	0
88 126	0	26	0	0	0	0	2	-125	0	0	0
88 2 5	0	21	0	0	0	0	0	-145	0	0	0
88 215	0	30	0	0	0	0	0	-175	0	0	0
88 225	0	27	0	0	0	0	6	-148	60	0	0
88 3 6	0	35	0	0	0	0	0	-182	0	0	0
88 316	0	41	0	0	0	0	0	-223	0	0	0
88 326	0	29	0	0	0	0	0	-253	0	0	0
88 4 5	0	17	0	0	0	0	0	-268	0	0	0
88 415	0	15	0	0	0	0	0	-284	0	0	0
88 425	3	14	0	0	0	0	0	-294	0	0	0
88 5 5	5	14	0	0	0	0	0	-303	0	0	0
88 515	0	8	0	0	0	0	0	-312	0	0	0
88 525	0	8	0	0	0	0	0	-319	0	0	0
88 6 4	0	8	0	0	0	0	0	-327	0	0	0
88 614	0	7	0	0	0	0	0	-335	0	0	0
88 624	40	18	0	0	0	0	0	-314	0	0	0
88 7 4	116	38	0	0	0	0	12	-245	0	0	0
88 714	100	31	0	0	0	0	28	-201	0	0	0
88 724	55	32	0	0	0	0	0	-178	0	0	0
88 8 3	141	35	2	0	0	0	18	-90	0	0	0
88 813	103	26	0	0	0	0	29	-35	0	0	0
88 823	19	30	0	0	0	0	0	-46	0	0	0
88 9 2	77	41	0	0	0	0	13	-20	0	0	0
88 912	25	23	0	0	0	0	1	-19	0	0	0
88 922	15	34	0	0	0	0	0	-39	0	0	0
8810 2	39	32	0	0	0	0	2	-32	0	0	0
881012	18	38	0	0	0	0	0	-53	0	0	0
881022	0	38	0	0	0	0	0	-90	0	0	0
8811 1	0	41	0	0	0	0	0	-132	0	0	0
881111	5	31	0	0	0	0	0	-159	0	0	0
881121	0	28	0	0	0	0	12	-129	70	0	0
8812 1	0	27	0	0	0	0	2	-157	0	0	0
881211	0	17	0	0	0	0	0	-171	0	0	0
881221	0	15	0	0	0	0	9	-137	60	0	0
881231	0	17	0	0	0	0	0	-152	0	0	0
89 110	0	24	0	0	0	0	0	-174	0	0	0
89 120	0	23	0	0	0	0	7	-146	60	0	0
89 130	0	25	0	0	0	0	0	-169	0	0	0
89 2 9	0	23	0	0	0	0	0	-192	0	0	0
89 219	0	31	0	0	0	0	3	-166	60	0	0
89 3 1	0	27	0	0	0	0	0	-192	0	0	0
89 311	4	41	0	0	0	0	0	-230	0	0	0
89 321	3	33	0	0	0	0	0	-261	0	0	0
89 331	7	27	0	0	0	0	0	-280	0	0	0
89 410	0	14	0	0	0	0	0	-294	0	0	0
89 420	0	12	0	0	0	0	0	-306	0	0	0
89 430	0	9	0	0	0	0	0	-315	0	0	0

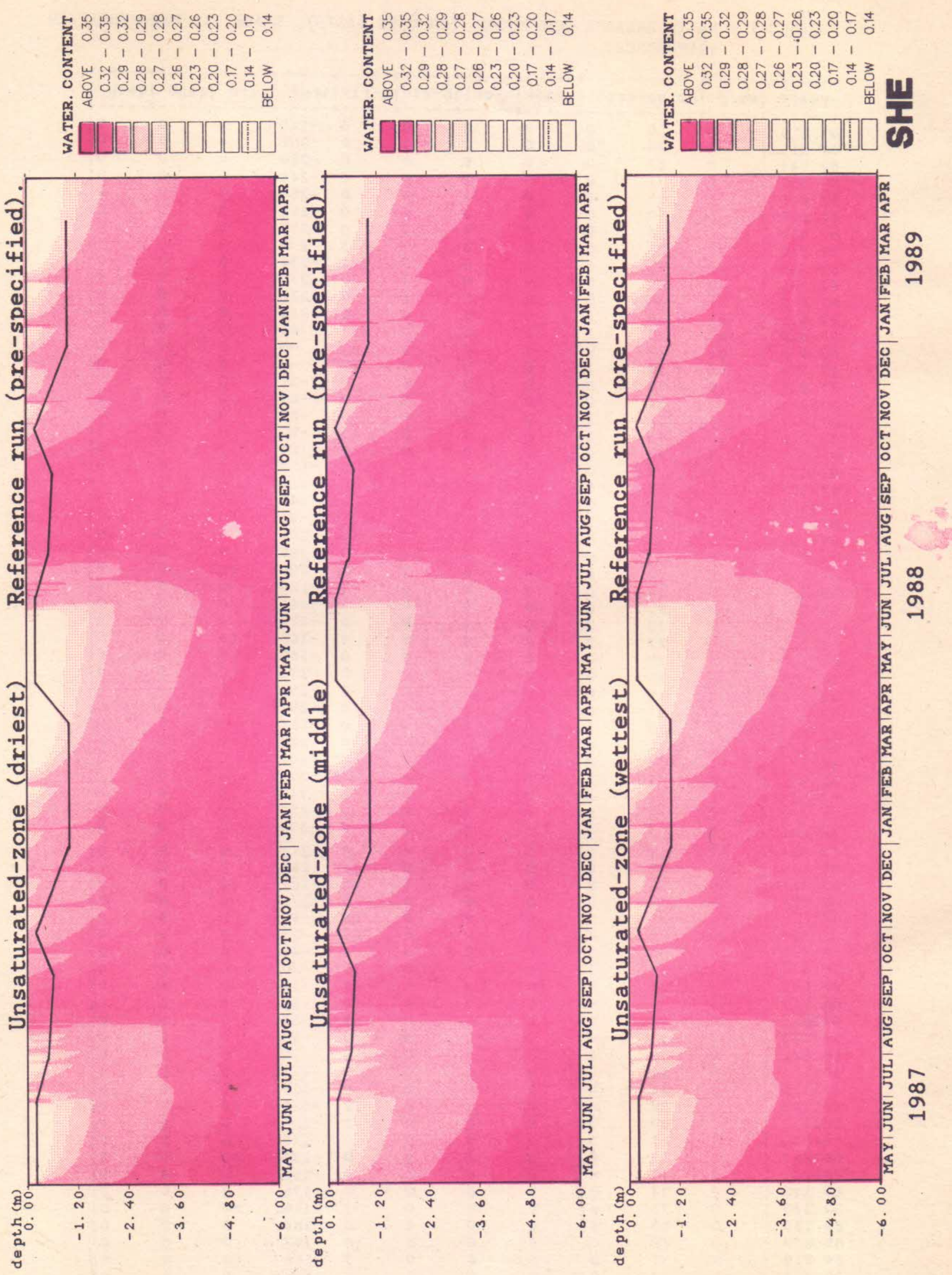


FIG.12 : SOIL MOISTURE STATUS IN THREE COLUMNS IN THE FIELD REPRESENTING WETTEST, MIDDLE AND DRIEST CONDITIONS (SCALE II, PRE-SPECIFIED, REFERENCE RUN)

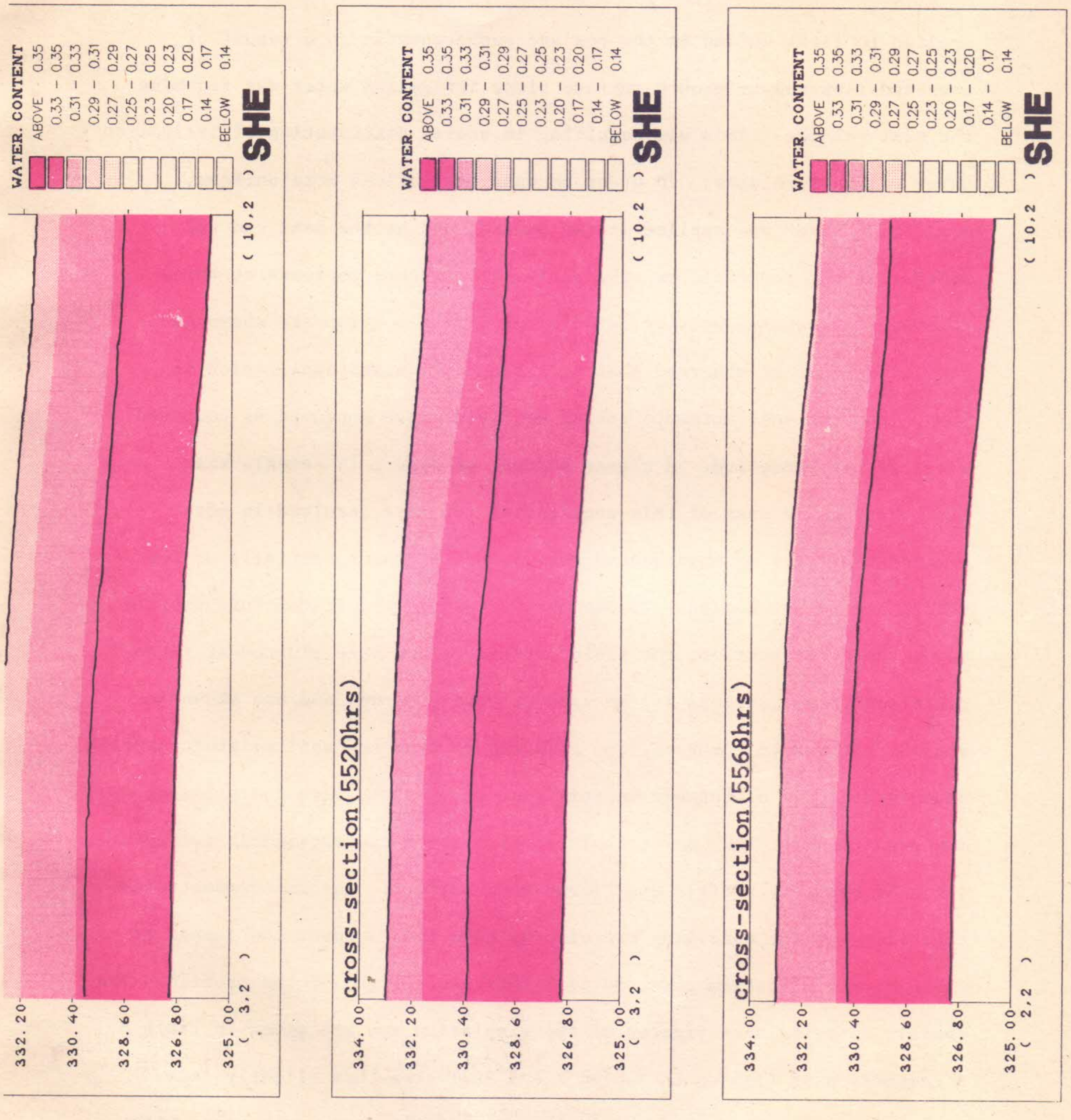


FIG. 13 : SOIL MOISTURE PROFILE CROSS SECTION ALONG THE FIELD (SCALE II, PRE-SPECIFIED, REFERENCE RUN)

(b) Run with watering at two locations

In the reference run the irrigation water was applied to first column in the row and susbsequently as a result of overland flow due to ground surface slope irrigation water was reaching the next columns. This was resulting in uneven distribution of irrigation water within 9 columns. In order to make irrigations more uniform, irrigation water was applied at two points, one at the head end and another at the centre. The time series of moisture contents at three columns representing wettest, middle and driest portion are shown in Fig.14. It can be observed that as a result of water application at two points the soil moisture status of fields have improved as compared with the reference run. A closer perusal of figure 14 reveals that the waterings in case of this sensitivity run have resulted in more prominent effects on unsaturated zone moisture status specially of the middle and driest fields. To see the variation in soil moisture profile along the cross section, the field cross-sections were plotted at three different times (same as in the case of previous run) and are shown in Fig.15. It can be observed from this figure that the soil moisture profile shows a distinct difference in this case as compared with the previous run shown in fig. 13. As a result of irrigation application at two points, the soil moisture profile has become more uniform. The run demonstrates capability of the modelling exercise to take into account the impact of irrigation application point on soil moisture status of the profile. The overall water balance figures of the simulation run are given in Table 8. A comparison of figures in Tables 7 & 8 indicates that slightly less flow in the drain was observed in this sensitivity run as compared with the previous run during the non-rainy period.

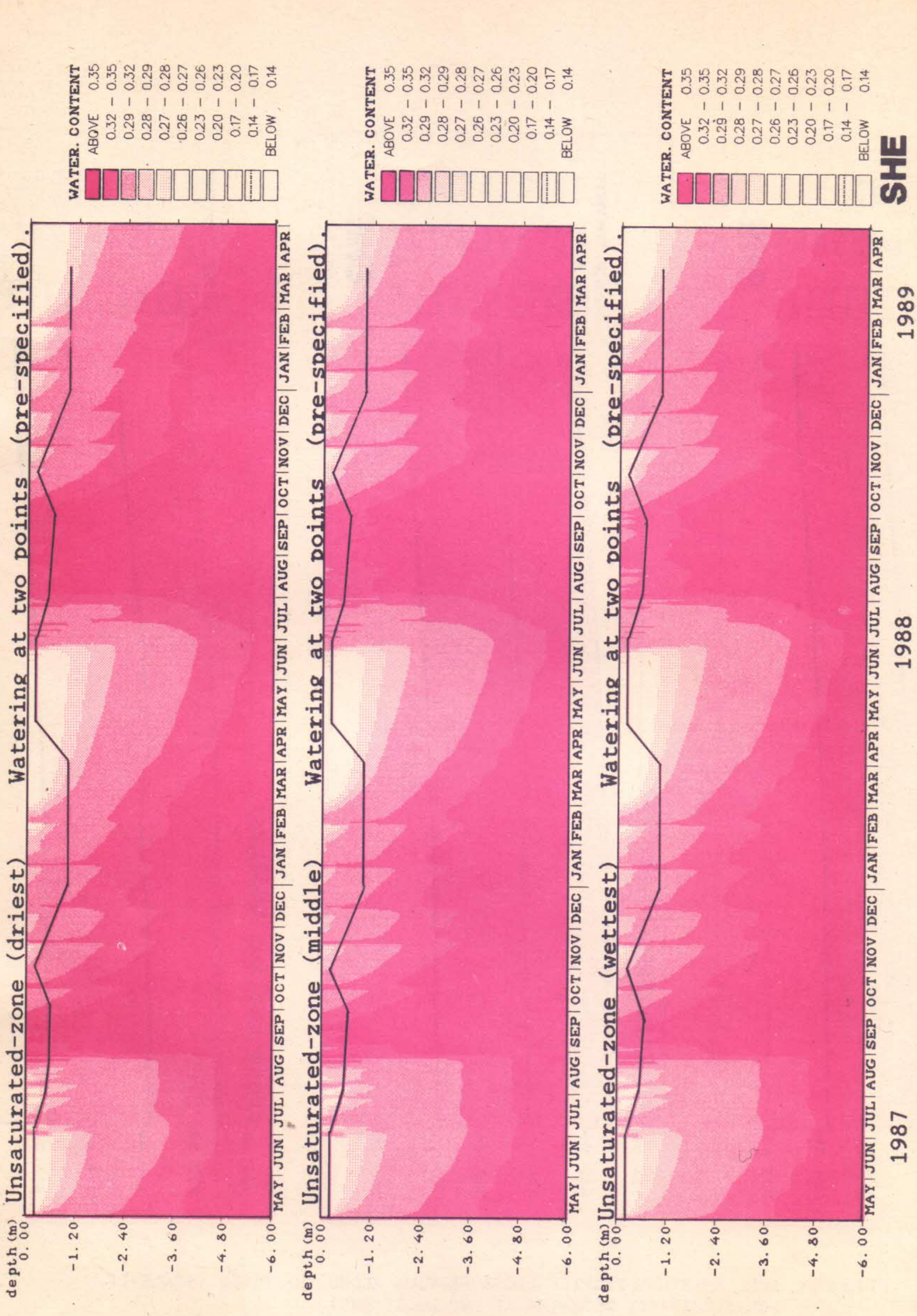


FIG.14 : SOIL MOISTURE STATUS IN THREE COLUMNS IN THE FIELD REPRESENTING WETTEST, MIDDLE AND DRIEST CONDITIONS (SCALE II, PRE-SPECIFIED, WATERING AT TWO LOCATIONS)

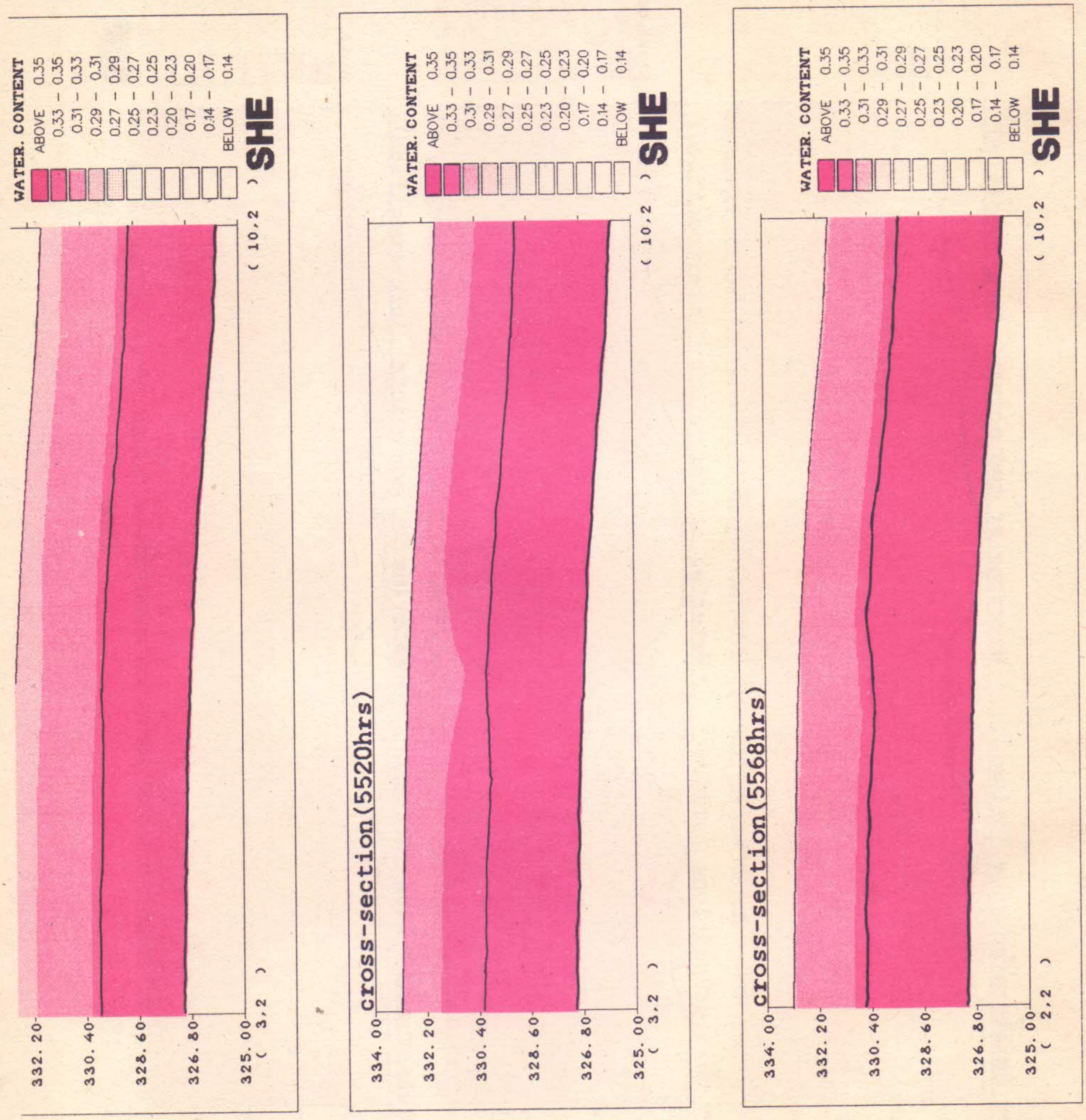


FIG. 15 : SOIL MOISTURE PROFILE CROSS SECTION ALONG THE FIELD (SCALE II, PRE-SPECIFIED, WATERING AT TWO LOCATIONS)

TABLE 8 : WATER BALANCE COMPONENTS (MONTHLY BASIS), SCALE II, PRE-SPECIFIED WATERING AT TWO LOCATIONS.

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-148	0	0	0
87 6 1	4	102	0	0	0	0	0	-244	0	0	0
87 7 1	7	39	0	0	0	0	0	-275	0	0	0
87 8 1	134	96	0	0	0	0	3	-243	0	0	0
87 9 1	541	101	0	0	0	0	279	-64	0	0	0
8710 1	139	89	0	0	0	0	41	-37	0	0	0
8711 1	69	121	0	0	0	0	14	-105	0	0	0
8712 1	3	86	0	0	0	0	17	-132	70	0	0
88 1 1	23	53	0	0	0	0	14	-112	60	0	0
88 2 1	0	73	0	0	0	0	10	-136	60	0	0
88 3 1	0	81	0	0	0	0	6	-159	60	0	0
88 4 1	0	100	0	0	0	0	0	-263	0	0	0
88 5 1	6	42	0	0	0	0	0	-298	0	0	0
88 6 1	3	29	0	0	0	0	0	-323	0	0	0
88 7 1	132	57	0	0	0	0	12	-261	0	0	0
88 8 1	266	97	2	0	0	0	39	-129	0	0	0
88 9 1	254	101	0	0	0	0	52	-13	0	0	0
8810 1	80	89	0	0	0	0	4	-27	0	0	0
8811 1	18	121	0	0	0	0	0	-133	0	0	0
8812 1	5	86	0	0	0	0	13	-157	70	0	0
89 1 1	0	51	0	0	0	0	8	-152	60	0	0
89 2 1	0	73	0	0	0	0	6	-172	60	0	0
89 3 1	0	78	0	0	0	0	3	-193	60	0	0
89 4 1	13	103	0	0	0	0	0	-281	0	0	0
89 5 1	0	33	0	0	0	0	0	-316	0	0	0

TABLE 9 : WATER BALANCE COMPONENTS (MONTHLY BASIS), SCALE II, PRE-SPECIFIED, DEEPER DRAIN.

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb	wbler
87 5 1	0	0	0	0	0	0	0	-148	0	0	0	0
87 6 1	4	102	0	0	0	0	1	-245	0	0	0	2
87 7 1	7	39	0	0	0	0	0	-276	0	0	0	1
87 8 1	134	96	0	0	0	0	4	-244	0	0	0	-3
87 9 1	541	101	0	0	0	0	275	-65	0	0	0	14
8710 1	139	89	0	0	0	0	46	-40	0	0	0	21
8711 1	69	121	0	0	0	0	17	-111	0	0	0	-2
8712 1	3	86	0	0	0	0	18	-141	70	0	0	71
88 1 1	23	53	0	0	0	0	15	-121	60	0	0	64
88 2 1	0	73	0	0	0	0	10	-146	60	0	0	59
88 3 1	0	81	0	0	0	0	6	-169	60	0	0	64
88 4 1	0	98	0	0	0	0	0	-270	0	0	0	-3
88 5 1	6	40	0	0	0	0	0	-304	0	0	0	1
88 6 1	3	27	0	0	0	0	0	-328	0	0	0	1
88 7 1	132	57	0	0	0	0	13	-264	0	0	0	1
88 8 1	266	97	2	0	0	0	41	-134	0	0	0	4
88 9 1	254	101	0	0	0	0	55	-20	0	0	0	15
8810 1	80	89	0	0	0	0	7	-38	0	0	0	-1
8811 1	18	120	0	0	0	0	3	-146	0	0	0	-3
8812 1	5	85	0	0	0	0	12	-169	70	0	0	70
89 1 1	0	51	0	0	0	0	8	-164	60	0	0	64
89 2 1	0	73	0	0	0	0	6	-183	60	0	0	59
89 3 1	0	77	0	0	0	0	1	-202	60	0	0	60
89 4 1	13	101	0	0	0	0	0	-287	0	0	0	3
89 5 1	0	32	0	0	0	0	0	-321	0	0	0	-2

(c) Sensitivity Run with deep cross-section of the drain at tail end

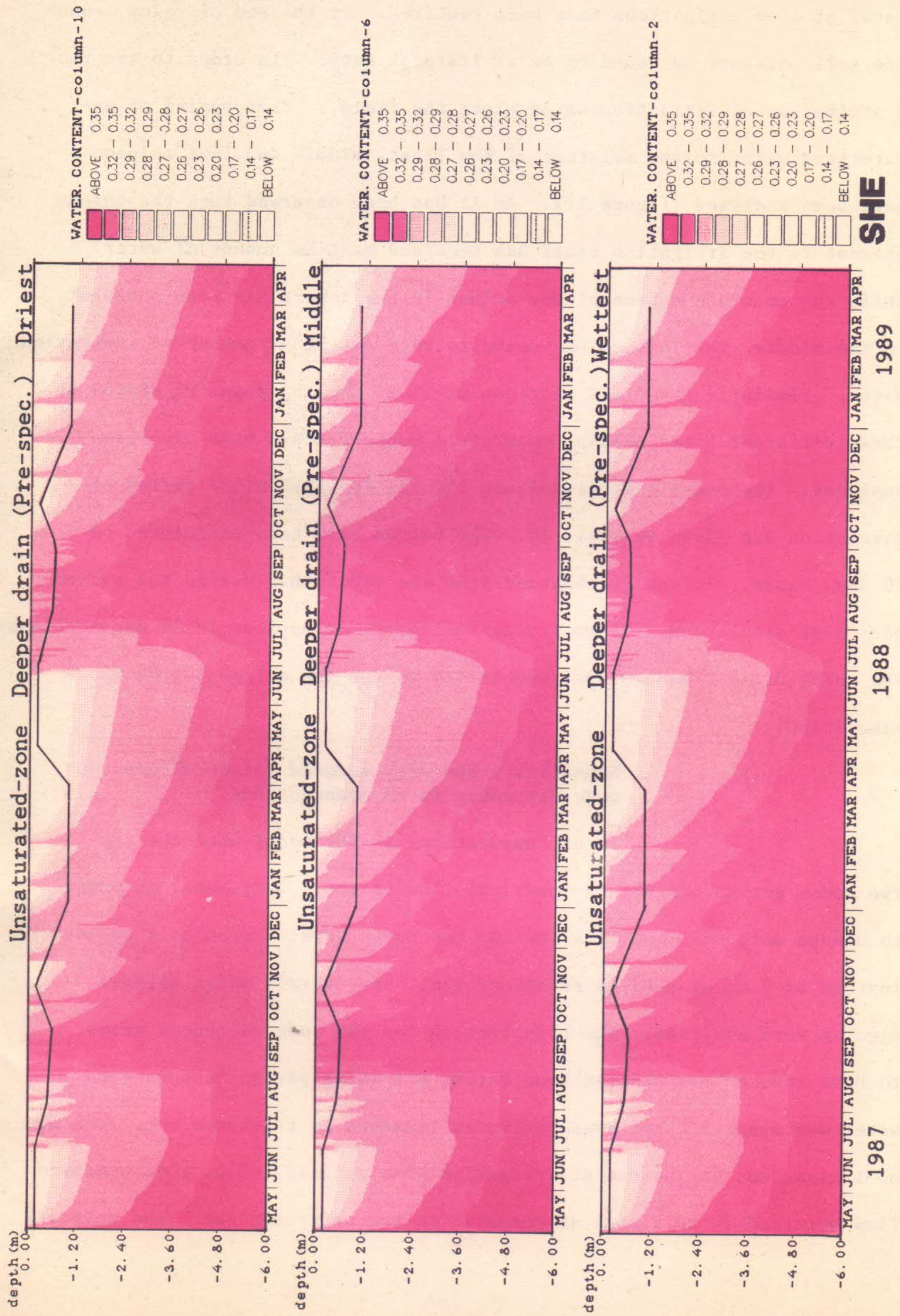
In the reference run, the drain at the tail end was taken as 30 cm deep. In order to see the effects of deepening of drain on drain flow, the depth of drain was increased from 30 cm (in the reference run) to 4 m in this sensitivity run. The drainflow in this simulation increased from 521 mm (the value in reference run) to 538 mm as can be seen from Tables 7 & 9. The increase in drain flow has not been significant as a result of increased depth of drain. This may be perhaps because drain is in hydrologic connection with the last column (driest) along the field which has least fluctuation in water table levels and major portion of drain flow takes place in rainy season which may be due to overland flow which will remain same irrespective of depth of drain. This also concludes that the contribution of groundwater flow in the drain flow is relatively less as the non-rainy flow in the drain in both the runs (reference and the present one) were not very much different. The soil moisture status and variations in water table during the simulation period are given in figure 16. A close examination of figure 16 and its comparison with the reference run as in figure 12 indicates that the positions of water table in the wettest and middle columns have not varied much. However, for driest columns the water table position in the present run is lower than the reference run, more particularly during rainy period. This may be due to more flow to the deeper drain in this case as compared to the reference run. This is also indicated by the water balance figures as given in Tables 7 and 9.

B. Automatic Scheduling Policy

(a) Reference Run

The simulation results indicate that irrigations

FIG. 16 : SOIL MOISTURE STATUS IN THREE COLUMNS IN THE FIELD REPRESENTING WETTEST, MIDDLE AND DRIEST CONDITIONS (SCALE II, PRE-SPECIFIED, DEEPER DRAIN)



have generally started from the month of January and till March end a total of five irrigations have been required. By the end of rainy season the soil moisture is found to be at its peak level. In order to see the distribution of irrigation water along the field, time series of unsaturated water column moisture of the first, middle and last columns have been analysed (figure 17). As it has been observed that the column nearest to the irrigation canal has received maximum amount of water. While the moisture status of the column in the centre has been somewhat in the middle, the last column seems to have got least amount of irrigation water. Similarly the cross sections of field showing moisture status at three different times showing moisture advance pattern have also been analysed. The overall water balance figures for the entire period of simulation are given in Table 10. The values have been calculated on 10 days basis. It can be observed from the table that during the entire period of simulation, 796 mm irrigation water was applied in 24 applications. The total drain flow was observed as 526 mm for the entire period of simulation.

(b) Sensitivity Run with reduced values of top two node distances in uz computations

In uz computations in SHE model when the top two nodes get saturated, the overland flow starts. Therefore, in order to create more overland flow the top two nodes were changed to 1 cm each instead of 2 cm as used in reference run. The overall water balance figures were analysed. The reduction in top two node distances seems to have reduced evaporation loss during non-rainy period because less water was available for evaporation as compared to reference run. The no. of irrigations and amount of irrigation also got reduced as more overland flow occurred in this case as compared to the reference run. The moisture

TABLE 10 : WATER BALANCE COMPONENTS (10 DAYS BASIS, SCALE II, AUTOMATIC, REFERENCE)

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-148	0	0	0
87 511	4	56	0	0	0	0	0	-201	0	0	0
87 521	0	30	0	0	0	0	0	-216	13	0	0
87 531	0	25	0	0	0	0	0	-229	13	0	0
87 610	4	24	0	0	0	0	0	-237	12	0	0
87 620	1	11	0	0	0	0	0	-248	0	0	0
87 630	1	16	0	0	0	0	0	-261	0	0	0
87 710	77	28	0	0	0	0	3	-214	0	0	0
87 720	27	32	0	0	0	0	1	-221	0	0	0
87 730	29	30	0	0	0	0	0	-222	0	0	0
87 8 9	32	33	0	0	0	0	0	-221	0	0	0
87 819	21	26	1	0	0	0	0	-227	0	0	0
87 829	407	37	3	0	6	0	232	-82	0	0	0
87 9 8	155	27	2	0	0	0	62	-1	0	0	0
87 918	65	34	1	0	0	0	39	0	0	0	0
87 928	0	32	0	0	0	0	0	-29	0	0	0
8710 8	0	36	0	0	0	0	0	-65	0	0	0
871018	28	38	2	0	0	0	0	-78	0	0	0
871028	40	43	0	0	0	0	13	-89	0	0	0
8711 7	0	33	0	0	0	0	0	-122	0	0	0
871117	0	29	0	0	0	0	0	-151	0	0	0
871127	3	28	0	0	0	0	0	-175	0	0	0
8712 7	0	20	0	0	0	0	0	-196	0	0	0
871217	23	16	0	0	0	0	0	-188	0	0	0
871227	0	15	0	0	0	0	0	-203	0	0	0
88 1 6	0	23	0	0	0	0	0	-227	0	0	0
88 116	0	22	0	0	0	0	0	-247	0	0	0
88 126	0	23	0	0	0	0	0	-245	27	0	0
88 2 5	0	18	0	0	0	0	0	-263	0	0	0
88 215	0	24	0	0	0	0	0	-286	0	0	0
88 225	0	22	0	0	0	0	0	-275	33	0	0
88 3 6	0	26	0	0	0	0	0	-265	36	0	0
88 316	0	35	0	0	0	0	0	-264	36	0	0
88 326	0	40	0	0	0	0	0	-267	37	0	0
88 4 5	0	32	0	0	0	0	0	-262	38	0	0
88 415	0	36	0	0	0	0	0	-268	29	0	0
88 425	3	36	0	0	0	0	0	-275	25	0	0
88 5 5	5	40	0	0	0	0	0	-240	70	0	0
88 515	0	37	0	0	0	0	0	-249	29	0	0
88 525	0	34	0	0	0	0	0	-256	27	0	0
88 6 4	0	30	0	0	0	0	0	-272	13	0	0
88 614	0	21	0	0	0	0	0	-259	33	0	0
88 624	40	22	0	0	0	0	0	-242	0	0	0
88 7 4	116	39	0	0	2	0	15	-179	0	0	0
88 714	100	31	0	0	0	0	34	-136	0	0	0
88 724	55	32	0	0	0	0	0	-112	0	0	0
88 8 3	141	35	2	0	0	0	37	-43	0	0	0
88 813	103	26	0	0	0	0	51	-8	0	0	0
88 823	19	30	0	0	0	0	1	-18	0	0	0
88 9 2	77	41	0	0	0	0	39	-9	0	0	0
88 912	25	23	0	0	0	0	1	-8	0	0	0
88 922	15	34	0	0	0	0	0	-28	0	0	0
8810 2	39	32	0	0	0	0	2	-22	0	0	0
881012	18	38	0	0	0	0	0	-42	0	0	0
881022	0	38	0	0	0	0	0	-80	0	0	0
8811 1	0	41	0	0	0	0	0	-122	0	0	0
881111	5	31	0	0	0	0	0	-147	0	0	0
881121	0	28	0	0	0	0	0	-176	0	0	0
8812 1	0	26	0	0	0	0	0	-204	0	0	0
881211	0	15	0	0	0	0	0	-218	0	0	0
881221	0	14	0	0	0	0	0	-232	0	0	0
881231	0	16	0	0	0	0	0	-247	0	0	0
89 110	0	23	0	0	0	0	0	-272	0	0	0
89 120	0	20	0	0	0	0	0	-267	24	0	0
89 130	0	20	0	0	0	0	0	-287	0	0	0
89 2 9	0	18	0	0	0	0	0	-274	31	0	0
89 219	0	24	0	0	0	0	0	-298	0	0	0
89 3 1	0	22	0	0	0	0	0	-284	36	0	0
89 311	4	34	0	0	0	0	0	-279	36	0	0
89 321	3	38	0	0	0	0	0	-278	37	0	0
89 331	7	36	0	0	0	0	0	-306	0	0	0
89 410	0	32	0	0	4	0	0	-284	59	0	0
89 420	0	40	0	0	0	0	0	-281	40	0	0
89 430	0	37	0	0	0	0	0	-256	62	0	0

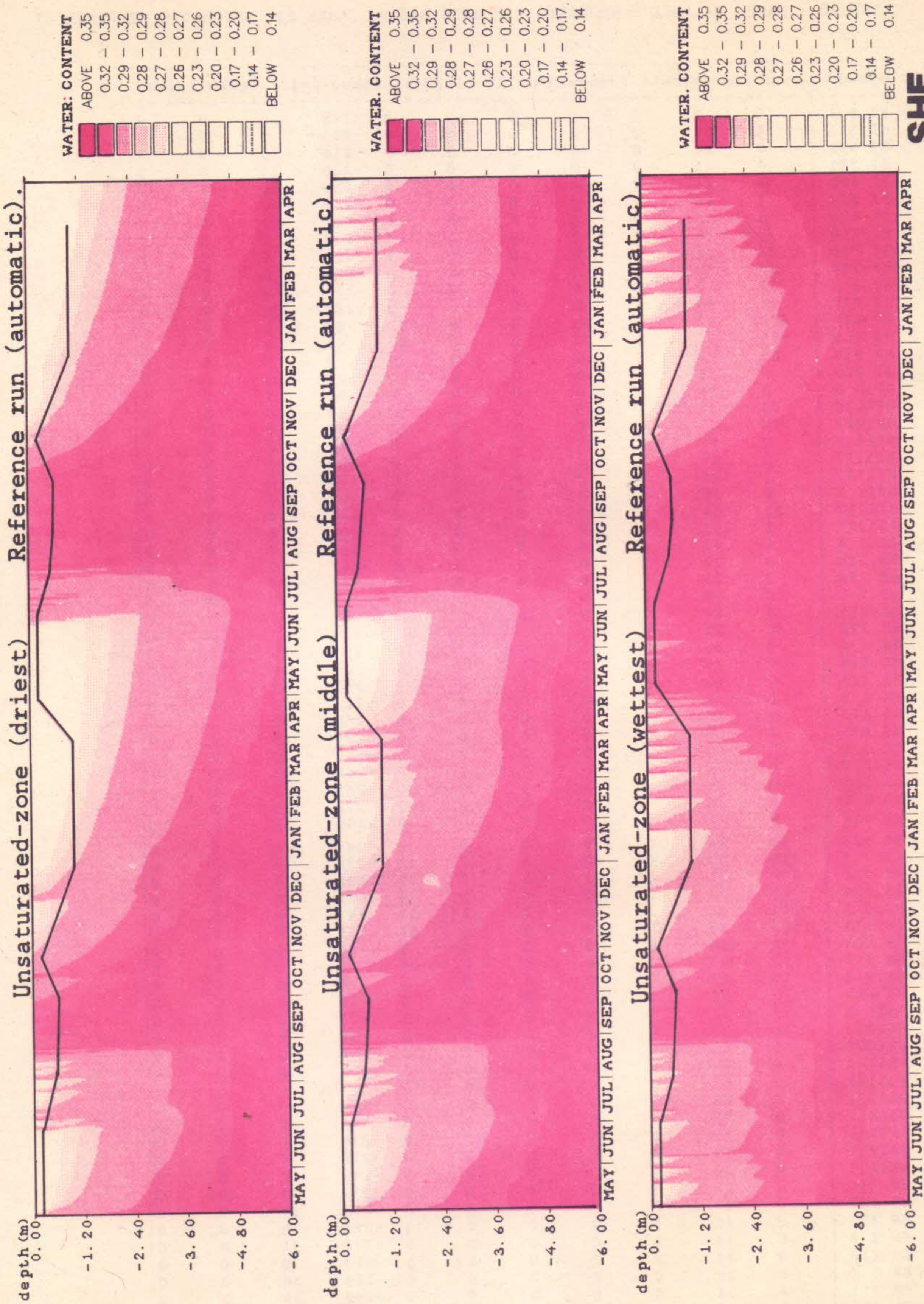


FIG. 17 : SOIL MOISTURE STATUS IN THREE COLUMNS IN THE FIELD REPRESENTING WETTEST, MIDDLE AND DRIEST CONDTIONS (SCALE II, AUTOMATIC, REFERENCE)

status of three columns representing wettest, middle and driest portion of field were analysed (fig. 18). As compared to the similar representation of the reference run, the moisture status was found better in this case. The cross section profiles at three different times were also observed. As compared to reference run better moisture status is observed in the simulation run. The water balance figure computed on 10 days basis are given in Table 11. A comparison of table 10 & 11 indicates that in this simulation run the irrigation amount got reduced to 741 mm (applied in 22 applications) as compared to the reference run where 796 mm irrigation was applied in 24 application. The total drain flow during irrigation period was recorded as 492 mm as against 526 mm as observed in the reference run. Therefore, it is observed from the simulation run that as a result of reduced distances of top two nodes in uz computation, more overland flow was generated which resulted in reduction in irrigation requirements.

(c) Sensitivity Run with increased value of upper limit of moisture content (from 0.31-0.35)

In case of automatic scheduling policy, as has been described earlier, the irrigation water is applied till a pre-determined upper limit of moisture content in the root zone is achieved. The reference run was taken with 31% as the upper moisture content limit in the root zone. In order to see the effects of the change in value of upper limit of moisture content for irrigation scheduling purpose, the upper limit was increased to 35%. The change in total water balance as computed on 10 day basis is as given in Table 12. As compared with the values as given in Table 10 (reference run), it can be seen that irrigation application got less frequent with more amount per application in this simulation run. A comparison of the entire period of simulation showed that 796 mm amount of water applied in 24 irrigation applications in reference run,

TABLE 11 : WATER BALANCE COMPONENTS (10 DAYS BASIS, SCALE II, AUTOMATIC, REDUCED TOP NODE DISTANCES).

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-148	0	0	0
87 511	4	56	0	0	0	0	0	-200	0	0	0
87 521	0	26	0	0	0	0	0	-224	0	0	0
87 531	0	23	0	0	0	0	0	-235	13	0	0
87 610	4	18	0	0	0	0	0	-249	0	0	0
87 620	1	11	0	0	0	0	0	-259	0	0	0
87 630	1	15	0	0	0	0	0	-271	0	0	0
87 710	77	27	0	0	0	0	3	-224	0	0	0
87 720	27	32	0	0	0	0	1	-231	0	0	0
87 730	29	30	0	0	0	0	0	-232	0	0	0
87 8 9	32	33	0	0	0	0	0	-231	0	0	0
87 819	21	26	1	0	0	0	0	-236	0	0	0
87 829	407	37	3	0	7	0	233	-94	0	0	0
87 9 8	155	27	2	0	0	0	59	-8	0	0	0
87 918	65	34	1	0	0	0	29	0	0	0	0
87 928	0	32	0	0	0	0	0	-29	0	0	0
8710 8	0	36	0	0	0	0	0	-65	0	0	0
871018	28	38	2	0	0	0	0	-78	0	0	0
871028	40	43	0	0	0	0	14	-89	0	0	0
8711 7	0	33	0	0	0	0	0	-122	0	0	0
871117	0	29	0	0	0	0	0	-152	0	0	0
871127	3	28	0	0	0	0	0	-176	0	0	0
8712 7	0	20	0	0	0	0	0	-196	0	0	0
871217	23	16	0	0	0	0	0	-188	0	0	0
871227	0	15	0	0	0	0	0	-204	0	0	0
88 1 6	0	23	0	0	0	0	0	-227	0	0	0
88 116	0	22	0	0	0	0	0	-248	0	0	0
88 126	0	22	0	0	0	0	0	-271	0	0	0
88 2 5	0	16	0	0	3	0	0	-269	20	0	0
88 215	0	25	0	0	0	0	0	-280	10	0	0
88 225	0	22	0	0	0	0	0	-268	35	0	0
88 3 6	0	27	0	0	0	0	0	-295	0	0	0
88 316	0	36	0	0	0	0	0	-294	37	0	0
88 326	0	39	0	0	0	0	0	-296	37	0	0
88 4 5	0	32	0	0	0	0	0	-291	37	0	0
88 415	0	35	0	0	1	0	0	-287	40	0	0
88 425	3	38	0	0	0	0	0	-273	48	0	0
88 5 5	5	36	0	0	1	0	0	-266	38	0	0
88 515	0	34	0	0	0	0	0	-259	41	0	0
88 525	0	30	0	0	0	0	0	-263	27	0	0
88 6 4	0	33	0	0	0	0	0	-268	27	0	0
88 614	0	17	0	0	0	0	0	-277	9	0	0
88 624	40	22	0	0	0	0	0	-258	0	0	0
88 7 4	116	39	0	0	0	0	14	-193	0	0	0
88 714	100	31	0	0	0	0	32	-151	0	0	0
88 724	55	32	0	0	0	0	0	-128	0	0	0
88 8 3	141	35	2	0	1	0	32	-54	0	0	0
88 813	103	26	0	0	0	0	47	-17	0	0	0
88 823	19	30	0	0	0	0	0	-25	0	0	0
88 9 2	77	41	0	0	0	0	28	-9	0	0	0
88 912	25	23	0	0	0	0	2	-8	0	0	0
88 922	15	34	0	0	0	0	0	-28	0	0	0
8810 2	39	32	0	0	0	0	2	-22	0	0	0
881012	18	38	0	0	0	0	0	-42	0	0	0
881022	0	38	0	0	0	0	0	-80	0	0	0
8811 1	0	41	0	0	0	0	0	-121	0	0	0
881111	5	31	0	0	0	0	0	-148	0	0	0
881121	0	28	0	0	0	0	0	-176	0	0	0
8812 1	0	26	0	0	0	0	0	-203	0	0	0
881211	0	15	0	0	0	0	0	-218	0	0	0
881221	0	14	0	0	0	0	0	-231	0	0	0
881231	0	16	0	0	0	0	0	-247	0	0	0
89 110	0	23	0	0	0	0	0	-271	0	0	0
89 120	0	19	0	0	0	0	0	-264	25	0	0
89 130	0	20	0	0	0	0	0	-285	0	0	0
89 2 9	0	18	0	0	0	0	0	-272	32	0	0
89 219	0	24	0	0	0	0	0	-296	0	0	0
89 3 1	0	21	0	0	0	0	0	-282	35	0	0
89 311	4	33	0	0	0	0	0	-275	37	0	0
89 321	3	38	0	0	0	0	0	-274	37	0	0
89 331	7	37	0	0	0	0	0	-303	0	0	0
89 410	0	32	0	0	0	0	0	-299	37	0	0
89 420	0	39	0	0	0	0	0	-279	59	0	0
89 430	0	36	0	0	0	0	0	-255	60	0	0

TABLE 12 : WATER BALANCE COMPONENTS (10 DAYS BASIS, SCALE II, AUTOMATIC, INCREASED VALUE OF UPPER LIMIT OF MOISTURE CONTENT).

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszo	qoco
87 5 1	0	0	0	0	0	0	0	-148	0	0	0
87 511	4	56	0	0	0	0	0	-201	0	0	0
87 521	0	32	0	0	0	0	0	-212	19	0	0
87 531	0	24	0	0	0	0	0	-237	0	0	0
87 610	4	27	0	0	0	0	0	-228	31	0	0
87 620	1	12	0	0	0	0	0	-240	0	0	0
87 630	1	17	0	0	0	0	0	-254	0	0	0
87 710	77	27	0	0	0	0	3	-207	0	0	0
87 720	27	32	0	0	0	0	1	-213	0	0	0
87 730	29	30	0	0	0	0	0	-214	0	0	0
87 8 9	32	33	0	0	0	0	0	-214	0	0	0
87 819	21	26	1	0	0	0	0	-219	0	0	0
87 829	407	37	3	0	6	0	232	-75	0	0	0
87 9 8	155	27	2	0	1	0	67	0	0	0	0
87 918	65	34	1	0	0	0	42	0	0	0	0
87 928	0	32	0	0	0	0	0	-29	0	0	0
8710 8	0	36	0	0	0	0	0	-65	0	0	0
871018	28	38	2	0	0	0	0	-78	0	0	0
871028	40	43	0	0	0	0	13	-89	0	0	0
8711 7	0	33	0	0	0	0	0	-122	0	0	0
871117	0	29	0	0	0	0	0	-151	0	0	0
871127	3	28	0	0	0	0	0	-175	0	0	0
8712 7	0	20	0	0	0	0	0	-196	0	0	0
871217	23	16	0	0	0	0	0	-188	0	0	0
871227	0	15	0	0	0	0	0	-203	0	0	0
88 1 6	0	23	0	0	0	0	0	-227	0	0	0
88 116	0	22	0	0	0	0	0	-247	0	0	0
88 126	0	24	0	0	0	0	0	-234	39	0	0
88 2 5	0	19	0	0	0	0	0	-253	0	0	0
88 215	0	26	0	0	0	0	0	-278	0	0	0
88 225	0	24	0	0	0	0	0	-254	48	0	0
88 3 6	0	30	0	0	0	0	0	-284	0	0	0
88 316	0	40	0	0	0	0	0	-272	52	0	0
88 326	0	44	0	0	0	0	0	-265	52	0	0
88 4 5	0	33	0	0	0	0	0	-246	52	0	0
88 415	0	39	0	0	6	0	0	-258	34	0	0
88 425	3	39	0	0	0	0	0	-280	7	0	0
88 5 5	5	41	0	0	1	0	0	-263	54	0	0
88 515	0	36	0	0	2	0	0	-245	56	0	0
88 525	0	33	0	0	0	0	0	-257	19	0	0
88 6 4	0	29	0	0	0	0	0	-268	18	0	0
88 614	0	20	0	0	0	0	0	-259	29	0	0
88 624	40	22	0	0	0	0	0	-241	0	0	0
88 7 4	116	39	0	0	1	0	14	-177	0	0	0
88 714	100	31	0	0	0	0	32	-134	0	0	0
88 724	55	32	0	0	0	0	0	-110	0	0	0
88 8 3	141	35	2	0	1	0	37	-39	0	0	0
88 813	103	26	0	0	0	0	52	-7	0	0	0
88 823	19	30	0	0	0	0	1	-16	0	0	0
88 9 2	77	41	0	0	0	0	15	-9	0	0	0
88 912	25	23	0	0	0	0	1	-8	0	0	0
88 922	15	34	0	0	0	0	0	-28	0	0	0
8810 2	39	32	0	0	0	0	2	-22	0	0	0
881012	18	38	0	0	0	0	0	-42	0	0	0
881022	0	38	0	0	0	0	0	-90	0	0	0
8811 1	0	41	0	0	0	0	0	-122	0	0	0
881111	5	31	0	0	0	0	0	-148	0	0	0
881121	0	28	0	0	0	0	0	-176	0	0	0
8812 1	0	26	0	0	0	0	0	-204	0	0	0
881211	0	15	0	0	0	0	0	-218	0	0	0
881221	0	14	0	0	0	0	0	-232	0	0	0
881231	0	16	0	0	0	0	0	-247	0	0	0
89 110	0	23	0	0	0	0	0	-272	0	0	0
89 120	0	20	0	0	0	0	0	-258	34	0	0
89 130	0	21	0	0	0	0	0	-279	0	0	0
89 2 9	0	19	0	0	0	0	0	-298	0	0	0
89 219	0	27	0	0	0	0	0	-281	45	0	0
89 3 1	0	23	0	0	0	0	0	-303	0	0	0
89 311	4	38	0	0	0	0	0	-286	52	0	0
89 321	3	43	0	0	0	0	0	-275	52	0	0
89 331	7	40	0	0	0	0	0	-307	0	0	0
89 410	0	39	0	0	0	0	0	-290	56	0	0
89 420	0	40	0	0	0	0	0	-289	42	0	0
89 430	0	34	0	0	0	0	0	-271	52	0	0

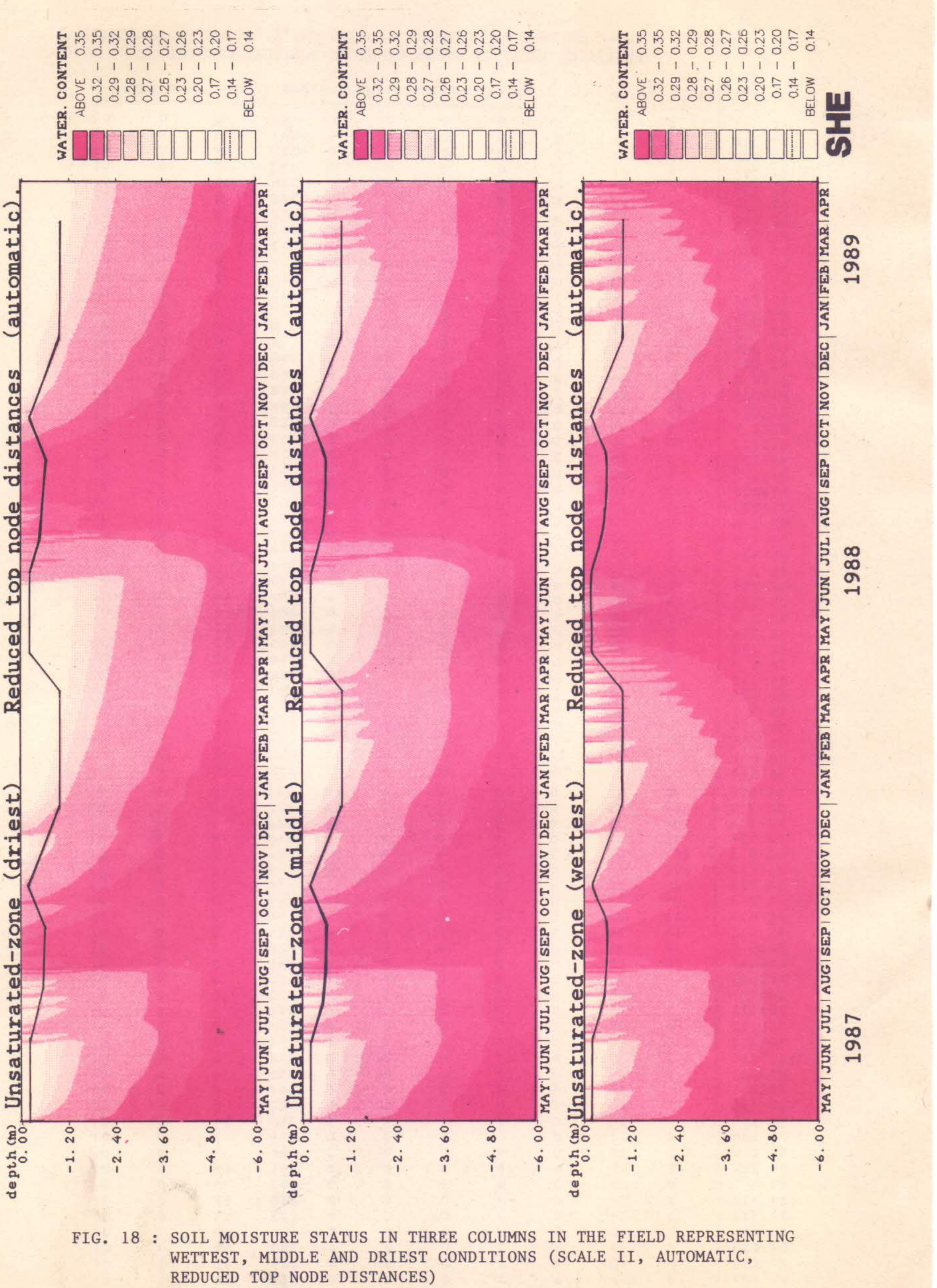


FIG. 18 : SOIL MOISTURE STATUS IN THREE COLUMNS IN THE FIELD REPRESENTING WETTEST, MIDDLE AND DRIEST CONDITIONS (SCALE II, AUTOMATIC, REDUCED TOP NODE DISTANCES)

this run showed a total application of 843 mm of water in 21 applications. The variation of uz moisture content and water table position throughout the simulation period is shown in figure 19. As compared with the figure 17 (reference run), this run shows more prominent irrigations with less frequency. The middle column shows better moisture status as compared with the middle column of the reference run. The results are as per expectations and demonstrate proper functioning of the scheduling procedure as introduced in the modelling exercise. The results indicate that such an approach may need correct assessment of the upper limit of irrigation application. Generally the upper limit is taken as the field capacity of the soil. However, in order to take care of likelihood of some rainfall events a slightly lower value than field capacity can be taken as upper limit of moisture for irrigation.

5.3.3 Small Irrigation System (Scale III) Simulation

The extension of Scale II simulation studies to cover a number of fields along an irrigation source has been done in Scale III simulation exercises. The model has considered five fields for simulation exercise along an irrigation source. At the tail end of the field a drainage canal runs for collecting waste water/return flow from irrigation. There is no over flow across the fields. The parameter values as discussed in the Scale II simulation were used in Scale III simulations also. Two kinds of irrigation policies, namely; automatic and pre-specified were adopted for carrying out various simulation exercises. Since more than one field is to be irrigated in the simulation of Scale III, provision to assign priority of irrigation was introduced in the computations. Moreover, the canal capacity may not always be enough to be able to supply irrigation water simulataneously to all fields. Also due to scarcity of water, it may not always be possible to give full supplies as per

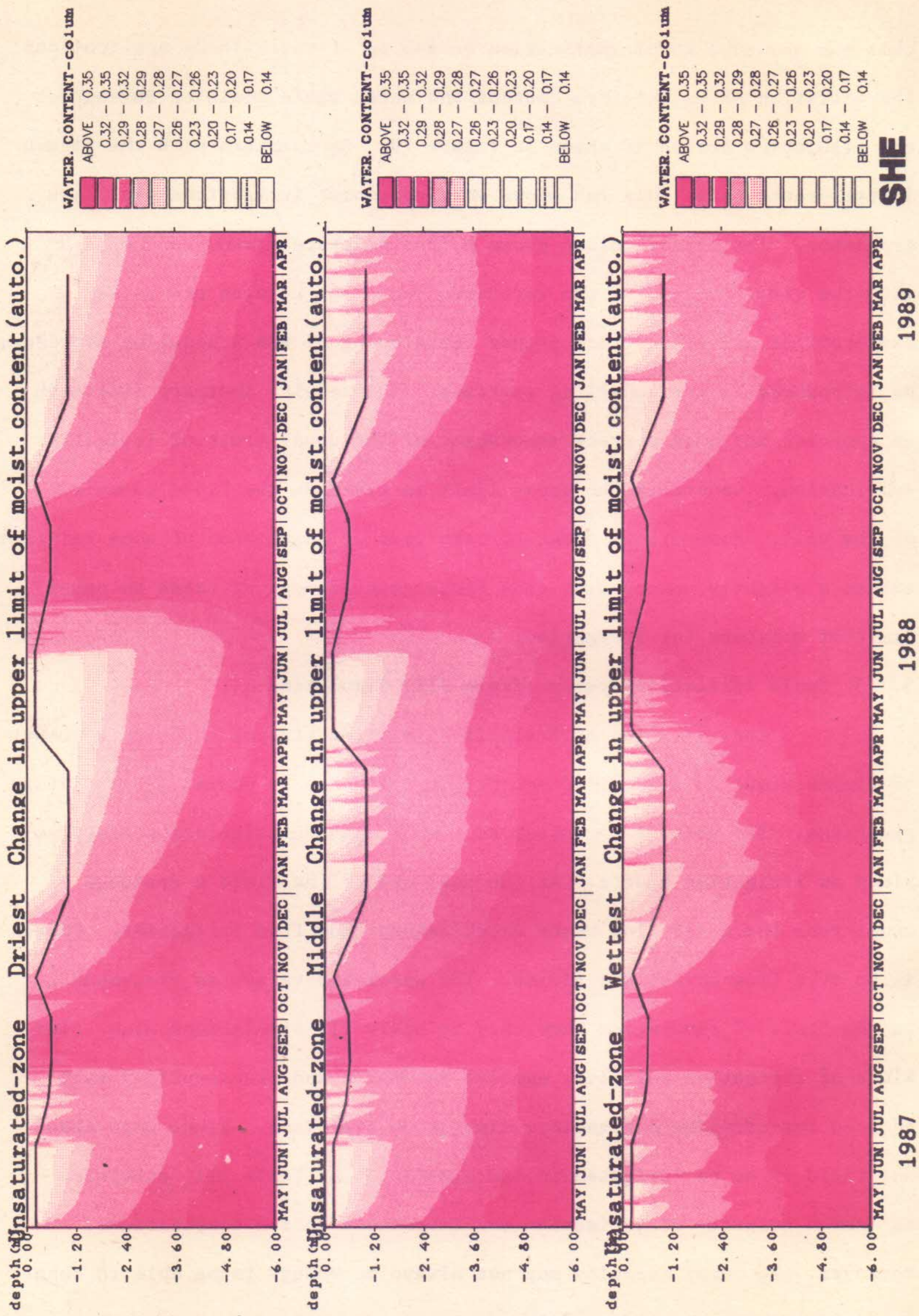


FIG.19 : SOIL MOISTURE STATUS IN THREE COLUMNS IN THE FIELD REPRESENTING WETTEST, MIDDLE AND DRIEST CONDITIONS (SCALE II, AUTOMATIC, INCREASED VALUE OF UPPER LIMIT OF MOISTURE CONTENT)

demand to all fields. Therefore, a provision to reduce allocation of water to fields as per shortage factors has also been introduced in the computations. These informations are included as input to the simulation exercises. The results of various simulation runs are given as below :

A. Pre-specified Scheduling Policy

(a) Reference Run

The amount and timings of irrigations were predecided in this policy of irrigation. The Scale III had provisions to consider shortages in water supply in irrigation source as also prioritisation of irrigations among fields was introduced in Scale III simulations. In the reference run no shortage condition was simulated for which prioritisation of fields was not required. The simulation run was taken from 1 May '87 to 1 May '89 as in previous cases. The irrigation schedules were obtained for all fields. The water distribution profiles for three different fields showing unevenness in water application is shown in Figure 20. A close perusal of Figure 20 indicates that as a result of uneven distribution of water the water table reached to about 4 m from ground surface in pre-monsoon months in year 1988 in the case of first plot of field No.2 (refer figure 3) while in the last plot of field No.6 (refer figure 3) the water table reached to about 6 m depth in pre-monsoon months of the same year. The overall water balance figures for the entire simulation period are given in Table 13. It can be observed from the table that a total of 758 mm flow in the drain was observed during the period of simulation in this simulation run.

(b) Simulation run with short water supply and priority allocation to fields

In order to demonstrate capability of the model to handle situations of short supply of irrigation water and priority

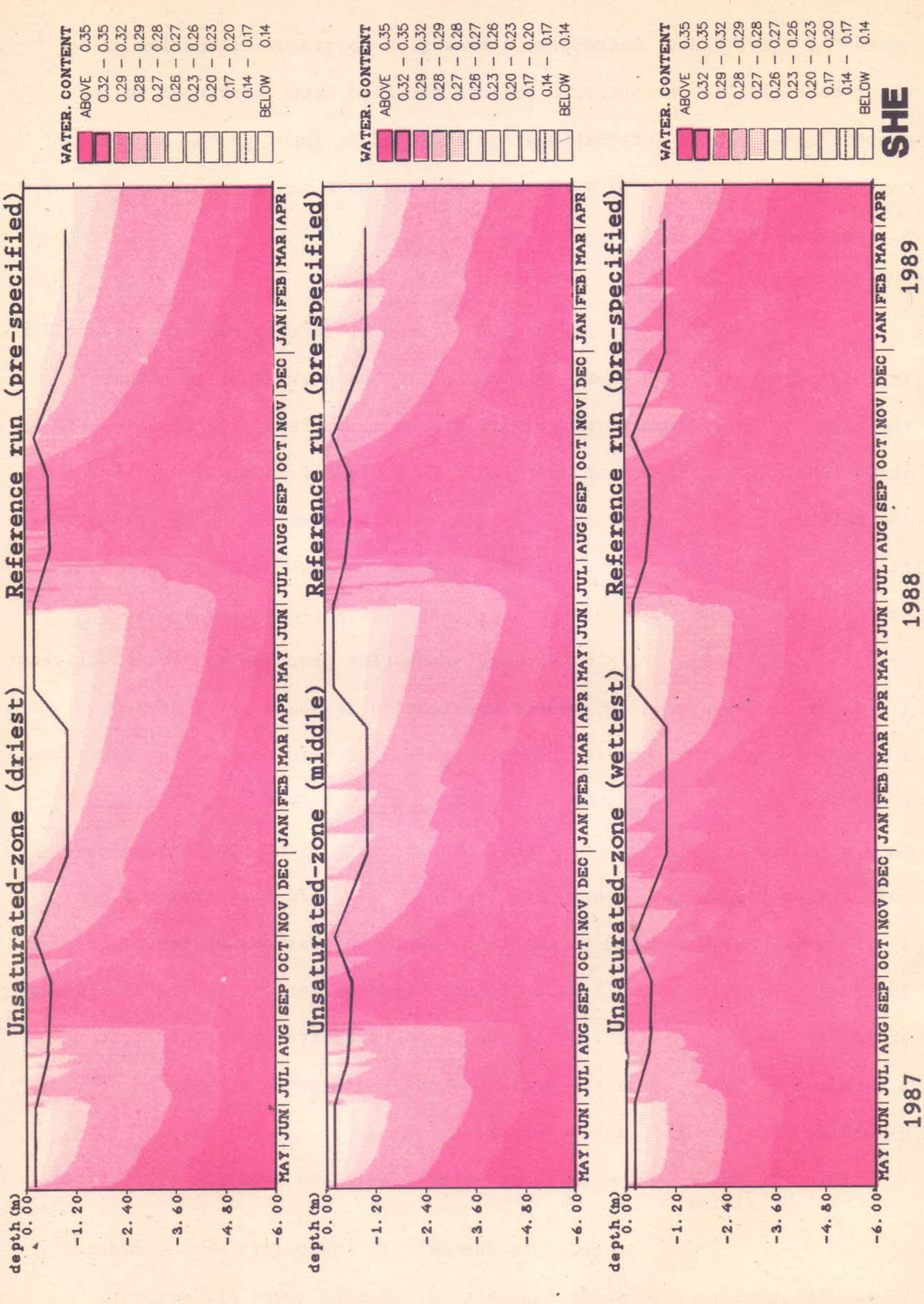


FIG. 20 : WATER DISTRIBUTION PROFILES FOR THREE FIELDS (SCALE III, PRE-SPECIFIED, REFERENCE)

TABLE 13 : WATER BALANCE COMPONENTS (MONTHLY BASIS, SCALE III, PRE-SPECIFIED, REFERENCE).

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-150	0	0	0
87 6 1	4	107	0	0	0	1	-123	-241	0	0	0
87 7 1	7	39	0	0	0	1	-9	-264	0	0	0
87 8 1	134	96	0	0	0	1	-5	-222	0	0	0
87 9 1	541	101	0	0	0	1	270	-44	0	0	0
8710 1	139	89	0	0	0	1	67	-35	0	0	0
8711 1	69	121	0	0	0	1	7	-96	0	0	0
8712 1	3	86	0	0	0	1	-18	-159	70	0	0
88 1 1	23	52	0	0	0	1	-16	-169	60	0	0
88 2 1	0	71	0	0	0	1	-17	-225	60	0	0
88 3 1	0	60	0	0	0	1	-17	-265	60	0	0
88 4 1	0	66	0	0	0	1	-9	-323	0	0	0
88 5 1	6	31	0	0	0	1	-9	-339	0	0	0
88 6 1	3	24	0	0	0	1	-9	-351	0	0	0
88 7 1	132	55	0	0	0	1	1	-272	0	0	0
88 8 1	266	97	2	0	0	1	27	-128	0	0	0
88 9 1	254	101	0	0	0	1	58	-20	0	0	0
8810 1	80	89	0	0	0	1	1	-31	0	0	0
8811 1	18	121	0	0	0	1	-5	-131	0	0	0
8812 1	5	85	0	0	0	1	-19	-191	70	0	0
89 1 1	0	47	0	0	0	1	-17	-218	60	0	0
89 2 1	0	61	0	0	0	1	-18	-262	60	0	0
89 3 1	0	52	0	0	0	1	-18	-294	60	0	0
89 4 1	13	72	0	0	0	1	-9	-342	0	0	0
89 5 1	0	24	0	0	0	1	-9	-358	0	0	0

TABLE 14 : WATER BALANCE COMPONENTS (MONTHLY BASIS, SCALE III, PRE-SPECIFIED, SHORTAGES AND PRIORITY ALLOCATION TO FIELDS).

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-150	0	0	0
87 6 1	4	107	0	0	0	0	-38	-242	0	0	0
87 7 1	7	39	0	0	0	0	-8	-264	0	0	0
87 8 1	134	96	0	0	0	0	-5	-223	0	0	0
87 9 1	541	101	0	0	0	0	271	-45	0	0	0
8710 1	139	89	0	0	0	0	65	-36	0	0	0
8711 1	69	121	0	0	0	0	6	-95	0	0	0
8712 1	3	86	0	0	0	0	-21	-155	38	0	0
88 1 1	23	52	0	0	0	0	-16	-164	32	0	0
88 2 1	0	71	0	0	0	0	-17	-219	32	0	0
88 3 1	0	61	0	0	0	0	-18	-258	32	0	0
88 4 1	0	69	0	0	0	0	-8	-320	0	0	0
88 5 1	6	32	0	0	0	0	-8	-337	0	0	0
88 6 1	3	25	0	0	0	0	-9	-349	0	0	0
88 7 1	132	55	0	0	0	0	3	-272	0	0	0
88 8 1	266	97	2	0	0	0	30	-131	0	0	0
88 9 1	254	101	0	0	0	0	57	-23	0	0	0
8810 1	80	89	0	0	0	0	1	-35	0	0	0
8811 1	18	121	0	0	0	0	-4	-135	0	0	0
8812 1	5	85	0	0	0	0	-22	-191	38	0	0
89 1 1	0	47	0	0	0	0	-18	-216	32	0	0
89 2 1	0	61	0	0	0	0	-18	-259	32	0	0
89 3 1	0	51	0	0	0	0	-18	-289	32	0	0
89 4 1	13	73	0	0	0	0	-8	-339	0	0	0
89 5 1	0	25	0	0	0	0	-8	-357	0	0	0

allocation of fields a run was taken with the head end canal supplying about 10% of the actual demand of fields. The field no. 2 & 3 were given highest priority followed by fields 4 & 5 and finally the field no. 6 (refer Fig.No.3). The shortage factors introduced as input are such that fields 2 & 3 get 60% of their actual demand while other fields get 50% of their actual demand. The schedule of irrigations were obtained from the simulation runs. It has been observed that first only field No.2 & 3 get water of 42 mm each (60% of actual demand) and then fields 4 & 5 get 35 mm water (50% of actual demand) which is followed by the irrigation of the last field no.6 which also gets 35 mm water (50% of demand). The next round of irrigation starts 228 days after beginning of simulation and similar kind of cycle follows.

The overall water balance figures were also computed for the period of simulation. As can be seen that due to shortage of water irrigation amounts have been reduced as compared to reference run. As can be observed from Table 14, the drain flow during the entire period has reduced to 677 mm as compared to 758 mm observed in the reference run. However, large water balance error has been observed in the initial months of simulation. A representation of moisture status of uz columns at three different locations (first column of field no.2, 3rd column of field no. 4 and last column of field no.6) is shown in Fig. 21 which shows spatial distribution of soil moisture over the entire area during simulation period. A comparison of figures 20 and 21 indicates less effects on water table conditions in this simulation exercise as a result of shortage in application of water. The impacts are more pronounced in case of driest fields as evident by water table positions in the later part of simulation. It is observed from this simulation run that due to relatively less moisture in the root zone, the water table positions

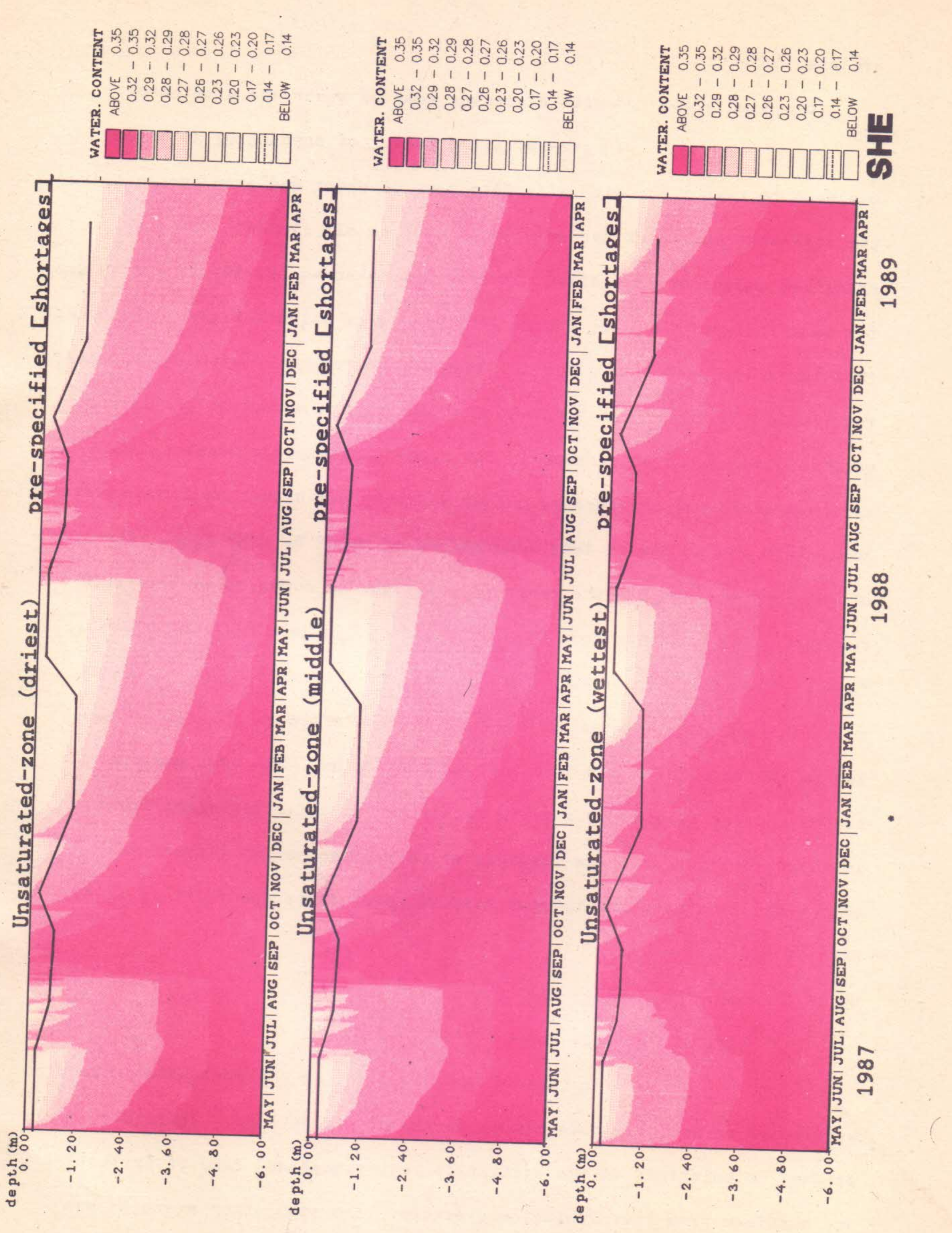


FIG. 21 : WATER DISTRIBUTION PROFILES OF THREE FIELDS (SCALE III, PRE-SPECIFIED, SHORTAGES AND PRIORITY ALLOCATION)

are also affected.

(c) Simulation run with alternate rows of wheat and gram crops

In pre-specified policy of scheduling an attempt was made to take a run with alternate rows of wheat and gram crops unlike the reference run which had only wheat crop in all fields. The pre-specified amount of irrigation for gram was taken as 60, 50, 50 and 50 mms for four irrigations. The change in total water balance figures throughout the simulation period is given in Table 15. As compared with the reference run (Table 13), it can be observed that though the amount of irrigation water applied has been reduced in the present simulation however, the moisture status of unsaturated column was observed better than the reference run. This may be due to less consumption of water by gram crop. The loss of water by evaporation was comparatively less as compared to reference run during non-rainy period. During the period of simulation a drain flow of 794 mm was observed as against 758 mm observed in the reference run. The water balance error has been of same order in this simulation run as in the reference run in the initial months. The soil moisture status and the ground water table variations in three different fields is shown in Figure 22. As compared to the reference run (figure 20), this simulation resulted in less rise in water table specially in later part of the simulation.

B. Automatic Scheduling Policy

(a) Reference Run

In case of automatic policy the irrigation schedules were based on soil moisture status in the crop root zone. Therefore, precise calculations of the irrigation requirement and time of irrigation are obtained from the simulation exercise. The simulation exercise has yielded irrigation schedules and relatively more number of irrigations as

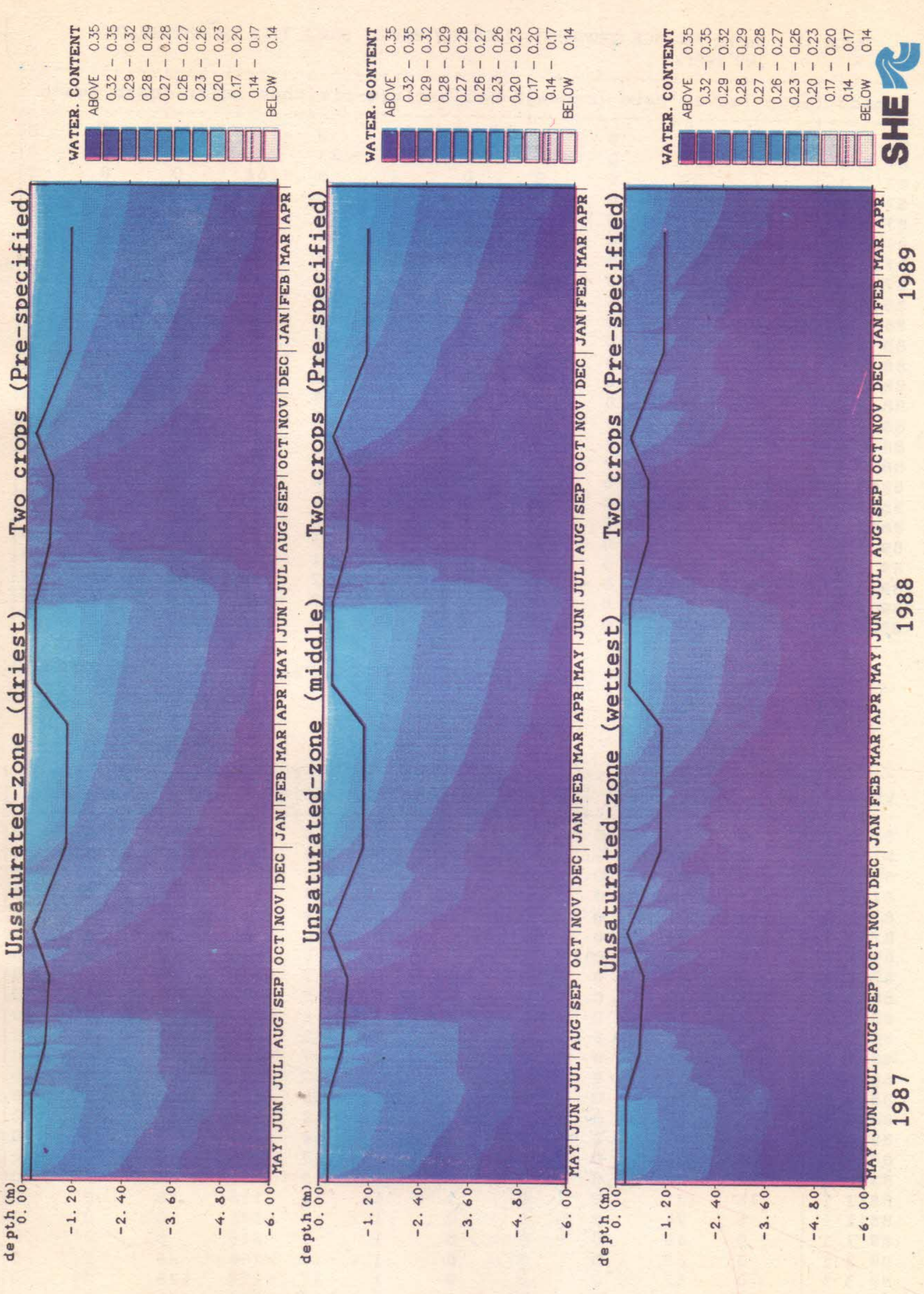


FIG. 22 : WATER DISTRIBUTION PROFILES OF THREE FIELDS (SCALE III, PRE-SPECIFIED, TWO CROPS)

TABLE 15 : WATER BALANCE COMPONENTS (MONTHLY BASIS, SCALE III, PRE-SPECIFIED, TWO CROPS)

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-150	0	0	0
87 6 1	4	107	0	0	0	1	-123	-241	0	0	0
87 7 1	7	39	0	0	0	1	-9	-264	0	0	0
87 8 1	134	96	0	0	0	1	-5	-222	0	0	0
87 9 1	541	101	0	0	0	1	270	-44	0	0	0
8710 1	139	89	0	0	0	1	67	-35	0	0	0
8711 1	69	121	0	0	0	1	7	-96	0	0	0
8712 1	3	77	0	0	0	1	-23	-145	66	0	0
88 1 1	23	51	0	0	0	1	-20	-151	56	0	0
88 2 1	0	71	0	0	0	1	-20	-202	56	0	0
88 3 1	0	67	0	0	0	1	-21	-245	56	0	0
88 4 1	0	61	0	0	0	1	-9	-299	0	0	0
88 5 1	6	41	0	0	0	1	-9	-325	0	0	0
88 6 1	3	29	0	0	0	1	-9	-340	0	0	0
88 7 1	132	56	0	0	0	1	2	-265	0	0	0
88 8 1	266	97	2	0	0	1	29	-122	0	0	0
88 9 1	254	101	0	0	0	1	59	-14	0	0	0
8810 1	80	89	0	0	0	1	2	-26	0	0	0
8811 1	18	121	0	0	0	1	-5	-126	0	0	0
8812 1	5	74	0	0	0	1	-23	-171	66	0	0
89 1 1	0	48	0	0	0	1	-21	-193	56	0	0
89 2 1	0	66	0	0	0	1	-21	-239	56	0	0
89 3 1	0	58	0	0	0	1	-22	-274	56	0	0
89 4 1	13	66	0	0	0	1	-9	-316	0	0	0
89 5 1	0	34	0	0	0	1	-9	-342	0	0	0

TABLE 16 : WATER BALANCE COMPONENTS (MONTHLY BASIS, SCALE III, AUTOMATIC, REFERECE).

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-150	0	0	0
87 6 1	4	118	0	0	0	1	-142	-233	42	0	0
87 7 1	7	50	0	0	0	1	-20	-255	29	0	0
87 8 1	134	96	0	0	0	1	-4	-214	0	0	0
87 9 1	541	101	0	0	0	1	274	-41	0	0	0
8710 1	139	89	0	0	0	1	70	-35	0	0	0
8711 1	69	121	0	0	0	1	6	-95	0	0	0
8712 1	3	75	0	0	0	1	-7	-159	0	0	0
88 1 1	23	51	0	0	0	1	-8	-177	0	0	0
88 2 1	0	72	0	0	0	1	-8	-241	0	0	0
88 3 1	0	62	0	0	0	1	-35	-264	98	0	0
88 4 1	0	82	0	0	0	1	-67	-280	192	0	0
88 5 1	6	87	0	0	0	1	-60	-294	207	0	0
88 6 1	3	76	0	0	0	1	-58	-311	142	0	0
88 7 1	132	72	0	0	0	1	-12	-233	37	0	0
88 8 1	266	97	2	0	0	1	44	-107	0	0	0
88 9 1	254	101	0	0	0	1	67	-3	0	0	0
8810 1	80	89	0	0	0	1	3	-17	0	0	0
8811 1	18	121	0	0	0	1	-4	-118	0	0	0
8812 1	5	74	0	0	0	1	-8	-178	0	0	0
89 1 1	0	49	0	0	0	1	-9	-215	0	0	0
89 2 1	0	65	0	0	0	1	-16	-266	26	0	0
89 3 1	0	57	0	0	0	1	-47	-274	128	0	0
89 4 1	13	88	0	0	0	1	-59	-286	165	0	0
89 5 1	0	82	0	0	0	1	-61	-301	210	0	0

compared with pre-specified irrigation. Since the input file of vegetation parameters has listed values for the entire year, irrigation schedules for the whole year have been obtained which are mainly for non-rainy months.

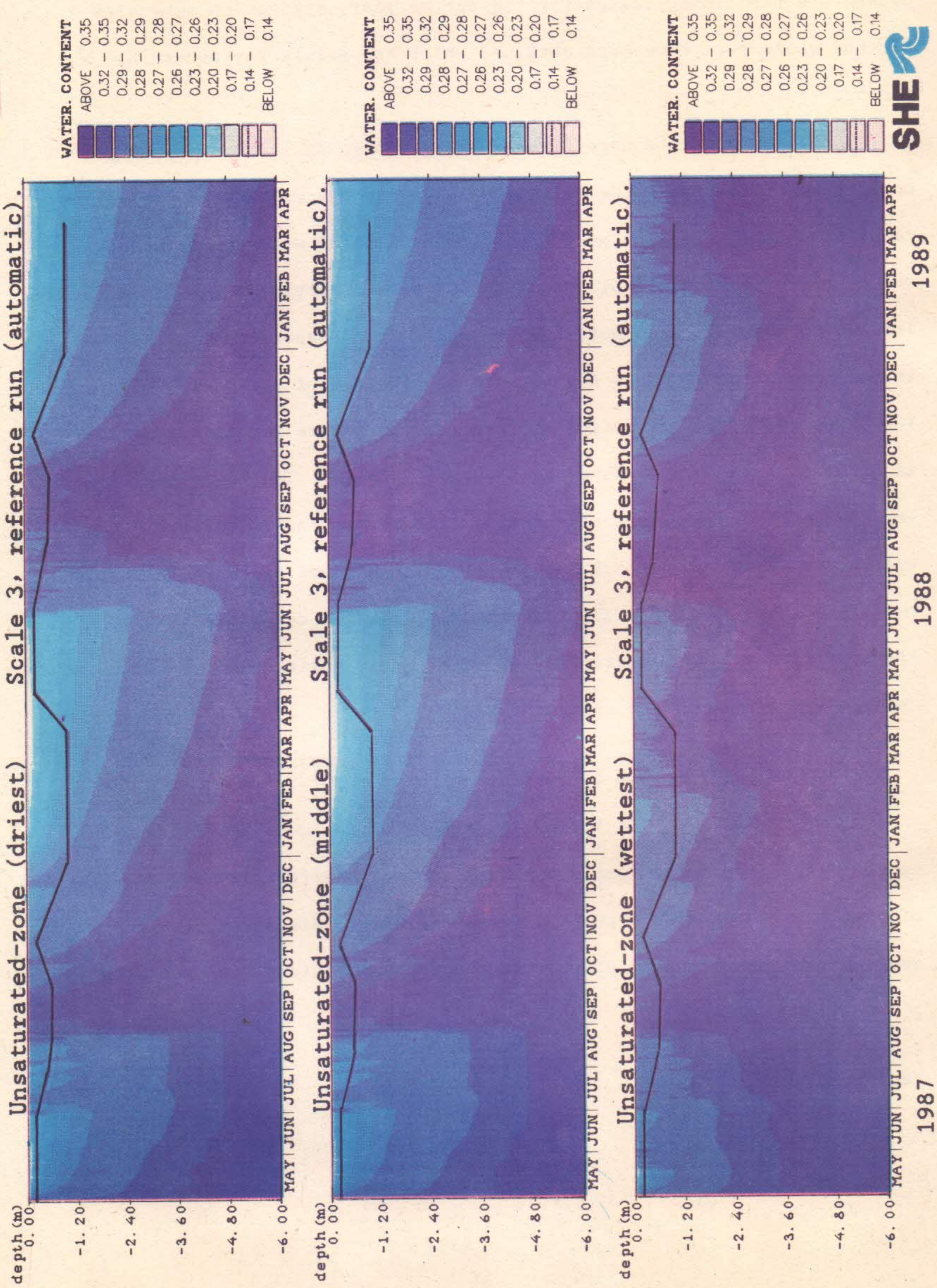
The water balance figures are given in Table 16. Due to non-occurrence of rainfall, the simulation exercise has calculated irrigation requirement for non-rainy period also. As compared with the reference run of pre-specified policy more flow has been observed in the drain during irrigation season. Also more loss of water from evaporation is experienced in the simulation which is due to more application of irrigation water. The total amount of irrigation applied for the entire simulation period is equal to 1276 mm and the drain flow was 1089 mm. In the initial months large water balance errors were found. The variations in soil moisture status and water table positions in three plots (same as taken for earlier runs) are shown in figure 23. As compared with the reference run of pre-specified policy (figure 20) the water table position shows large changes especially in the wettest field.

(b) Simulation Run with short water supply and priority allocation to fields

The Scale III simulation included provision of cutting short the water supply to fields as per availability and assignment of priority as per crop type in different fields. Accordingly, a run was taken with assignment of shortage factors and priority as per details given below :

Field No. 3 (Reference Fig.)	Priority	Shortage factor (%)
2	1	60
3	1	60
4	2	50
5	2	50
6	3	50

FIG. 23 : WATER DISTRIBUTION PROFILES OF THREE FIELDS (SCALE III, AUTOMATIC, REFERENCE)



The above input information indicates that fields 2 & 3 have highest priority followed by fields 4 & 5 and lastly field no.6. The shortage factor of 60% indicates providing 60% of irrigation demand to the fields. The simulation results indicated that due to introduction of shortage factors, less amount of water has been applied to the fields as can be seen in Table 17. While in the reference run 1276 mm of irrigation water was applied, in the present run only 843 mm was applied. As a result the moisture status of unsaturated zone was poorer than the reference run. Due to less application of water the evaporation loss also got reduced as in reference run the total evaporation loss was 1975 mm which reduced to 1942 mm in the present run. The status of unsaturated column of soil moisture representing three different fields is shown in figure 24.

(c) Sensitivity Run with alternate rows of wheat and gram crops

In order to see the effects of changed crop type on scheduling of irrigation a run was taken with alternate rows of wheat and gram crops. The overall water balance figures are given in Table 18. As compared with the reference run, the amount of irrigation water is relatively less in this simulation which is due to introduction of less water consuming crops in two fields out of five fields. As a result of less water application, less flow in the drain was recorded as compared to the reference run. As against 1089 mm total drain flow in the reference run, this run yielded a total drain flow of 1006 mm. Also less evaporation loss occurred during dry months compared to the reference run. Shortage factors were also introduced and as compared to the previous run, less amount of water was needed for irrigation owing to change in crop type in two fields from wheat to gram. This run computed a total irrigation

TABLE 17 : WATER BALANCE COMPONENTS (MONTHLY BASIS, SCALE III, AUTOMATIC, SHORTAGES & PRIORITY ALLOCATION).

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-150	0	0	0
87 6 1	4	118	0	0	0	0	-57	-232	23	0	0
87 7 1	7	50	0	0	0	0	-20	-253	15	0	0
87 8 1	134	96	0	0	0	0	-3	-214	0	0	0
87 9 1	541	101	0	0	0	0	273	-40	0	0	0
8710 1	139	89	0	0	0	0	75	-36	0	0	0
8711 1	69	121	0	0	0	0	7	-96	0	0	0
8712 1	3	75	0	0	0	0	-7	-160	0	0	0
88 1 1	23	51	0	0	0	0	-8	-179	0	0	0
88 2 1	0	72	0	0	0	0	-8	-243	0	0	0
88 3 1	0	60	0	0	0	0	-39	-260	64	0	0
88 4 1	0	76	0	0	0	0	-62	-275	139	0	0
88 5 1	6	80	0	0	0	0	-57	-291	119	0	0
88 6 1	3	70	0	0	0	0	-49	-307	70	0	0
88 7 1	132	71	0	0	0	0	-10	-235	21	0	0
88 8 1	266	97	2	0	0	0	46	-112	0	0	0
88 9 1	254	101	0	0	0	0	63	-7	0	0	0
8810 1	80	89	0	0	0	0	3	-19	0	0	0
8811 1	18	121	0	0	0	0	-4	-120	0	0	0
8812 1	5	73	0	0	0	0	-7	-181	0	0	0
89 1 1	0	49	0	0	0	0	-8	-218	0	0	0
89 2 1	0	65	0	0	0	0	-24	-260	29	0	0
89 3 1	0	53	0	0	0	0	-49	-262	97	0	0
89 4 1	13	84	0	0	0	0	-48	-280	115	0	0
89 5 1	0	80	0	0	0	0	-61	-295	122	0	0

TABLE 18 : WATER BALANCE COMPONENTS (MONTHLY BASIS), SCALE III, AUTOMATIC, TWO CROPS.

yymmdd	ac.p	ac.ep	csto	csnow	h-ovl	h-riv	q-riv	thuz	qirr	qszb	qocb
87 5 1	0	0	0	0	0	0	0	-150	0	0	0
87 6 1	4	116	0	0	0	1	-139	-234	23	0	0
87 7 1	7	48	0	0	0	1	-19	-257	16	0	0
87 8 1	134	96	0	0	0	1	-4	-216	0	0	0
87 9 1	541	101	0	0	0	1	273	-42	0	0	0
8710 1	139	89	0	0	0	1	72	-35	0	0	0
8711 1	69	121	0	0	0	1	6	-95	0	0	0
8712 1	3	75	0	0	0	1	-7	-159	0	0	0
88 1 1	23	50	0	0	0	1	-8	-175	0	0	0
88 2 1	0	71	0	0	0	1	-8	-238	0	0	0
88 3 1	0	63	0	0	0	1	-32	-267	51	0	0
88 4 1	0	73	0	0	0	1	-56	-282	131	0	0
88 5 1	6	73	0	0	0	1	-45	-304	119	0	0
88 6 1	3	62	0	0	0	1	-42	-321	72	0	0
88 7 1	132	68	0	0	0	1	-12	-244	29	0	0
88 8 1	266	97	2	0	0	1	42	-117	0	0	0
88 9 1	254	101	0	0	0	1	63	-10	0	0	0
8810 1	80	89	0	0	0	1	2	-22	0	0	0
8811 1	18	121	0	0	0	1	-4	-123	0	0	0
8812 1	5	73	0	0	0	1	-8	-182	0	0	0
89 1 1	0	47	0	0	0	1	-9	-217	0	0	0
89 2 1	0	65	0	0	0	1	-14	-269	8	0	0
89 3 1	0	56	0	0	0	1	-47	-278	96	0	0
89 4 1	13	80	0	0	0	1	-49	-291	111	0	0
89 5 1	0	69	0	0	0	1	-45	-315	122	0	0

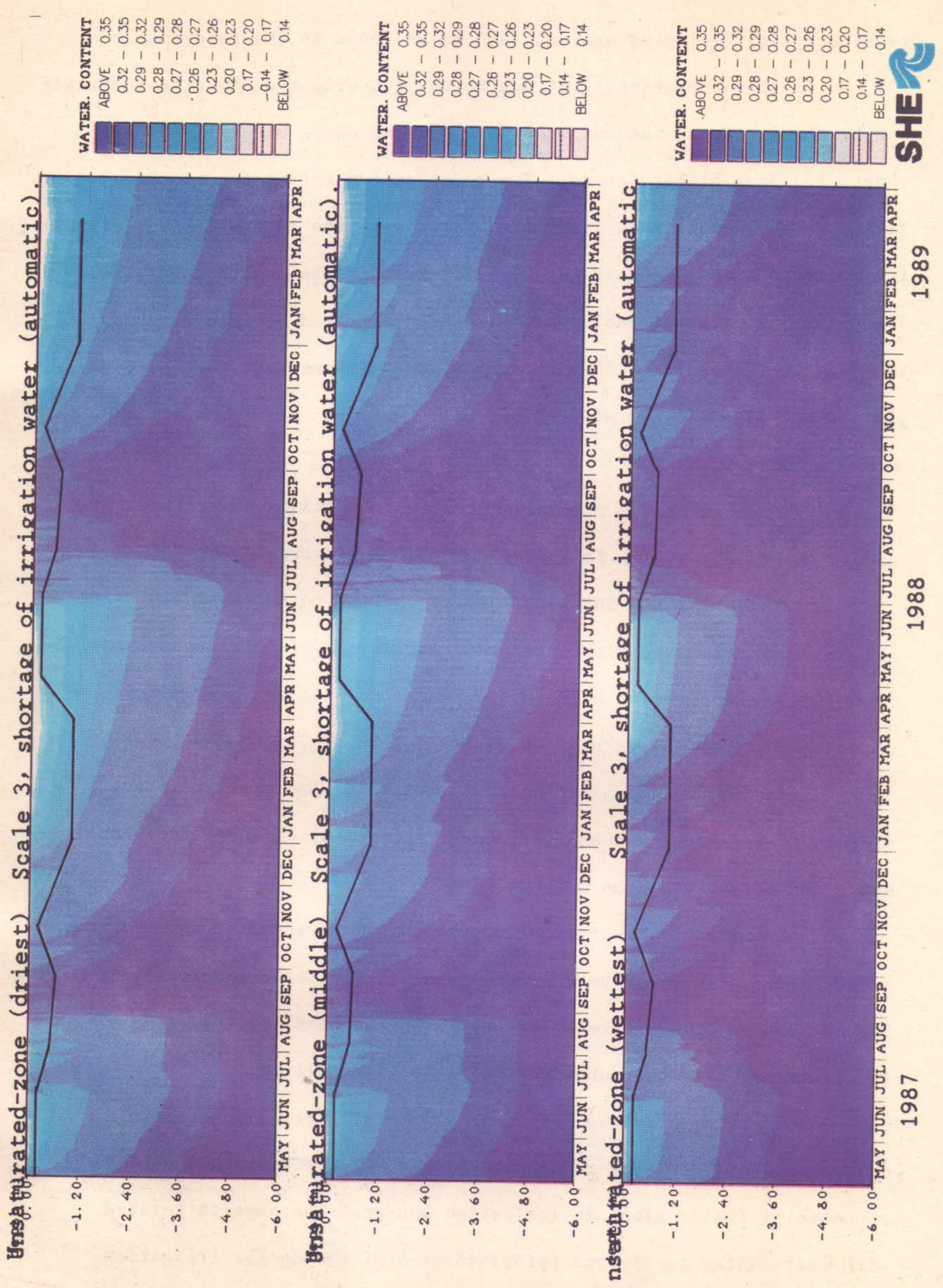


FIG. 24 : WATER DISTRIBUTION PROFILES OF THREE FIELDS (SCALE III, AUTOMATIC, SHORTAGES AND PRIORITY ALLOCATION)

requirement of 778 mm as against 1276 mm as found in the reference run.

It was observed that due to changed crop type to gram in fields 3 & 5, the irrigation amount have been reduced while other fields with wheat crop have higher demand. The moisture content status of three fields is shown in Figure 25. As compared with the reference run (Fig.23) the moisture status in this run was different in the unsaturated zone. The positions of water table have also been affected because of change in crops in two fields. This change is more prominent in case of driest plot of the field No.6 (refer figure 3).

6.0 CONCLUDING REMARKS

Based on the simulation studies carried out using irrigation module of SHE model, the following concluding remarks can be made :

i) The SHE model has capability to successfully model the processes involved with irrigation including moisture advancement front, vertical movement of moisture in the soil column and effects of changed vegetation parameters on irrigation requirements.

ii) The plot (Scale I) modelling has yielded effect of changed parameter values (soil and vegetation) on irrigation requirements and moisture status of root zone.

iii) The simulation of moisture advancement front in an irrigation field has been demonstrated in the field (Scale II) modelling The unevenness of moisture distribution at the head and tail ends of the field has also been observed in Scale II modelling.

iv) In case of Scale III (small irrigation system) an attempt has been made to introduce scheduling of irrigations for a number of fields along an irrigation source. The aspects related with short water supply and prioritisation of fields for irrigation have also been introduced in the field.

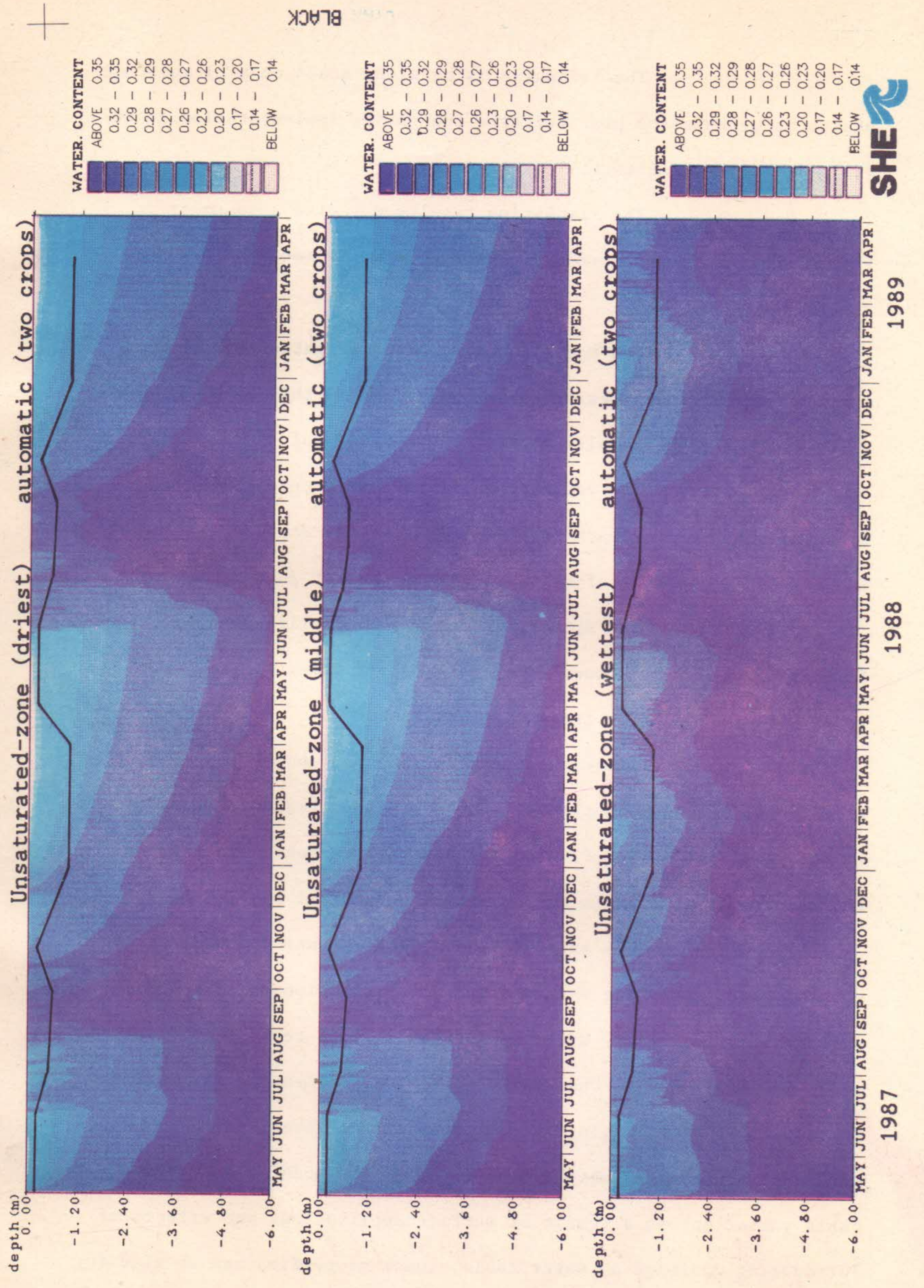


FIG. 25 : WATER DISTRIBUTION PROFILES OF THREE FIELDS (SCALE III, AUTOMATIC, TWO CROPS)

v) The irrigation scheduling based on soil moisture status is perhaps the best criteria though its implementation in the field is rather difficult.

vi) The simulation results may give assessment for return flow, however, further investigations are required for more accurate values.

vii) The modelling of entire irrigation system is a complex process and a beginning has been made in this study and three different scales of modelling have been carried out.

viii) The validation of simulation results is not possible since in the fields scheduling of irrigations is done on varying criteria and regular monitoring of moisture status in root zone is not done.

ix) The studies in Scale III modelling can be extended further to take into account the status of storages in irrigation reservoirs for deciding irrigation schedules.

x) Since the studies have been done for hypothetical situations, therefore application of results to real field conditions is not possible. However, with the use of more realistic field situations, the results of simulation can be used in practical applications.

xi) The extensive data requirements and need of sophisticated computing system are major limitations of SHE model applications. However, with the availability of resources, pilot studies using SHE model can be undertaken and major problems of irrigation command like water logging and drainage can be investigated in detail and remedial measures can be found. Since the model can simulate water table variations as a result of surface applications and effects of introducing drainage on water table, these properties can be used for addressing water logging and drainage problems.

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