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GROUND WATER SIMULATION FOR PLANNING SALINITY MANAGEMENT

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ABSTRACT

Secondary salinization due to rise in water table is a growing problem in parts of Sirsa and Hissar districts of Haryana. Projections of waterlogged area made through simulation studies indicated that of the total area of 49,0000 ha, 70 percent would reach critical water table level of less than 3.0 m, and nearly 280,000 ha (57% of the total areas would be completely waterlogged with water table within 1.0 m, by 2000 A.D. This calls for introduction of antiwaterlogging measures. The differential rate of rise in water table in different parts of the area provides scope for carrying out improvements over a period of time.

INTRODUCTION

Irrigation remains the most important means of overcoming the climatic constraints to increased and stabilized food production in arid and semi-arid regions. However, introduction of irrigation from imported water transported over long distances results in increased ground water accessions. In general, ground water in such areas is of poor quality and its exploitation for irrigation is on a limited scale. The increased ground water accessions disturb the dynamic equilibrium of the ground water hydraulic system with consequent development of waterlogging and salinity. Since build-up of water table is a phenomenon of insidous nature and occurs gradually, its visual effects are seen after the damage is already done.

Management strategies for prevention and control of waterlogging and salinity can be planned in advance if the forecast of conditions likely to prevail in future, is made. Ground water modelling, through simulation, is a valuable tool to predict water table behaviour and has been used by a number of workers to suggest appropriate management strategies (Ridder and Erez, 1977, Heidari,1982, Yazicigil and Rasheeduddin,1987). A detailed review of the state of art of ground water modelling is given in Prickett(1975) and (Gorelick,1983). Described herein is the application of Tyson and Weber model (1964) to a part of the Lower Ghaggar Basin (LGB) irrigated by Bhakra Canal System (BCS) in Haryana. Projections of ground water conditions have been used to estimate the area that is likely to go out of production as a result of waterlogging.

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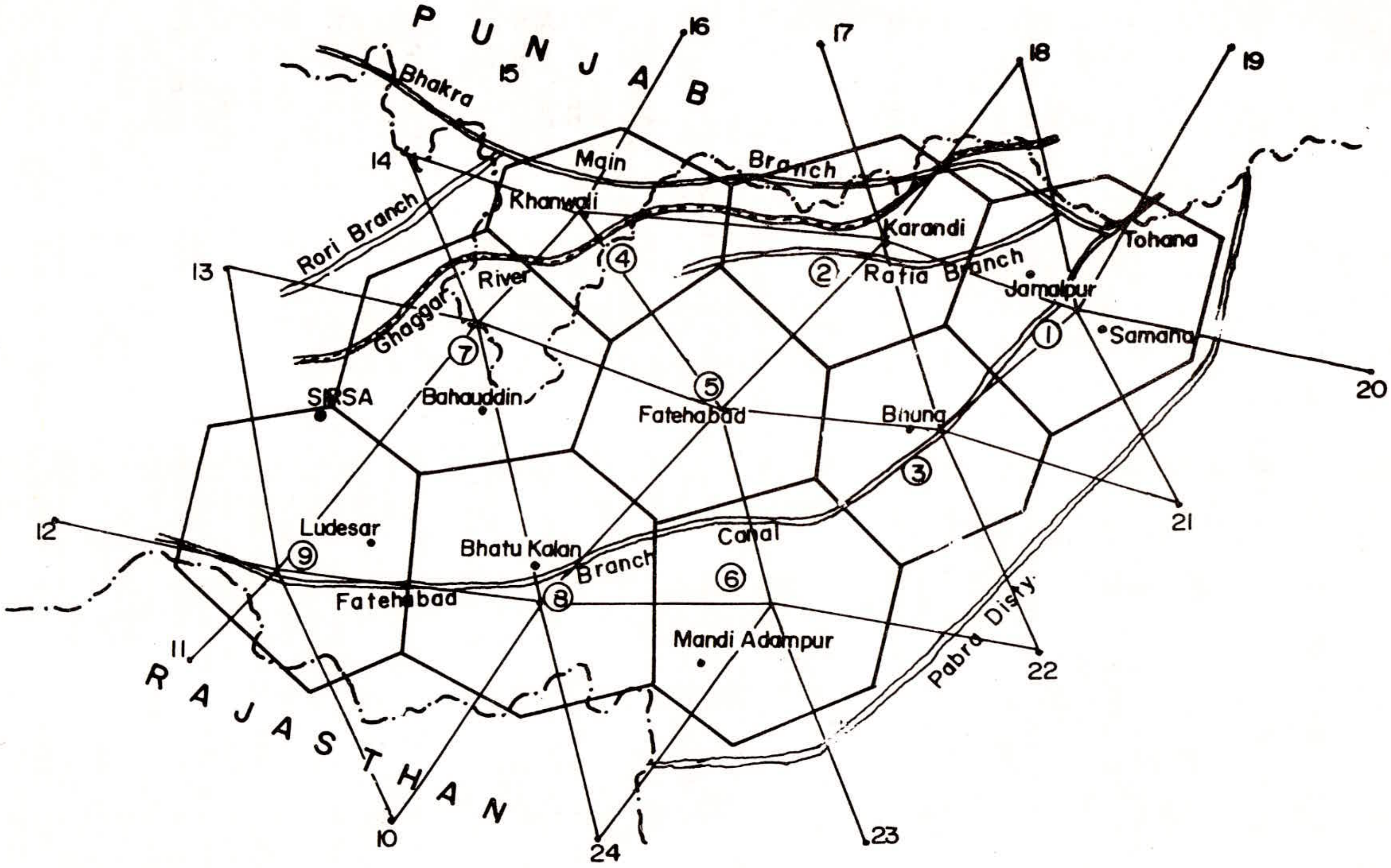

Fig.1. Asymmetric polygonal network of the project area.

Physiography

The study area, which is 5000 Sq/km. in extent, forms a part of the LGB and is covered by the districts of Sirsa and Hissar (Fig.1). It has a flat terrain with average gradient of 0.5 m/km. Part of the area is marked by the presence of sand dunes with steep slope. Ghaggar which originates from Morni Hills and flows from northeast to southwest direction is the only natural drainage channel. It is mostly influent in the study area. The average annual rainfall is between 300-400 mm whereas the potential evapotranspiration is between 1300-1600 mm.

Hydrogeology

Detailed hydrogeological investigations of the exploratory bore holes made by Haryana State Minor Irrigation Tubewell Corporation and Central Ground Water Board at 57 locations indicate that the basement rocks are at a depth of 200-300 m below ground water on the western side and at 270-330 m on the southern side. Thus the thickness of the alluvium decreases towards the southwest. Panel diagram prepared on the basis of available lithological logs and production tubewells upto a depth of 275 m suggests that the alluvial deposits were occuring in irregular shapes (Fig.2). Strata encountered has different grades of sand varying from medium to very fine sand along -with salt and impervious clay beds. The nature of the aquifer varies from unconfined to semi-confined with thickness ranging from 20 m to 150 m in a depth of 200 m. Western part of the area has transmissivity ranging from 43 m^2/day to 1200 m^2/day, but it increases in the central region upto 2900 m^2/day. The specific yield varies from 10-15 percent. Though the average specific capacity values are in the range of 200-400 lpm per meter of draw-down but in some cases the much lower values of the order of 45 lpm/meter draw-down have also been observed.

Water Quality

Except for the wells located near the canal or near the River Ghaggar, the ground waters have appreciable quantity of salt. The water has both, the salinity as well as the sodicity problem and the quality deteriorates with depth. The water quality data at different locations in the project area are given in Table 3. According to the classification followed by HSMITC the ground water recharge is 331 MCM in fresh water zone (EC-0-2 mmhos/cm) 399 MCM in marginally saline zone (EC,2-6 mmhos/cm) and 78 MCM in saline water zone (EC 6 mmho/cm respectively.

Irrigation

The area is irrigated by Bhakra canal system and a number of branch canals, distributaries, minors and subminers pass through the area. The total length of the primary and secondary water conveyance system is 1455 km of which 835km is lined. Of the total gross are of 440x10^3 ha in the irrigation command, the culturable command area is only 394x10^3 ha. The annual

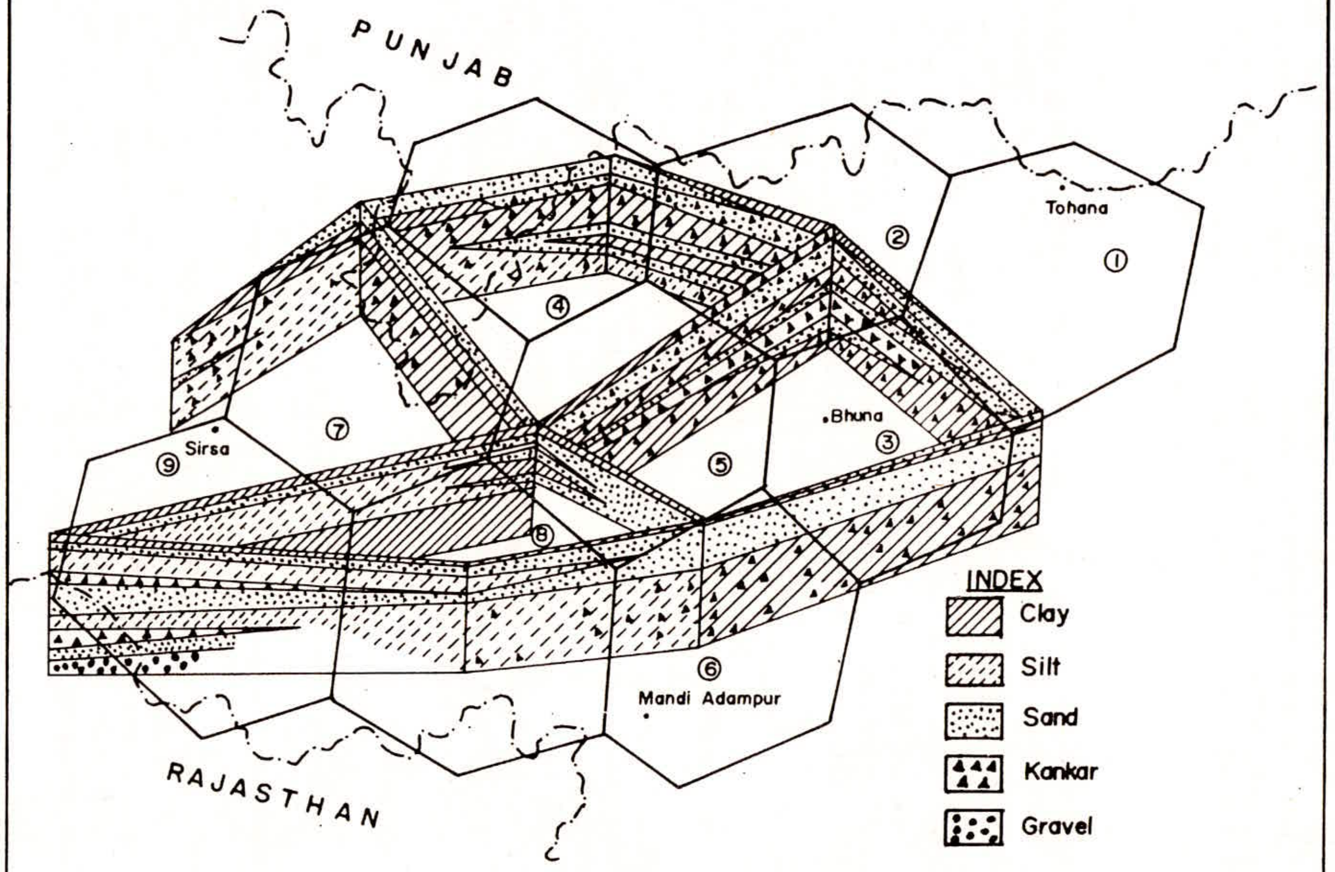

Fig. 2. Pannel diagram of the project area.

irrigation intensity is 70 percent with a water allowance of 1.0 m^3/sec., for every 5000 ha. Water supply being limited, it is distributed on rotational basis and only low, and medium duty crops like bajra,sorghum,maize, cotton, wheat, mustard and gram are grown in the area.

STATEMENT OF THE PROBLEM

Introduction of canal irrigation in the project area on a large scale around 1955 led to increased ground water accessions. Since, in most part of the area ground water is saline/ sodic and the aquifer formations are poor, adequate ground water development, to take care of the increased recharge, has not taken place. As a result water table has started rising at an alarming rate and by 1984-85, nearly 57×10^3 ha land had come in 0-3 m water table zone. This resulted in considerable loss of agricultural production. Since it is a growing problem, it is necessary to develop appropriate water resources management strategies to overcome this menace.

THE SIMULATION MODEL

The simulation model developed and used for a part of the LGB is essentially Tyson and Weber model(1963). It involves: construction of asymmetric polygon network, preparation of ground water basin parameters and input data and the verification.

Construction of Nodal Net Work

To discretize the ground water basin into nodal area, a network of polygons is super-imposed on it. Adopting guidelines in Boonstra and Ridder(1981), the area was divided into asymmetric grids by using Thiessen polygon method. In all, 24 nodes were constructed of which 9 were internal nodes (Fig.1). The number of sides in each polygon was 6 and the area of each polygon ranged between 412.5-622.5 Sq.km.

The most important and difficult problem is the definition of boundaries at the external nodes. There may be three types of boundaries including zero flow, flow controlled or head controlled. In the present case, the ground water basin is not an isolated one and its boundaries extend well beyond the study area. Based on the ground water simulation studies conducted by HSMITC for the whole of Haryana state(Anonymous,1984), the boundaries at the external nodes of the study area were identified as flow controlled.

MODEL INPUTS

The model inputs include

- Specific yield
- Recharge/discharge
- Ground surface and base of the unconfined aquifer above mean sea level.

- Aquifer thickness
- Hydraulic head

Hydraulic Conductivity(K)

Computation of flow across the boundaries of the nodal areas is based on weighted mean hydraulic conductivity values midway between all the nodes. Hydraulic conductivity values have been determined at 52 locations through pump test of the exploratory tubewells and were used to plot isoconductivity contours or isoperms. Hydraulic conductivity on the side of nodal area, has been arrived at by interpolation or by taking weighted mean two or more isoperms crossed as side. The value of K varied from 13 m/day to 20.0 m/day at different nodes (Table 1).

Specific Yield

In unconfined aquifers the calculation of change in storage of ground water requires representative values of specific yield at each nodal point. The values of specific yield were again computed from pump test at 52 locations. The observed values ranged from 10 to 12 percent (Table 1).

Hydraulic Head

Hydraulic head at all the nodal points is required to compute ground water flow from one nodal area to another. For these calculations only initial hydraulic heads are required which were found by super-imposing the network on the watertable contour map for $t = 0$, in the beginning of the historical period that has been taken as June,1978. Representative values of the hydraulic head have been calculated for each node by interpolation. During the calibration process, to test the validity of the model, nodal hydraulic heads generated by the model were compared with these historic hydraulic heads.

Ground Water Recharge

Seepage losses from irrigation conveyance and distribution system, losses in field application, influent from the River Ghaggar and seasonal rainfall are the source of recharge.

Computation of seepage losses was based on hydraulic data, number of running days of the irrigation channels and the seepage loss coefficient. The value of seepage loss coefficient was taken as $2.44\ m^3/sec/10^6m^2$ for unlined and $0.61\ m^3/sec/10^6m^2$ for lined channels. Contribution from distribution and application losses beyond the canal outlet was taken as 30-35 percent of the water diverted at the head of the water course outlet. Twenty percent of the rainfall was taken as ground water recharge as per norms adopted by NABARD.

Discharge

Ground water withdrawl through shallow and deep tubewells and evapotranspiration losses constitute the major

Table 1: Topographic,Hydroleologic,and Water Quality Data for Different Polygons in the Project Area

Item	POLYGON								
Area of Polygon (sq.Km.)	581.3	531.35	443.8	412.5	512.5	525.0	568.8	662.5	662.5
Ground surface elevatation (m, above msl)	226.8	219.2	216.6	209.3	210.6	211.0	202.7	207.1	198.7
Base of unconfined aquifer (m, above msl)	146.7	100.0	125.0	109.8	106.8	124.7	113.9	133.2	146.1
Permeability(m/day)	14.5	16.4	13.6	20.0	18.8	13.7	19.2	13.8	14.1
Specific yield(%)	12.0	11.0	10.0	12.0	10.0	10.0	11.0	10.0	12.0

components of discharge. Polygon wise number of tubewells, the running hours and the average discharge of a tubewell were used to compute the water withdrawal. To account for return flow, only 70 percent of the ground water withdrawal was taken as net draft.

The potential evapotranspiration lossess in each polygon were computed by using Penman method. The overall hydraulic balance was assessed from the recharge and discharge values of each polygon.

CALIBRATION OF THE MODEL

Using the computer programme available at Regional Computer Centre, Chandigarh, the model was calibrated with the input data from June 1978 to June,1984. For this calibration, the relaxation factor was taken 0.80 and the allowable error as 0.5 MCM/year. The delta time (Δt) was one month. It was assumed that no appreciable evaporation from ground water took place if the water table were below 0.80 m.

The computer output showed that initially the value of hydraulic head generated by the computer did not match with the historic hydraulic heads. This required adjustments in the value of specific yield, transmissivity and in certain cases the recharge initially, the values of specific yield in all polygons were in the range of 10-12.5 percent. These had to be adjusted upward and the final values adopted ranged between 12.51 to 15.01 percent. Some changes were also made in the recharge values. The predicted and historic hydraulic heads for the period of calibration are given in Table 2. It is seen that values match within the accepted limits of error.

MODEL APPLICATION

The calibrated model was used for forecasting the water table behaviour on monthly basis from 1984-2000 A.D. The water-table levels during June and October were used to compute extent of area under different water table ranges. The estimates of probable losses in production and farm income were made from the extent of area affected by waterlogging and salinity.

Water Table Behaviour

Though the model predicted monthly water tables, but only values for the months of June and October have used. It is seen (Fig.3) that in all the polygons the water table had a rising trend though the rate of rise was higher in polygons 4,5,6, 7 and 8 and relatively lower in polygons 1 and 2 and 9. When the average water table reaches within 1-2 m of ground surface, part of the area would face submergence conditions. Polygon 4 reached static water table (beyond which there was no increase in 1986-87, polygons 3,5 and 8 in 89-90 and 5,6 in 1992-93 and 1 and 2 in 1999-2000 A.D. It may be added that when water

Table:2 Observed and Predicted Hydraulic Heads (m, above msl) for the month of June (Model Calibration)

Node	1978-79	1979-80	1980-81	1981-82	1982-83	1983-84
1.	217.5	218.3 (217.7)*	218.6 (218.8)	218.7 (219.6)	218.8 (219.8)	219.1 (219.8)
2.	212.4	212.5 (212.9)	213.1 (213.1)	213.1 (213.4)	212.9 (213.4)	213.1 (213.3)
3.	204.4	205.6 (205.0)	205.6 (205.6)	207.7 (207.3)	208.7 (208.2)	209.6 (209.3)
4.	203.2	204.4 (204.5)	205.4 (204.9)	206.5 (205.7)	206.6 (206.1)	206.5 (206.3)
5.	198.4	199.6 (199.2)	200.4 (199.9)	201.3 (200.2)	202.1 (201.9)	202.8 (202.7)
6.	193.9	195.1 (194.7)	196.1 (195.5)	197.3 (196.3)	198.4 (196.9)	199.5 (197.3)
7.	185.9	196.8 (186.2)	187.8 (187.3)	189.1 (188.1)	190.0 (189.0)	190.7 (189.7)
8.	196.5	197.6 (197.1)	198.4 (198.0)	199.1 (198.8)	200.0 (199.5)	200.9 (199.9)
9.	198.7	184.6 (184.0)	185.4 (185.3)	186.3 (186.8)	187.2 (187.2)	188.9 (187.9)

*Values in paranthesis are observed values.

Table:3 Ground Water Salinity (dS/m) in different parts of the projects areas

Polygon	Open wells		Shallow tubewell		Deep tubewell	
	Range	Average	Range	Average	Range	Average
1	0.4-3.8	2.3	0.5-17.3	2.2	0.2-5.2	1.0
2	0.5-17.3	1.9	0.0-2.9	2.3	0.2-5.2	1.0
3	1.1-11.0	3.4	0.5-11.8	3.5	1.8-29.0	8.1
4	0.5-3.9	1.6	0.3-12.0	2.6	0.4-15.0	4.1
5	0.3-6.7	4.0	0.5-10.0	3.2	2.6-20.3	10.3
6	0.5-11.0	1.8	0.3-11.0	2.6	0.9-13.9	3.4
7	1.1-3.9	1.6	0.3-12.0	2.6		
8	0.5-11.0	1.8	0.3-11.0	2.0	0.8-13.9	3.4
9	0.6-4.7	1.5	0.5-5.6	2.6	0.5-7.0	1.8

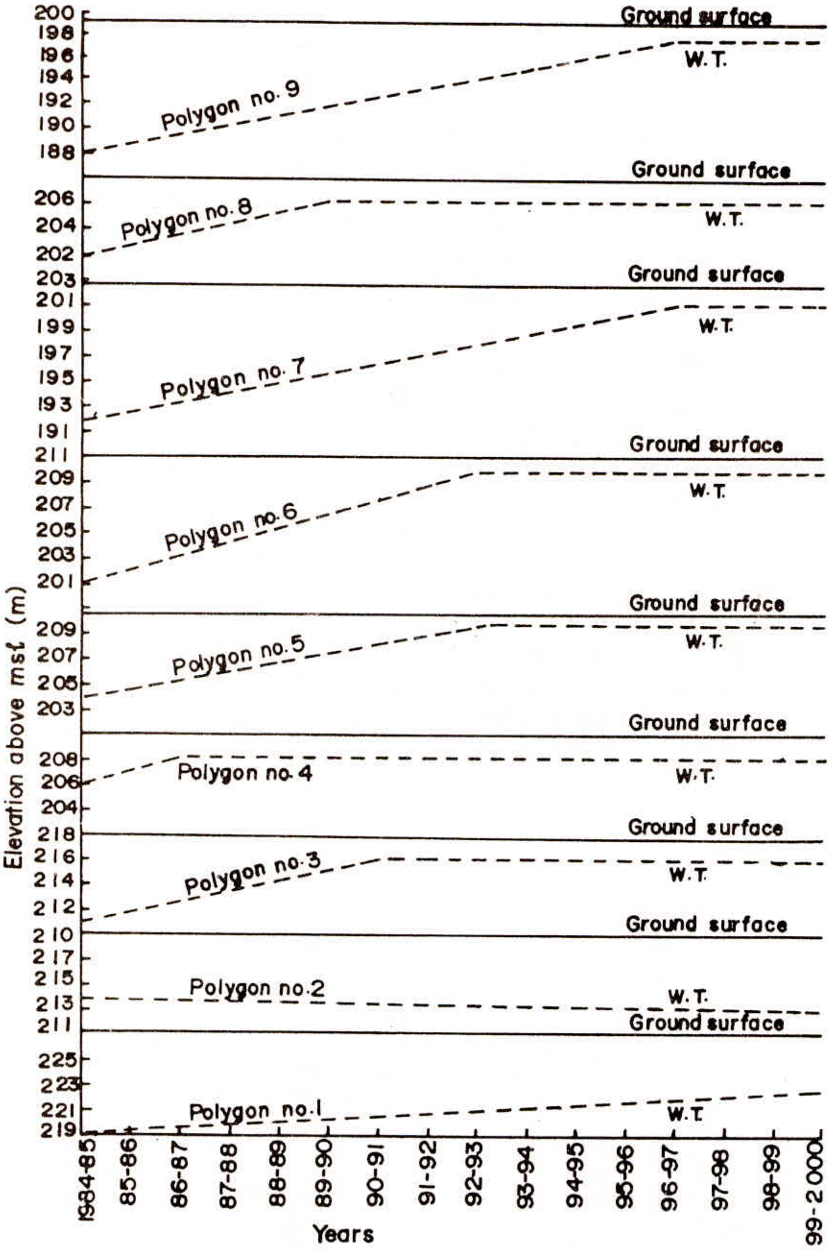

Fig. 3. Projected water table elevations in the project area (m above msl)

table comes within 0.30 to 0.50 m of the ground surface, it contributes significantly to evapotranspiration losses. With the result, that except for depressional area where ground water may appear on the surface, it remains within 0.30-0.50 m without any further rise. When such conditions occur in areas underlain by saline ground water, it leads to secondary salinisation.

Extent of Waterlogged Area

Depth to water table contours for the month of Jube in 2000 A.D. are shown in Fig.4. Such contours were prepared for the years 1984-85, 1989-90, 1994-95 and 1999-2000 A.D. Computing area under different water table levels, the area to be affected by high water table conditions, was worked out and is given in Table 4. It is seen polygons 4,7 and 8 will have almost 100 percent area with water table of less 1.0 m by 2000 A.D. On the other hand only 20-25% area will be affected in polygons 1 and 2. The ground water quality in polygons 1 and 2 is relatively good. This has helped in higher ground development in these areas. For example, ground water withdrawal in polygons 4 and 8, where water table has risen at a faster rate, is only 392 and 119 m^3/ha/year, as compared to 1012 and 1275 m^3/ha/year in polygons 1 and 2. Of the total project area of 49,0000 ha by 2000 A.D., the area within 1m and 3 m depth to water table contour will be 28,0000 ha (57%) and 344000(70%), respectively. Since the area is underlain by saline aquifers, waterlogged area will turn saline, as part of it has already become, resulting in loss of agricultural production. Estimates prepared by Gangwar and Van-Den Toorn(1987), show that in monetary terms in 2000 A.D., the losses will Rs. 84/ha, 254/ha and 641/ha in waterlogged areas underlain by aquifers of fresh,marginal and saline nature, respectively.

SALINITY CONTROL

The rise in water table and the consequent secondary salinisation occurs due to increased ground water accessions. It is therefore, reasonable to assume that the problem can be minimized by reducing sub-surface return flows which contribute to ground water recharge at various stages of irrigation and consequent build-up of water table in saline aquifers. The management strategies for minimizing sub-surface flows generally include: improved water conveyance through lining of the secondary and tertiary conveyance and distribution system and efficient on-farm water management achieved through a series of improvements such as proper irrigation scheduling, land levelling and introduction of advanced methods of water application. Proper ground water management in the form of selective pumping through skimming wells, and evacuation of highly saline ground water out of the system may be necessary in same cases. Mathematical programming approach may be useful in arriving at the optimal level of different management options listed above. Multiobjective linear programming models were developed and applied to this area by Tyagi(1986). The optimal mix of management strategies for reducing irrigation return flow by 70 percent included: (1) 46% reduction by improved surface water

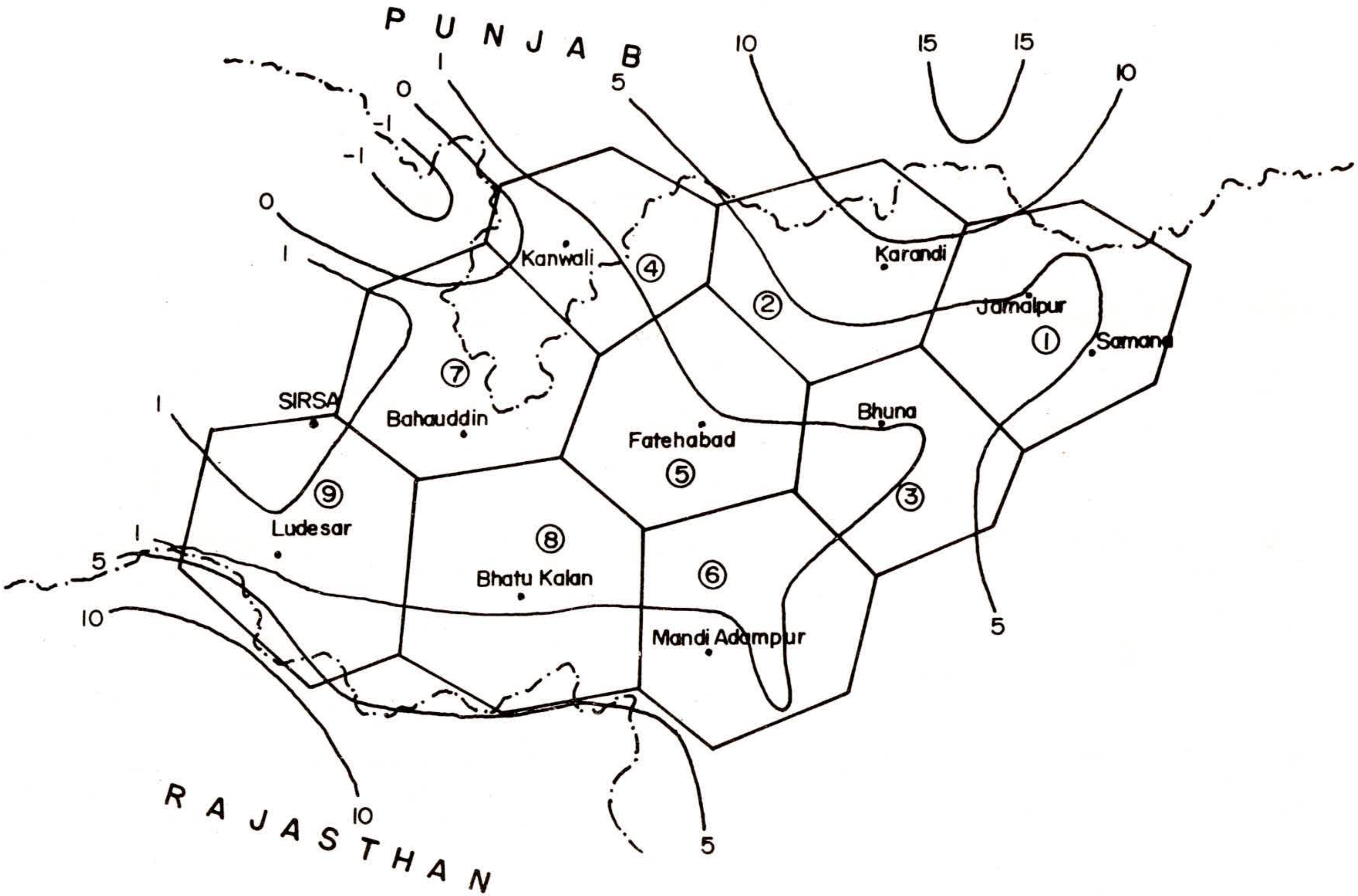

Fig.4. Depth to water table contour in June 2000 A.D.

Table: 4 Areas Having Water Table within 1.0 m and 3.0 m of Ground Surface in Different Polygons During June (1000 ha).

Year	Polygons								
	1	2	3	4	5	6	7	8	9
1984-85	$\frac{\text{Nil}}{2.30^*}$	$\frac{\text{Nil}}{7.44}$	$\frac{\text{Nil}}{3.11}$	$\frac{4.95}{16.50}$	$\frac{2.05}{15.38}$	$\frac{\text{Nil}}{\text{Nil}}$	$\frac{1.71}{5.12}$	$\frac{2.98}{6.96}$	$\frac{\text{Nil}}{\text{Nil}}$
1989-90	$\frac{\text{Nil}}{9.69}$	$\frac{4.43}{13.28}$	$\frac{4.34}{12.5}$	$\frac{14.44}{33.00}$	$\frac{12.81}{28.55}$	$\frac{4.20}{14.18}$	$\frac{7.95}{28.4}$	$\frac{7.95}{17.09}$	$\frac{\text{Nil}}{\text{Nil}}$
1994-95	$\frac{8.72}{20.34}$	$\frac{4.40}{13.28}$	$\frac{14.20}{31.06}$	$\frac{41.25}{41.25}$	$\frac{26.63}{35.88}$	$\frac{23.63}{48.83}$	$\frac{37.00}{58.88}$	$\frac{33.13}{66.25}$	$\frac{0.5}{3.1}$
1999-2000	$\frac{11.63}{24.99}$	$\frac{4.40}{13.26}$	$\frac{33.28}{44.38}$	$\frac{41.25}{41.25}$	$\frac{35.88}{43.56}$	$\frac{49.88}{52.50}$	$\frac{56.81}{56.81}$	$\frac{66.25}{66.25}$	$\frac{2.0}{6.0}$
Percent of polygon area in 1990-2000	$\frac{20.0}{43.0}$	$\frac{08.0}{25.0}$	$\frac{75.0}{100.0}$	$\frac{100.0}{100\ .0}$	$\frac{70.0}{85.0}$	$\frac{95.0}{100.0}$	$\frac{100.0}{100.0}$	$\frac{100.0}{100.0}$	$\frac{15.0}{45.0}$

*Values in denominator are areas having watertable within 3.0 m of ground surface application methods (2) 28% by ground water pumping through shallow tubewells from fresh and marginally saline ground waters (3) 14% by linning of primary and secondary conveyance system and (4) 12% by introduction of a combination of sprinkler and surface irrigation system. These improvements are likely to cost considerable amount of money which may not be available at a time. The information on rise of water table developed through simulation of ground water aquifer may be used with advantage in preparing an investment schedule to suit the available finances.

SUMMARY

In large irrigation projects, substantial increase in ground water accessions in inevitable. Increased accessions, if not controlled in time, lead to secondary salinization in areas underlain by saline aquifers. Ground water modelling through simulation can aid in planning appropriate management strategies.

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

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