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A Semidiscrete Model for Water and Solute Movement in Tile-Drained Soils
2. Field Validation and Applications

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An exact-in-time two-dimensional finite element model for simulating convective-dispersive solute transport in a tile-drained field is validated against observed data from a subsurface drainage experiment. The model is capable of predicting the long-term effects of different irrigation and drainage practices on the salt distribution in an artificially drained soil-aquifer system. The model was used to predict transient changes in the salinity of the soil, the shallow groundwater table, and the drain effluent. Results are also presented on the effects of imposing alternative drain spacing–depth combinations, initial groundwater salinities, solute distribution coefficients, and different types of layering of the aquifer, on the computed salinity distributions in the unsaturated zone, the groundwater, and the drain effluent.

INTRODUCTION

Waterlogging and the often associated problems of soil and groundwater salinity in arid and semiarid areas are generally very slow to develop or correct. Traditionally, these problems are solved by installing a subsurface drainage system for collecting and removing drainage water. Since the disposal of saline drainage water poses serious environmental hazards, much emphasis is being given to improved management of on-farm irrigation as a cost-effective method of minimizing the volume of drainage water and its dissolved constituents [*Suarez*, 1989; *Tanji*, 1990]. Unfortunately, drainage measures are generally location specific, and it is often impossible or too cumbersome to experimentally evaluate the long-term field performance of different drainage designs under alternative irrigation management practices. This problem has motivated the development of predictive tools in the form of numerical models designed to simulate water and solute transport in soil-aquifer systems.

Part 1 [*Kamra et al.*, this issue] of this study describes a semidiscrete model for simulating two-dimensional solute transport in a tile-drained soil-aquifer system during steady water flow. The exact-in-time numerical solution yields explicit expressions for the solute concentration as a function of time. The input data requirements of the model include several drainage system parameters. (such as drain depth, drain spacing, and radius of the drain), aquifer parameters (porosity and hydraulic conductivity of the aquifer material, depth to impervious layer, and groundwater salinity), soil parameters (notably the soil water retention and unsaturated hydraulic conductivity functions, and initial soil salinity), solute adsorption parameters (the equilibrium distribution coefficients of the saturated and unsaturated zones), and inflow parameters (rainfall, evapotranspiration, quantity and quality of irrigation water). The model is designed to study the sensitivity of the distribution and movement of water and salts in a tile-drained soil to changes in the above irrigation and drainage input and system parameters. In addition, the model provides a tool for formulating management guidelines to control salinity buildup, and for evaluating the effectiveness of drainage systems.

This part 2 of the study presents a field validation of the model. We will use the model to make long-term predictions of the desalinization of a tile-drained soil, and of the associated changes in the quality of the groundwater and the drain effluent. In addition, the model will be used to study the long-term effects of different drain spacing–depth combinations, solute adsorption parameters, initial groundwater salinity, and aquifer layering on the salt distribution in the soil, groundwater, and drain effluent.

EXPERIMENTAL DRAINAGE FIELD

The two-dimensional solute transport model was validated against field data obtained from a subsurface tile drainage experiment carried out by the Central Soil Salinity Research Institute, Karnal, Haryana State, India, on its Saline Soil Research Farm near Sampla in the District of Rohtak, Haryana State. The drainage system was installed in the summer of 1984 in a 10 ha highly saline area. The experiment involved drain spacings of 25, 50, and 75 m at an average depth of 1.80 m. Each drain condition was replicated 3 times. The soil salinity of the surface 15 cm of soil in the study and adjoining areas ranged from 20 to 100 dS m^{-1}. Dissolved salts were mainly calcium, magnesium, and sodium chlorides. Before installation of the drains, the water table in the area typically fluctuated between a depth of 1.5 m (during the early summer) and the soil surface (during the rainy season in early fall). Salinity of the groundwater near the water table varied from 10 to 40 dS m^{-1}. Detailed information on the field experiments, and the design, installation, and performance of the subsurface drainage system, has been presented by *Rao et al.* [1986]. Figure 1 gives a schematic layout of the drainage system at the Sampla research facility.

The unsaturated soil hydraulic properties were represented by the functional forms of *van Genuchten* [1978] as given by (2)–(4) in part 1 [*Kamra et al.*, 1991]. The constants θ_r, θ_s, α, and n in these equations were found by least squares fitting of the functions to field-measured soil water retention data. The hydraulic properties corresponded to

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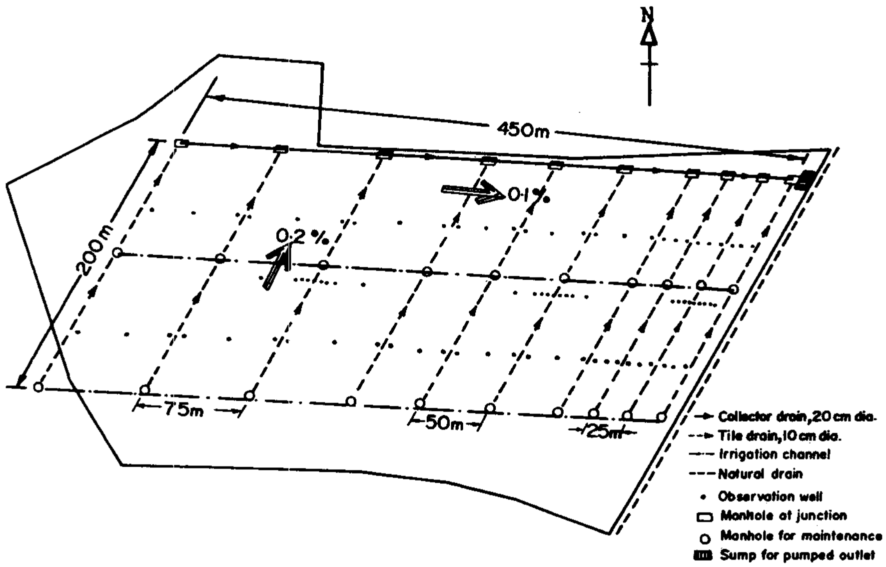

Fig. 1. Layout of the subsurface tile drainage system at Sampla.

those of a sandy loam soil having a saturated hydraulic conductivity of approximately 1.0 m/d. The values of selected hydraulic and drainage system parameters are listed in Table 1. Observed soil salinity profiles for the plots with the three drain spacings during the 1984–1985 study period are presented in Table 2. The table also gives the observed changes in salinity of the groundwater (EC_g) and the drain effluent (EC_d) during that same period. The observed water table hydrographs for the three plots during 1984 and 1985 are shown in Figure 2.

In order to compute the steady state water flux through the unsaturated zone, the year was divided into three parts: a monsoon or rainy period from July to September, a winter period from October to February, and a summer period from March to June. The steady downward flux of water during the monsoon and winter periods was computed by subtracting the estimated seepage from surrounding areas from the observed cumulative drain discharges and averaging the net result over the appropriate time period. The contribution of groundwater to evaporation and changes in the moisture status of the unsaturated zone was assumed to be negligible. Computation of the steady upward flux from the observed hydrographs in Figure 2 during the summer (March–June) requires a functional relationship between the upward flux and the depth of the water table. We used for this purpose an empirical relationship established experimentally by *Khosla et al.* [1980] for the sandy loam soils in the study area. These authors also determined the "critical" water table depth of these soils to be at approximately 80 cm below the soil surface (they defined this parameter as the water table depth at which the steady upward flux becomes less than 0.1 cm/d).

Table 3 presents the observed average seasonal drain discharge rates for the three drain spacings at Sampla [after *Rao et al.*, 1988]. These rates include the contributions from deep percolation due to excess rainfall or irrigation, and subsurface lateral seepage from the surrounding areas. Drain discharges from the 25-m drain-spacing plots were significantly higher than those from the other plots, probably because the 25-m drain-spacing plots were located at the lowest points in the area. Surface runoff and seepage from the surrounding areas must have significantly increased the volume of water drained from these plots. The water table hydrographs in Figure 2 show that the 25-m drain-spacing plots had slightly higher water table elevations than the 50- and 75-m drain-spacing plots during most of the year. This trend continued during the summer when there is no recharge from the soil surface, and suggests that relatively large amounts of seepage water entered the 25-m drain-spacing plots from the surrounding areas. The seasonal drain discharge rates given in Table 3, after correcting for the seepage contributions, were used to estimate the net steady water fluxes in the unsaturated zone. *Rao et al.* [1988] estimated the seepage rates (averaged over 1984–1988) for the experimental fields to be 20% and 60% of the observed drain discharge during the monsoon and winter periods, respectively. The values of the net steady water flux effective for leaching of the soil during the rainy and winter seasons are also presented in Table 3.

TABLE 1. Values of Selected Soil Hydraulic and Drainage System Parameters

Parameter	Value(s)
Drain spacing, $2S$	25, 50, 75 m
Drain depth, d	1.8 m
Depth of impervious layer below drain axis, D	1.2 m
Saturated hydraulic, conductivity of the aquifer, K_s	3.0 m/d
Soil water retention parameters	
θ_r	0.100
θ_s	0.449
α	0.0088 1/cm
n	1.672
m	0.402
Soil bulk density, ρ	1.5 g/cm^3
Distribution coefficient, K_d	0.0 cm^3/g
Longitudinal dispersivity, α_L	0.8 m
Transverse dispersivity, α_T	0.08 m

TABLE 2. Observed Soil Salinity Distributions at the Subsurface Tile-Drained Field Site in Sampla

	Drain Spacing, m														
	25					50					75				
Soil depth, cm	June 1984	Oct. 1984	April 1985	June 1985	Nov. 1985	June 1984	Oct. 1984	April 1985	June 1985	Nov. 1985	June 1984	Oct. 1984	April 1985	June 1985	Nov. 1985
0	78.0	6.6	6.2	9.5	3.7	82.0	11.5	14.7	12.5	5.0	65.8	8.8	25.7	18.2	7.2
10	50.7	5.3	6.0	8.7	3.3	50.7	8.1	11.9	12.1	4.6	46.1	8.3	23.2	17.2	6.6
30	23.6	4.0	5.9	8.9	2.9	19.4	4.7	10.1	11.8	5.3	26.4	9.1	19.7	17.8	7.9
50	19.4	3.7	5.8	8.8	3.5	15.8	7.9	10.9	11.6	5.9	13.4	9.0	19.1	19.5	13.0
75	17.0	4.3	7.6	10.2	4.5	16.8	11.1	11.4	13.1	6.4	11.1	9.4	16.8	20.1	14.1
105	12.2	7.6	9.8	9.4	5.7	15.5	14.3	14.9	14.6	7.7	12.6	10.2	19.3	21.0	17.5
150	13.8	8.7	11.7	12.2	6.6	16.7	15.8	14.9	15.0	10.4	14.2	13.1	20.1	21.3	18.1
180	15.2	9.4	11.7	12.8	5.5	18.4	17.9	15.0	16.1	12.9	15.7	14.3	18.2	21.8	19.7
EC_d	28.0	14.0	36.0	18.0	13.0	27.0	17.0	40.0	19.0	14.5	23.0	15.0	40.0	21.0	16.0
EC_g	24.0	15.0	28.0	18.0	15.0	24.0	15.0	28.0	18.0	15.0	22.0	14.0	30.0	18.0	15.0

Distributions are in units of decisiemens per meter.

FINITE ELEMENT DISCRETIZATION; INITIAL AND BOUNDARY CONDITIONS

The adopted finite element network consisted of 63 elements and 82 nodes (Figure 3). A strip sink with three nodes was used to approximate the drain outflow boundary. The width of the strip was assumed to be one fourth of the circumference of the tile drain and the surrounding envelope. The elements were given smaller vertical dimensions in the root zone and smaller horizontal dimensions in the vicinity of the drain where the largest pressure head gradients were expected. During periods of net upward flow, the soil surface becomes an outflow boundary. Drain flow during those periods ceases, and the water table becomes the lower boundary of the flow domain requiring appropriate modification of the discretization. Since the initial salinity status of the soil was not known at all nodes of the flow domain, the average salinity profile observed at the midplane between the drains was assumed to be the same along other verticals in the unsaturated zone. The initial salinity was assumed to be constant in the saturated zone (Table 2) since little or no variation in groundwater quality was observed at the Sampla site up to a depth of about 5 m.

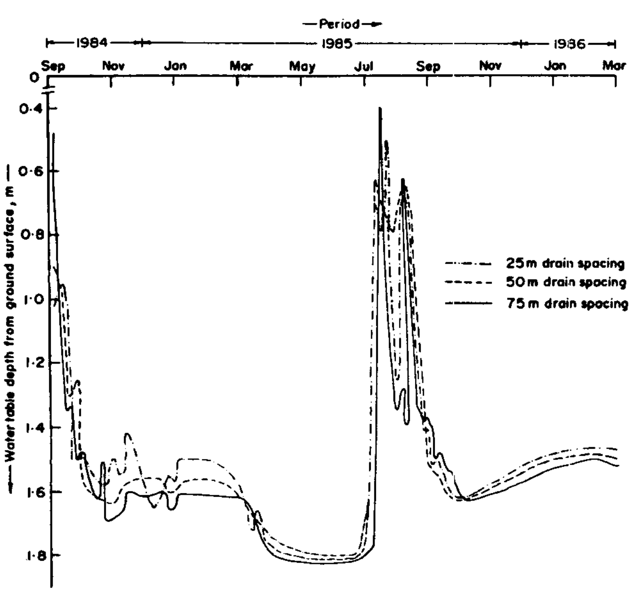

Fig. 2. Water table fluctuations below the experimental drainage plots at the Sampla field site.

For long-term predictions the water balance of the area was established on an annual basis to compute a steady state water flux through the unsaturated zone (Table 3). This information was used to modify the salinity input boundary condition for individual seasons so that they could be used on an annual basis. For example, the concentration of the irrigation water, C_e, was diluted in proportion to its fraction of the net amount of water moving downward during the whole year. While predictions were made for up to 20 years, results presented here mostly involved calculations after 1, 2, 5, and 10 years. The predicted salinity profiles during the first 2 years will be compared with observed distributions.

RESULTS

Downward Flux Phase

Numerical results for different values of the longitudinal dispersivity α_L were used for calibrating the model to observed soil solution and drain effluent concentrations at the Sampla field site. Figure 4 shows results for the 50-m drain-spacing plot during the rainy seasons of 1984 and 1985. Numerical solutions for different values of α_L are compared with observed salinity profiles during the June–October 1984 period (Figure 4*a*). The transverse dispersivity α_T was assumed to be always one tenth of the longitudinal dispersivity. Figure 4*b* shows that a dispersivity value of 0.8 m derived from the calibration resulted in a relatively good match between the observed and predicted results during July–October 1985.

Upward Water Flux

During the evaporation phase we obtained considerable differences between the measured and predicted salinities of the soil surface layer, irrespective of the selected values of the dispersivities. These differences were most likely caused by the assumption that the upward water flux is always at steady state. This assumption may be especially incorrect during periods with many soil wetting and drying cycles. Figure 5*a* shows observed and predicted salinization curves for the 50-m drain-spacing plot during one period (April 2 to

TABLE 3. Observed Seasonal Average Drain Discharges and Steady State Water Fluxes for Three Drain-Spacing Plots at the Field Site in Sampla

	Average Drain Discharge, mm/d			Steady Water Flux, mm/d		
	Drain Spacing, m			Drain Spacing, m		
Year	25	50	75	25	50	75
		Rainy Season (July–September)				
1984	9.1	2.6	1.6	7.3	2.1	1.1
1985	6.6	1.8	1.7	4.5	1.4	1.3
Average*	8.1	2.2	1.7	6.3	1.7	1.3
		Winter Season (October–March)				
1984–1985	2.6	0.7	0.7	−0.15	−0.55	−0.7
1985–1986	4.7	1.4	1.1	0.25	−0.20	−0.3
Average*	3.7	1.1	0.9	†	†	†
		Annual				
				1.0	0.7	0.4

*Average of last 5 years, 1984–1988, used for long-term predictions.
†Means not determined because data were insufficient.

June 25, 1985) with relatively little rain except for a brief shower (June 12). While the observed and predicted salinity distributions have similar trends inside the profile, relatively large differences are apparent in the upper 20 cm of the soil. On the other hand, during a period without rain, the observed and predicted salinity distributions remained close throughout the soil profile (Figure 5*b*). A longitudinal dispersivity of 0.8 m resulted in good agreement between the observed and predicted salinity profiles during both the infiltration and evaporation periods. Consequently, values of 0.8 m for α_L and 0.08 m for α_T will be used later for all long-term predictions of solute transport in the tile-drained soil-aquifer system.

Long-Term Predictions

Observed and predicted soil salinity profiles for the 25-m and 75-m drain spacing plots are presented in Figures 6*a* and 6*b*, respectively. The results indicate close agreement between the observed and predicted salinity profiles during the first 2 years, except again in the surface 20 cm of soil for some cases. The model predicts that soil salinity in the entire soil profile for the 25-m drain spacing will become less than 2.0 *dS* m^{-1} after 5 years, whereas the 75-m drain-spacing plot will continue to have salinities of more than 4.0 dS m^{-1} in the deeper layers of the profile, even after 10 years of subsurface drainage.

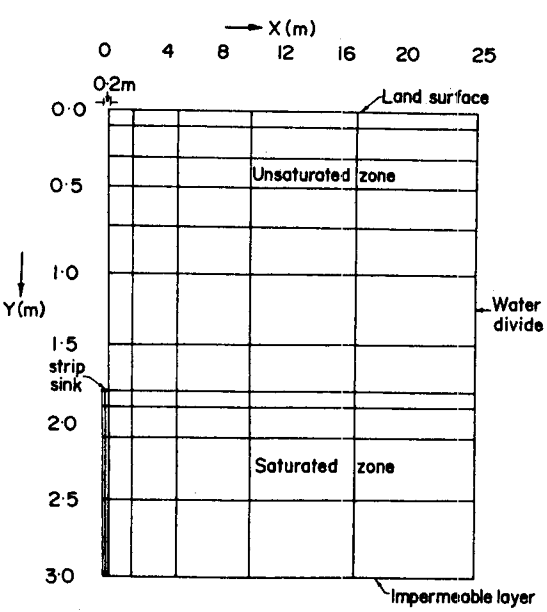

Fig. 3. Finite element discretization of the tile-drained soil-aquifer system during steady downward water flow ($2S$ = 50 m).

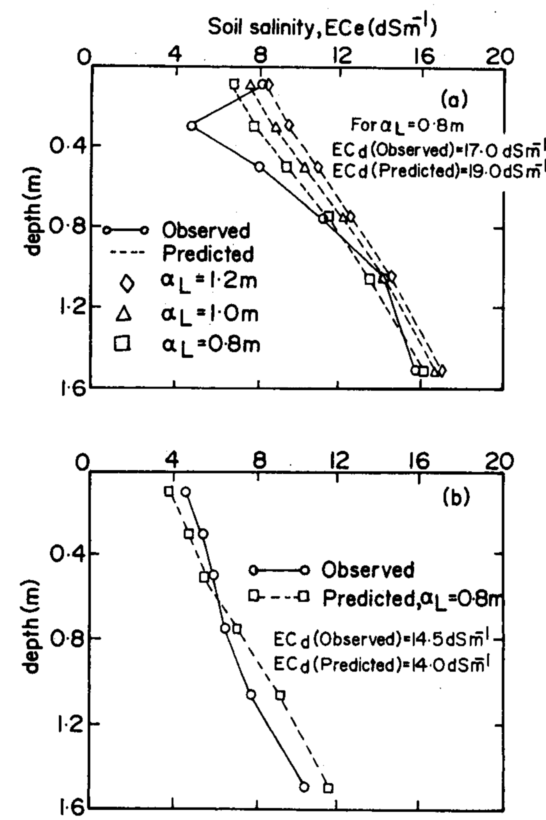

Fig. 4. Observed and predicted salinity profiles during (*a*) the calibration period (June–October 1984) and (*b*) the prediction period (July–November 1985), assuming $2S$ = 50 m and α_T = 0.1 α_L.

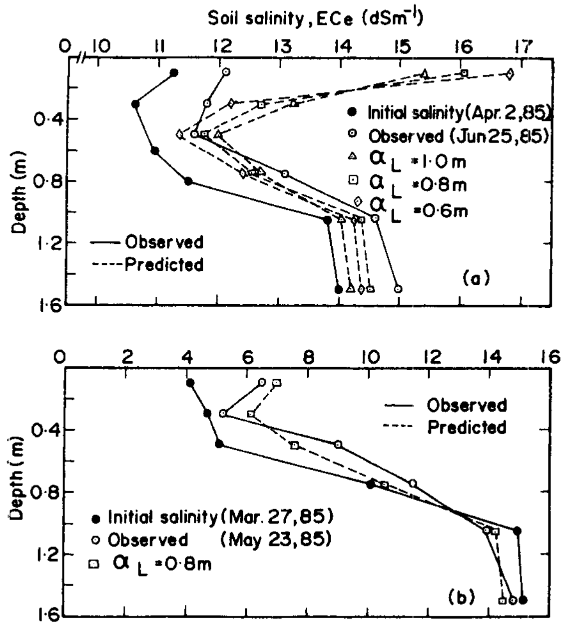

Fig. 5. Observed and predicted salinity profiles during the evaporation phase with (*a*) intermittent rainfall and soil drying and (*b*) without rain ($2S$ = 50 m, and $\alpha_T = 0.1\ \alpha_L$).

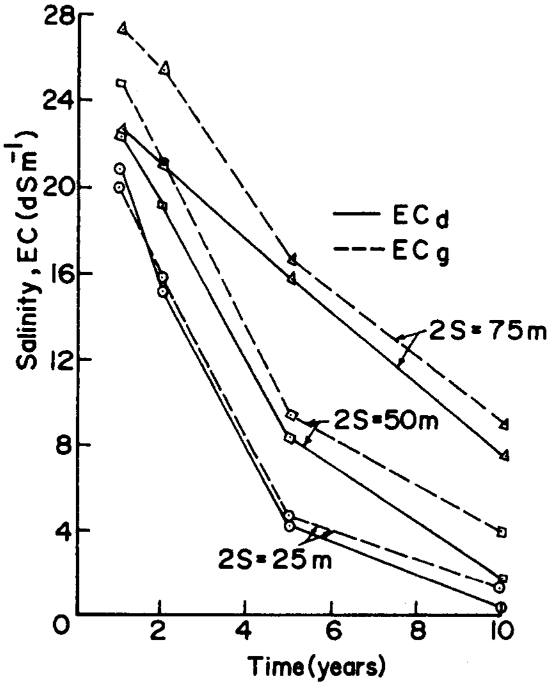

Fig. 7. Predicted changes in salinity of the drain effluent, EC_d, and the groundwater, EC_g, just below the drains for three different drain spacings.

Quality of Drain Water Effluent and Groundwater

Figure 7 shows the predicted changes in the salinity of the drain effluent, EC_d, and the groundwater, EC_g, for the three plots having different drain spacings. Notice that the salinity of the drain effluent decreases very rapidly for the 25- and 50-m drain spacings as compared to the 75-m drain spacing. Five years after installing the drains, the drain water salinity for the 50-m drain-spacing case had reduced to 8 dS m^{-1}, half of the salinity for the 75-m drain spacing. Figure 7 shows similar predictions for the groundwater salinity EC_g. These results are contrary to observations at the Sampla field site which indicated no significant differences in the quality of the drain effluent among the three drain-spacing treatments. The drainage effluent from all plots continued to have salinities in the range 15–25 dS m^{-1} throughout the year, even after 5 years of continuous operation of the drains [*Rao et al.*, 1988]. Also, no improvement in the quality of the groundwater was observed, even though the predicted results indicated a sharp reduction in groundwater salinity from an initial 24.0 to about 10 dS m^{-1} or less (Figure 7) for the 50- and 25-m drain spacings after 5 years of subsurface tile drainage. The soil profile at this time had become virtually salt-free as shown by the observed values in Table 2. We attribute the lack of a significant decrease in groundwater and drain water salinity to continued inflow of water and salts from the surrounding areas where the water table is high. Although seepage from the surrounding fields was included in the water balance of the area for the purpose of computing the steady state water flux, the salt load of this inflowing water was not considered in the simulation. This was due to the fact that the analyses of *Kirkham* [1958] and *Toksöz* and *Kirkham* [1971] employed in this study to describe two-dimensional flow of water to drains in homogeneous and two-layered aquifers, respectively, are applicable when the confining bottom layer is impervious to water flow. Since groundwater salinity does not significantly influence the salt distribution in the soil profile (to be discussed later), the predicted and observed salinity profiles in the unsaturated zone match favorably in spite of a poor comparison between observed and predicted groundwater salinities.

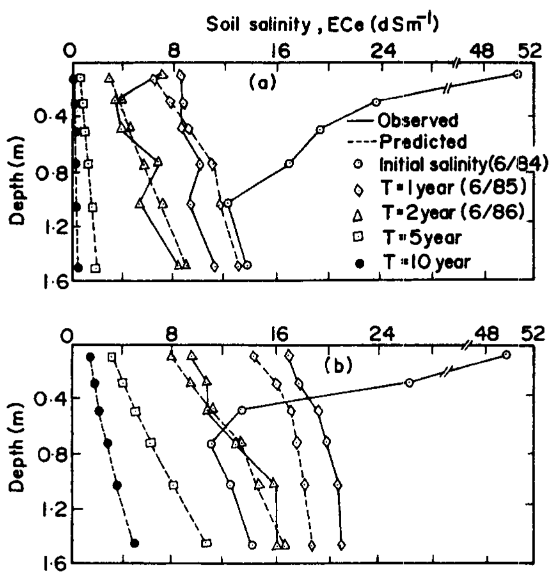

Fig. 6. Observed and predicted salinity profiles for the (*a*) 25-m and (*b*) 75-m drain spacing plots (α_L = 0.8 m, α_T = 0.08 m).

MODEL APPLICATIONS

After partial validation of the model for conditions at the Sampla field site, the model was used to evaluate the effect of (1) drain spacing and drain depth, (2) solute adsorption, (3)

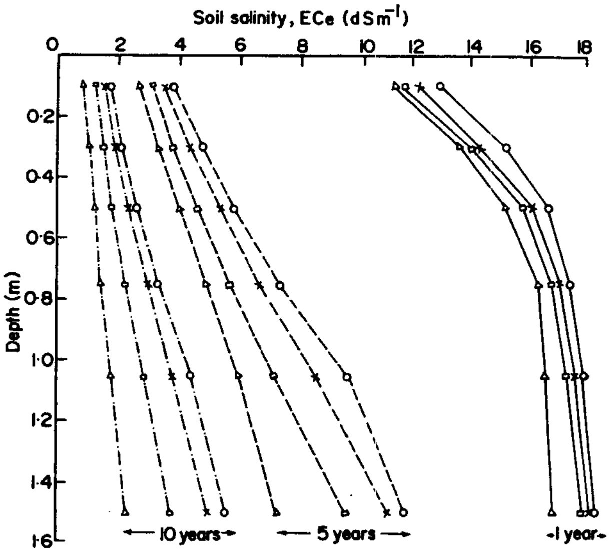

Fig. 8. Soil salinity profiles for different drain-spacing–depth combinations: circles, $2S = 48$ m, $d = 1.0$ m; crosses, $2S = 67$ m, $d = 1.5$ m; squares, $2S = 77$ m, $d = 2.0$ m; triangles, $2S = 85$ m, $d = 2.5$ m ($\alpha_L = 0.8$ m, $\alpha_T = 0.08$ m).

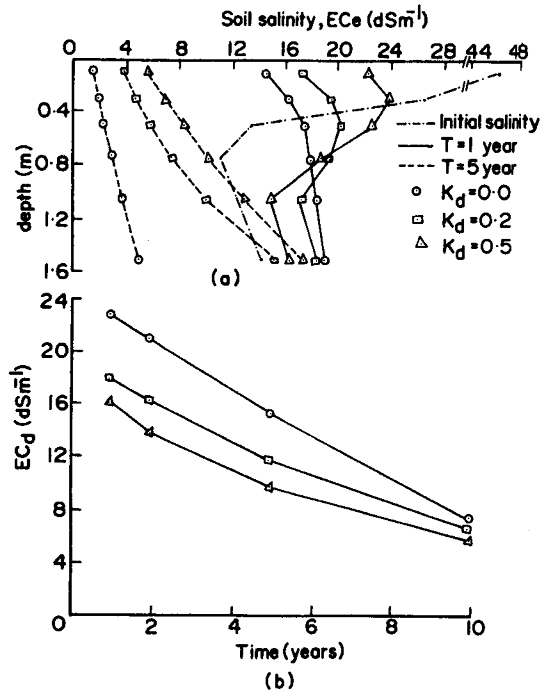

Fig. 10. Effect of the distribution coefficient, K_d, on the salt distribution in (*a*) the soil profile and (*b*) the drain effluent ($2S = 75$ m).

initial groundwater salinity, and (4) aquifer layering on the dynamics of salt movement in a tile-drained soil-aquifer system.

Effect of Drain Spacing and Drain Depth

The numerical model was used to study the comparative performance of several drain spacing ($2S$) and drain depth (d) combinations in reducing soil and groundwater salinity, and the related quality of drainage water effluent. Four drain spacing-depth combinations were used in the comparison, that is, (1) $2S = 48$ m and $d = 1.0$ m, (2) $2S = 67$ m and $d = 1.5$ m, (3) $2S = 77$ m and $d = 2.0$ m, and (4) $2S = 85$ m and $d = 2.5$ m. These combinations have drain discharge versus hydraulic head (q-h) relationships which are the same as for the recommended drain spacing-depth combination of $2S = 75$ m, $d = 1.80$ m for the Sampla area [*Rao et al.*, 1986]. The soil and drain effluent salinity distributions for the above four drain spacing-depth combinations are given in Figures 8 and 9, respectively. The results indicate that the desalinization

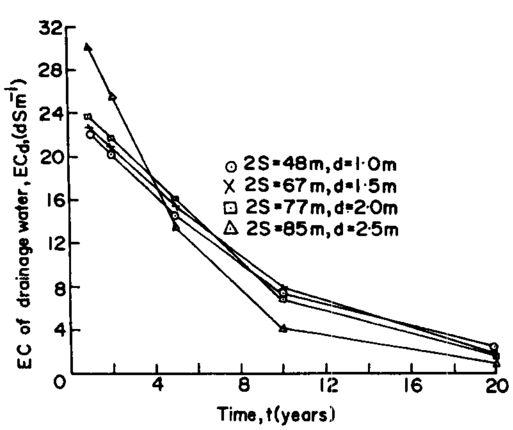

Fig. 9. Predicted changes in the salinity, EC_d, of the drain effluent for different drain-spacing–depth combinations.

process of the soil profile is more effective with the deeper drains. However, the shallower drains are also quite effective in rapidly reducing salinity in the top 80 cm of the soil profile (the soil root zone). The salinity of the drain effluent for the deeper and more widely spaced drains is higher than for the other three drain spacing–depth combinations during the first 3 years, after which the salinity becomes less than those for the other cases (Figure 9). This situation is understandable, since a much larger soil volume is involved in the leaching process for the deeper drains, thus resulting in an initially much heavier salt loading to the drains. However, once most of the salts are removed, the soil profile for the deeper drain depth becomes relatively salt-free, and the salinity of the drain effluent reduces more rapidly as compared to the more shallow tile drain depths. Because of the relatively high salt load, the disposal of effluent from the deeper drains appears to be relatively more difficult (from a surface water pollution point of view) than that from the shallower drains during the initial operation of the drainage system. This conclusion may require additional testing since the assumption of steady state water flow in the shallower drains could have introduced larger errors for the field predictions than what has been reported here.

Effect of Solute Adsorption-Exchange

Equilibrium-controlled adsorption or exchange can be easily incorporated in the convection-dispersion equation through the use of an ion exchange isotherm. For a linear isotherm the proportionality constant between the adsorbed and solution concentrations is called the distribution coefficient, K_d. A high K_d indicates a relatively high affinity of the porous medium for a specific solute species, hence a low mobility in the flow system. The model was used to study the effect of K_d on the movement of a specific solute species in

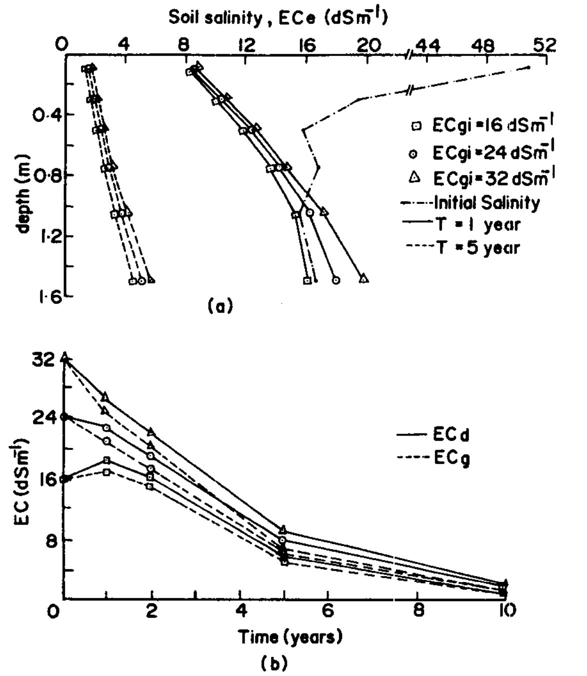

Fig. 11. Effect of initial groundwater salinity, EC_{gi}, on the salt distribution in (*a*) the soil profile and (*b*) the groundwater and the drain effluent ($2S$ = 50 m, α_L = 0.8 m, α_T = 0.08 m).

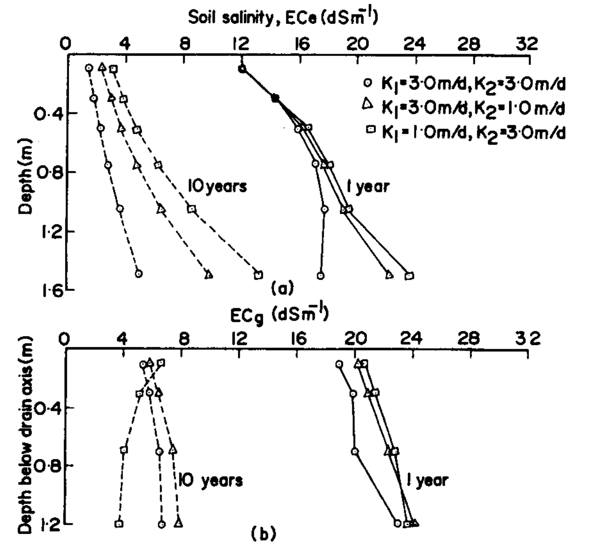

Fig. 12. Effect of aquifer layering on calculated salt distributions in (*a*) the soil profile and (*b*) the groundwater ($2S$ = 75 m, α_L = 0.8 m, α_T = 0.08 m).

a tile-drained soil. Figure 10 shows the computed concentration distributions in the soil profile and the salt loading of the drain effluent for the 75-m drain-spacing case assuming K_d values of 0 (no sorption), 0.2, and 0.5 cm^3/g. Notice that as the value of K_d increases, and hence the amount of solutes adsorbed on the solid matrix increases, the solute loading of the drain effluent decreases.

Effect of Initial Groundwater Salinity

The model was used to study the effect of initial groundwater salinity, EC_{gi}, on the long-term salt distribution in the soil, the groundwater, and the drain effluent. Figure 11 shows the distributions obtained for three different initial groundwater salinities (16, 24, and 32 dS m^{-1}), assuming a drain spacing of 50 m. The results indicate that the effect of EC_{gi} on soil salinity is more pronounced in the deeper soil layers than close to the surface (Figure 11*a*). The differences become less as time progresses, until the salinity of groundwater, irrespective of its initial status, reduces to almost the same level as the soil salinity (Figure 11*b*). The salinity of the groundwater and the drain effluent during the first few years reduces less when the initial salinity of the groundwater is lower (16.0 dS m^{-1}). Actually, with an EC_{gi} of 16 dS m^{-1} the quality of the groundwater and the drain effluent deteriorates in the first year and then starts improving. This may be caused by the fact that the proportion of salts being leached from the soil profile relative to salts being drained from the saturated zone increases as the initial salinity of the groundwater decreases.

Effect of Aquifer Layering

Toksöz and *Kirkham*'s [1971] analysis of steady water flow to drains in a two-layered aquifer was used to simulate the salt distribution in a soil-aquifer system. The aquifer was assumed to consist of two distinct horizontal layers [*Kamra et al.*, this issue, Figure 1] with the upper layer extending to a depth A (0.6 m in this study) below the drain axis. The model was applied to two hypothetical aquifer stratification patterns, (1) K_1 = 3, K_2 = 1 (both in meters per day) and (2) K_1 = 1, K_2 = 3, where K_l and K_2 are the hydraulic conductivities of the upper and lower layers, respectively. Figures 12 and 13 compare the results with those of a homogeneous aquifer (K_1 = K_2 = 3 m/d) assuming a drain spacing of 75 m.

It is evident from Figure 12 that the layering of an aquifer can significantly affect the salt distribution in both the unsaturated and saturated zones. When the upper layer of the aquifer is less permeable than the lower layer ($K_1 < K_2$), the movement of water and salts to the drains from the upper layer diminishes, resulting in a slower desalinization of the soil profile (Figure 12*a*) as compared to cases where the aquifer is either homogeneous or has a less permeable layer in the lower part of the aquifer. The predicted concentration distributions in the saturated zone (Figure 12*b*) are quite

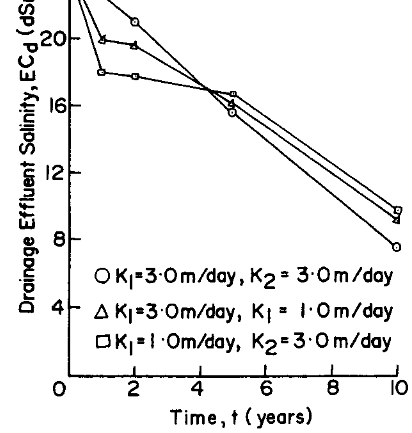

Fig. 13. Effect of aquifer layering on the salinity of the drain effluent (2S = 75 m, α_L = 0.8 m, α_T = 0.08 m).

interesting. Notice that the quality of the groundwater improved more rapidly in zones of high permeability than in the less permeable layers. Since desalinization of the soil and the upper layer of the aquifer is relatively less efficient when $K_1 < K_2$, the salt load of drainage effluent is initially relatively low (Figure 13); at the same time, the quality of the drainage effluent improves more slowly than for the other layered profiles considered in this study.

Effect of Other Parameters

The model was also used to study the effect of the size of the drains, and the longitudinal and transverse dispersivities. These parameters were found to have a relatively insignificant impact on the salt distributions in the tile-drained soils [*Kamra*, 1989].

SUMMARY AND CONCLUSIONS

Considering the potentially serious consequences of soil and groundwater pollution in irrigated agricultural areas, the long-term effects of modern agricultural practices must be evaluated. A semidiscrete two-dimensional linear finite element model of salt transport in a tile-drained soil-aquifer system was developed and tested in the field. The model assumes steady state water flow in the unsaturated and saturated domains of the flow system. The proposed model was designed to study the sensitivity of salt distributions in a tile-drained soil to practices commonly considered in irrigation and drainage management. Field data from a highly saline tile-drained site near Karnal, India, were used to experimentally validate the model. After calibration using observed data for two years, the model was used to obtain 10-year predictions of the salt distributions in the soil, the groundwater, and the drain effluent. Predicted and observed soil salinities compared favorably, except in the surface 20 cm soil layer. Differences in the surface layer are attributed to the assumption of having steady water flow during periods when short-term and highly dynamic oscillations in water contents and salt concentrations occur near the soil surface. Long-term predictions of the salinity of the groundwater and the drain effluent did not accurately match the observed field values because of the model's failure to consider the effects of salt loadings in the seepage water from the surrounding areas.

The model was used to evaluate the long-term performance of the subsurface drainage system assuming different drain spacing and depth combinations. The model predicted that deep but widely spaced drains are relatively more effective in desalinizing the entire soil profile. However, shallow, closely spaced drains are also quite effective in ameliorating the top 80 cm of the soil profile directly involved in crop production. Deep, widely spaced drains produced much higher salt concentrations in the drainage effluent during the first few years of operation than the more shallow, closely spaced drains. Aquifer stratification can significantly influence the salt distribution in soil, groundwater, and drainage effluent. This suggests that accurate descriptions are needed of the hydraulic properties of the different layers in the aquifer.

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