

LINKFLOW, A WATER FLOW COMPUTER MODEL FOR WATER TABLE MANAGEMENT: PART 2. MODEL VERIFICATION

P. L. Havard, S. O. Prasher, R. B. Bonnell, A. Madani

ABSTRACT. A computer simulation model, LINKFLOW, was developed (Havard et al., 1995) to simulate the movement of water during various water table management practices. This article described the validation of the linked saturated-unsaturated water flow model, LINKFLOW. The model was validated against published data on water table elevations during transient drainage. Simulation results were compared with measurements from field experimental plots. Results from the validation indicate a good comparison between simulated and measured values. Coefficients of variation for simulated and measured water table elevations were typically less than 15% for all water table management plots during the growing season. Verification showed that LINKFLOW could simulate the spatial influence of water table movement during various water management systems and account for soil property variation with depth and topography.

Keywords. Water table management, Computer model, Drainage, Subirrigation.

LINKFLOW, a linked 1D-unsaturated to 3D-saturated water flow computer simulation model, was developed to describe water flow during water table management. The computer model simulates moisture conditions in the soil profile for a wide range of soil, topographical, drain layout and weather conditions. The saturated flow component of the model is the computer simulation flow model, MODFLOW (MacDonald and Harbaugh, 1984). MODFLOW was modified and linked to a 1-D finite difference model of the unsaturated water flow to account for moisture movement. A description of the linked model development is given in Havard et al. (1995). The linked model has capabilities beyond current water table management models but needs to be validated before it can be applied to increase our understanding of water movement for different field situations.

VALIDATION OF LINKFLOW

Simulation results of the linked flow model were compared to published and measured water table elevations to test the model's accuracy. Published values of water table drawdown during drainage between two ditches were compared with simulated solutions from LINKFLOW.

SUBSURFACE DRAINAGE

Tang and Skaggs (1980) compared a numerical solution by Amerman (1969) of Richards' equation for the open

ditch drainage case with several approximate methods of solution. The soil type was a Panoche soil with soil physical characteristics reported in Nielsen et al. (1973). The soil profile was considered homogeneous and isotropic to a depth of 1.6 m where an impermeable layer was present. The initial water table level in the field was at the soil surface. The ditches, spaced 20 m apart, had a constant water level of 1 m below the soil surface when the drainage begins. Figure 1 plots the numerical values reported in Tang and Skaggs (1980) to the simulated water table elevations by LINKFLOW. Water table elevations at locations between the drainage ditches are shown for 2 and 50 h after beginning of drainage. Relative error values were 4.5% after 2 h and 7% after 50 h of drainage for simulated points located between drains. LINKFLOW, which was written for subsurface drains instead of open ditches, had the most error simulating water table elevations near the ditch location. LINKFLOW compared very well at the early time steps and for the water table elevations away from the ditch.

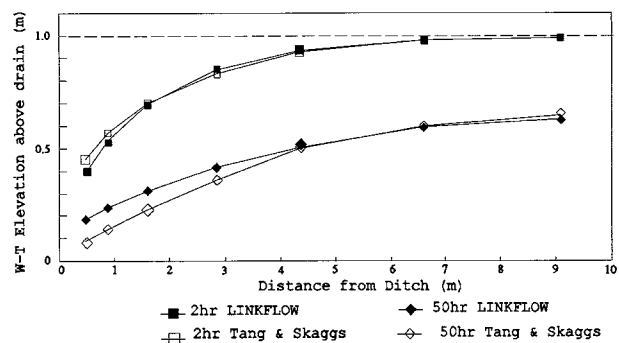


Figure 1—Comparison of water table (W-T) elevations for drainage to parallel ditches between LINKFLOW and data from Tang and Skaggs (1980) at two times after the beginning of drainage.

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FIELD PLOTS AND MEASUREMENTS

The field plots were at a farm near Saint-Victoire, Richelieu County in the Province of Quebec, Canada. These plots have been the site for several water table research studies (Rashid-Noah, 1981; von Hoyningen Huene, 1984; Gallichand, 1983; Memon, 1985; Sultani, 1989; Mackenzie, 1992) whose findings provided detailed site information on the soil and system operation. Values for hydraulic conductivity, soil profile dimensions, weather data and parameters for operation of the system were obtained from these earlier and on going studies. The soil profile consists of a dark brown, fine St-Samuel sandy loam layer for the first 0.20 to 0.30 m. Below this is an olive pale, medium sand to a depth of 1.5 m. Then a marine clay of several meters thickness occurs that can be treated as an impermeable layer (Rashid-Noah, 1981).

A schematic of the field and subsurface drain layout is shown in figure 2. The site was laid out with four treatments of different water table management methods and four replications to make up the 16 plots used during the 1987 growing season. The treatments included saline water subirrigation, fresh water subirrigation, controlled drainage, and conventional drainage. Measurements of water table depths and soil moisture contents were taken on all plots two to three times a week between 2 July and 28 August 1987. Corn was grown on the site during this period.

Water supplied for the subirrigation plots was controlled using four control chambers. The control chambers could maintain a level of water by using an adjustable float valve to add water, and an adjustable riser pipe to allow drainage when needed. Details concerning construction and operation are described in earlier studies (von Hoyningen Huene, 1984; Gallichand, 1983; Memon, 1985; Sultani, 1989).

Saline water from a well (plots 5, 6, 9, and 10), and fresh water (plots 3, 4, 12, and 15) from the town water supply mixed with drainage water were used to supply water to the field. Since saline water was readily available on site, a separate research study was underway to determine the effects of using saline well water for

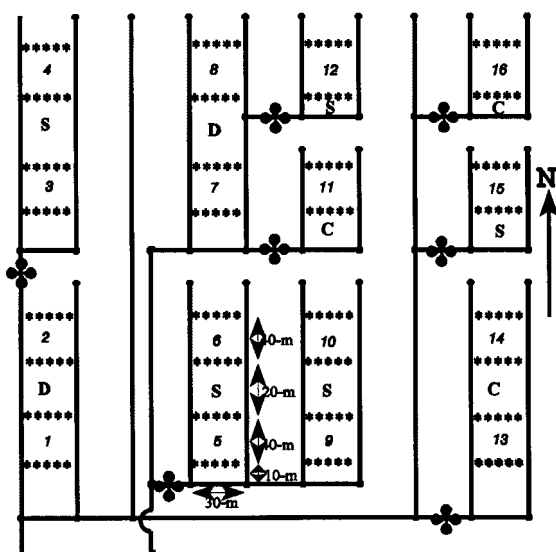


Figure 2—Drain and plot layout: with \clubsuit for control chambers; $*$, observation pipes; D, conventional drainage; S, subirrigation; and C, control drainage. Field dimensions approximately 300 m \times 300 m.

subirrigation on crop performance and the soil profile (Bonnell, 1993). Saline and fresh water subirrigation plots were considered as one treatment within the scope of this study. The lateral drains were covered with a knitted polyester sock filter material and spaced 30 m in all plots. The length of drains varied from 65 m to 130 m depending on the plot. Conventional drainage plots (plots 1, 2, 7, and 8) allow free drainage to the depth of installed drains (0.80 to 1.00 m depth).

Two sets of five water table observation wells were installed across each plot. The location of each well, shown by the $*$ in figure 2, was 0.15 m, 7.5 m, 15 m, 22.5 m, and 29.85 m, measured from over the drain centre on the east side of each plot. The wells consisted of perforated 19 mm I.D., 1.5 m long PVC pipes with perforations along the pipe. Each was wrapped in a polyester fabric material to prevent blockage by fine sand. Water levels were measured by lowering a calibrated rod equipped with an electronic sounding device which beeps when in contact with water. Readings were recorded from the top of the observation pipe to the water table. The top of each pipe was surveyed using a surveyors level so that these readings could be converted to water level elevations. Moisture contents were measured by a neutron probe at depths of 0.15 m, 0.30 m, and 0.45 m next to each water table well.

INPUT REQUIREMENTS FOR PLOT SIMULATIONS

LINKFLOW required the time length of each hydrologic event such as rainfall and evaporation. Daily values of rainfall and potential evapotranspiration values were used in the simulations for the field plots as reported by Sultani (1989).

The saturated hydraulic conductivity values used were reported by Rashid-Noah (1981), with values of saturated hydraulic conductivity decreasing from 1.2 m day⁻¹ near the surface to 0.4 m day⁻¹ approaching the clay layer around 1 m depth.

The unsaturated soil properties relations for hydraulic conductivity [$k(\psi)$], volumetric moisture content [$\theta(\psi)$], and moisture capacity [$C(\psi)$] as a function of soil water pressure head (ψ) used were taken from Mackenzie (1992) and are shown in table 1. LINKFLOW computes unsaturated hydraulic conductivity values according to the saturated conductivity for a given location. Therefore, in the model it is not possible for the unsaturated hydraulic conductivities to be higher than the saturated value. The topography was represented by point elevations on a grid over each of the plots. LINKFLOW simulated water movement for the entire treatment area, which in the case

Table 1. Moisture retention and conductivity properties used for the simulation of field plots

ψ (m)	$\theta(\psi)$ (cm ³ cm ⁻³)	$k(\psi)$ (m day ⁻¹)	$C(\psi)$ (m ⁻¹)
-0.02	0.498	1.6811	0.097
-0.10	0.479	1.3376	0.352
-0.18	0.447	0.8761	0.426
-0.26	0.414	0.5324	0.394
-0.34	0.385	0.3223	0.331
-0.42	0.361	0.2005	0.270
-0.50	0.341	0.1293	0.220
-0.58	0.325	0.0866	0.180
-0.66	0.312	0.0600	0.149
-0.74	0.301	0.0428	0.124

of double plots allowed spatial comparison with four rows of observation points; whereas, the shorter treatment areas contained two rows.

SUBIRRIGATION PLOTS COMPARISON

Plots 5 and 6 were subirrigated from 13 July to 28 August 1987, and measurements of moisture content and water table depths were taken twice a week. A low area was present at the top of the region and higher elevations at the bottom (south end). The maximum difference in elevation was approximately 0.30 m over the 130 m length.

The four rows of observation pipes were located at distances 10, 50, 70, and 110 m, respectively, from the south end of the plot. The region runs north-south with drains located on the east, west, and south boundaries. Water levels were better maintained on these plots than the other subirrigation plots, since it was located in a low region of the field. Figure 3 plots simulated water table depths with those measured in the field. The solid line represents a 1 to 1 relation between the observations and simulation values. The scatter in the data from the solid line is a measure of how well the data sets agreed for the range of water table depths measured. The coefficient of correlation, r , for this relationship is given in table 2. It represents strength of the linear relationship between measurements and simulation results. Table 2 also lists the average, relative, and standard errors between the measured and simulation water table depths. Figure 4 shows a good comparison of the simulated and observed water table depths with time at one location. Another location showed relative error as high as 15%. Despite this variation, these values fall into the typical range of

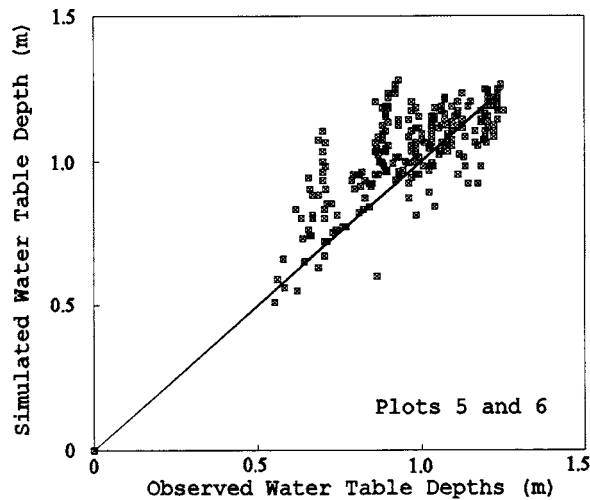


Figure 3—Comparing measured and simulation depth to water table in subirrigation plots 5 and 6. Solid line represents a perfect match.

Table 2. Statistics for the error between measured and simulation values for water table depth in subirrigation, conventional drainage and controlled drainage plots at locations between laterals

Distance from Drain	Subirrigation Plots 5 and 6			Conventional Drainage Plots 1 and 2			Controlled Drainage Plots 13 and 14		
	7.5 m	15 m	22.5 m	7.5 m	15 m	22.5 m	7.5 m	15 m	22.5 m
r	0.65	0.7	0.81	0.73	0.12	0.84	0.81	0.78	0.85
Average error	0.1	0.14	0.09	0.09	0.27	0.1	0.08	0.08	0.07
Relative error	10.2%	15.2%	8.9%	8.0%	13.0%	9.5%	7.5%	7.8%	6.4%
Std error (m)	0.136	0.17	0.108	0.102	0.3	0.115	0.099	0.110	0.085
Coef. of var.	0.138	0.19	0.111	0.098	0.263	0.109	0.088	0.105	0.078

standard error (0.1-0.4 m) reported for several studies using DRAINMOD simulations (Fouss et al., 1987; Workman and Skaggs, 1989; Kanwar and Sonoja, 1988). The simulated and measured moisture contents at 0.15 m depth are also compared in figure 4 at the same location. The measured moisture contents showed greater fluctuation than the simulated.

VERIFICATION ON A DRAINAGE PLOT

Plots 1 and 2 were subjected to the treatment of conventional drainage. The two plots are contained in a region that had a slight depression running north-south down the centre of the field. The total difference in topographic elevation is approximately 0.20 m over 145 m. The four rows of observation pipes were at distances 10, 50, 70, and 110 m from the south end of the plot. Plots 1 and 2 run north-south with drains located on the east, west, and south boundaries.

Relative errors as high as 13% (table 2) were observed between measured and simulate water table heights over the treatment area. The error (standard error between 0.102 to 0.30 m) which is within the range that has been reported in other studies with simulation models (Fouss et al., 1987; Workman and Skaggs, 1989; Kanwar and Sonoja, 1988).

Figure 5 shows the corresponding water table depths and moisture contents with time for two locations with conventional drainage. The measured and simulated data compared well with r values of 0.73 and 0.84, though one location was poor with an r value of 0.12. The simulation model did not show as great a response in moisture content

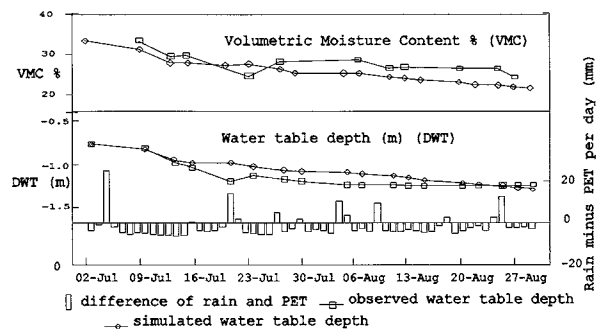


Figure 4—Depth to water table (DWT) and volumetric moisture content (VMC) vs time for simulation and observation data in subirrigation plot 5 at mid spacing in the southern set of observation pipes.

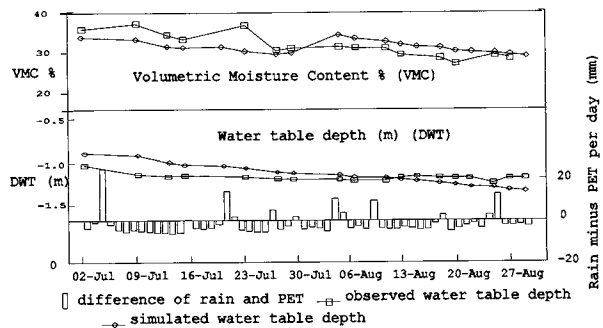


Figure 5—Depth to water table (DWT) and volumetric moisture content (VMC) vs time for simulation and observation data in conventional drainage plots 1 and 2 at mid spacing.

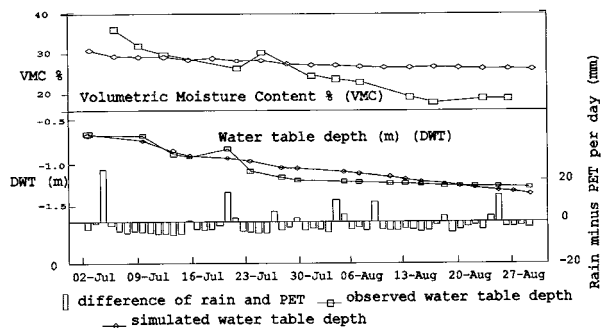


Figure 6—Depth to water table (DWT) and volumetric moisture content (VMC) vs time for simulation and observation data in controlled drainage plot 14 at mid spacing.

change to individual rainfall events as did the measured values. This difference in sensitivity in moisture contents occurs due to the model's values are an average value over the root zone while the measured value is for 0.15 m below the soil surface.

VERIFICATION WITH A CONTROLLED DRAINAGE PLOT

Plots 13 and 14 were subjected to the treatment of controlled drainage; that is, drain outflow was restricted whenever drainage was not necessary to avoid excessive water logging. The two plots are contained in the region that is relatively flat, with a total difference in elevation of approximately 0.10 m over 130 m. The four rows of observation points were at distances 10, 50, 70, and 110 m, respectively, from the south end of the plot. The region runs north-south with drains located on the east and west with the main on the southern boundary.

The simulated water table depth compared well to observations as reflected in the high coefficient of correlation values (0.78-0.85), relative errors of less than 8% and low coefficients of variation as indicated in table 2.

Figure 6 graphs the simulated and measured values for water table depth and moisture content with time. The water table depth values compared well, while the moisture content did not compare as well, particularly latter in the growing season for this plot.

CONCLUSIONS

This study found LINKFLOW was able to simulate the complex water flow processes involved with water table management system within accuracies obtained by similar model approaches and do so over a three-dimensional region of the field. Coefficients of variation for simulated and measured water table depths were typically less than 15% over the period of a growing season. LINKFLOW, provides a tool to make detailed simulations of water movement within a region of a field and account for variability of soil properties.

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