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in memory of Prof. Dr. Osman TEKINEL

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TÜBİTAK

TMMOB ZİRAAT MÜHENDİSLERİ ODASI

EVALUATING DRAINAGE DESIGN PARAMETERS BY NUMERICAL EXPERIMENTATION

Dursun Büyüktaş[72] *Ruhi Baştuğ*

ABSTRACT

Drainage is necessary for agricultural production in many humid regions of the world, where it is used to improve crop yields and trafficability by removing excess water from the surface and root zone. In irrigated arid regions, drainage is often needed to prevent waterlogging and to control salinity. Water table depths, soil water contents, and drain flow rates are critical in the proper design of drainage systems. Numerical models developed by solving the governing water flow equations provide the most exact prediction of these values. Both finite elements and finite difference methods have been used effectively in drainage research.

In this study, the effects of soil type and drainage design parameters such as drain spacing, drain depth, and depth to impervious layer on drain flow rate and water table depth are studied by numerical experimentation using SWMS_3D that simulates water flow, heat transfer and solute movement in variably saturated porous media. The model has been developed by U.S. Salinity laboratory and can deal with a wide range of boundary conditions, including ditches and drain tubes, as well as boundaries controlled by atmospheric conditions.

The results showed that light soils draining faster than that of the heavy soils. As drain spacing and drain depth increased, drain flow rate also increased. The water table depth in the middle of the drains was found to be higher when the depth of the impermeable layer below the drain increased. The numerical results are consistent with the results of the drainage studies. It is concluded that numerical models can be used to foresee the possible effects of drainage design criteria before installing tile drains in the field.

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Keywords: drainage, numerical model, simulations

INTRODUCTION

Agricultural drainage may be defined as the removal and disposal of excess water from agricultural lands. It is necessary for agricultural production in many humid regions of the world, where it is used to improve crop yields and trafficability by removing excess water from the surface and root zone. In irrigated arid regions, drainage is often needed to prevent waterlogging and to control salinity (SCS, 1973).

Agricultural drainage systems involve the movement of water through both unsaturated and saturated soil. Water flow processes in this system can be simply described by combining appropriate flux equations with expressions of material balance to form the partial differential equations. The problem statement is completed by specifying the boundary and initial conditions and the required equations of the state and auxiliary equations that relate variable coefficients to properties of soil, the fluids, and the dependent variables (McWhorter and Marinelli, 1999). However, governing equation for soil water flow, known as Richards Equation, is highly non linear because

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both the hydraulic conductivity and soil water pressure head depend on the soil water content. Exact analytical solutions of this equation are only possible for simplified flow cases under a number of restrictive assumptions. On the other hand, numerical solution of the flow equation offers a powerful tool in approximating the real nature of the unsaturated/saturated zone for a wide variety of soil systems and external conditions (Feddes et al., 1988).

The partial differential equation can be solved numerically by a method used in other areas of engineering. These methods are finite difference, integrated finite difference, finite elements, and boundary elements methods. Of these methods, the finite difference and the finite elements have received most of the attention for application in modeling flows through agricultural soils. The application of these numerical techniques to the governing differential equation yields a set of algebraic equations, which can be solved either directly or iteratively with imposed boundary and initial conditions. The advantage of numerical solution approach, compared to the analytical solution approach, is the flexibility in handling arbitrary boundary and initial conditions, arbitrary spatial parameter distributions, and nonlinearities in the governing equations (Nieber and Feddes, 1999).

A number of numerical models have been developed for simulating the movement of water and solute transport in variably saturated porous media. They range from approximate methods for conducting a water balance in the soil profile to complex numerical solutions of differential equations (e.g. Srivastava and Yeh, 1992; Simunek et. al, 1995; Somma et al., 1995; Buyuktas and Wallender, 2002). Many of the models developed have been field tested and are routinely applied to describe the hydrology of shallow water table soils, including the effect of drainage and related water management practices on yields.

In the past, the focus of the drainage project has been to improve land productivity and increase crop yield. However, there is now additional pressure to ensure system sustainability, from technological, economic, and environmental standpoint. Considering that the drainage projects are large scale, have environmental impacts, and large amount of many is invested, it is essential that the systems be properly designed, installed, and operated. More attention must be paid to the planning and design process if investments are to be protected and benefits to all stakeholders maximized. Although it is important to recognize that some fieldwork is essential, computer simulation models may be used in designing drainage systems (Madramootoo, 1999). The use of computer simulation models will give the opportunity to forecast how the drainage system will be working before installing in the field.

In this study, the effects of soil type and drainage design parameters such as drain spacing, drain depth, and depth to impervious layer on drain flow rate and water table depth are studied by numerical experimentation using SWMS_3D that simulates water flow, heat transfer and solute movement in variably saturated porous media.

DESCRIPTION OF NUMERICAL MODEL AND DOMAIN

The simulations were performed using the model, SWMS_3D, developed by Simunek et. al, (1995). The water movement and solute transport are modeled by numerical solution of Richards' equation and convection-diffusion equation, respectively, using Galerkin finite element method, subject to appropriate initial and boundary conditions. The model can deal with a wide range of boundary conditions, including ditches and drain tubes, as well as boundaries controlled by atmospheric conditions. SWMS_3D can handle flow domains delineated by irregular boundaries.

The flow region may be composed of non-uniform soils having an arbitrary degree of local anisotropy. The details of the model can be found elsewhere (Simunek et al., 1995).

Numerical domain used in the simulation is given in Figure 1. Initially, the domain was assumed saturated. This situation occurs after heavy rains or irrigations. Different soil types (loam, silty loam and silt) were simulated by changing van Genuchten parameters (α, n, m, Ks), taken from Carsel and Parrish (1988). Different drain spacing (60 m, 100 m and 150 m), drain depths (1.8 m, 2.2 m and 27 m) and depth to impervious layer (2 m, 5 m, 10 m and 20 m) were used in the simulations. At the soil surface a specified flux (zero) boundary condition while a no-flow boundary was used at the bottom and all other sides. The tile drain in the domain were treated as a boundary node surrounded by four regular square elements with adjusted hydraulic conductivities using the electric analog approach of Vimoke et al. (1963) and Fipps et al. (1986). The numerical domain was divided into quadrilateral elements. Finer discretizations were used near the soil surface and around the subsurface tile drain to accommodate abrupt changes in local fluxes and hence pressure gradients. The simulations were performed over 60 days. The results are presented in terms of drain flow rate or water table depth.

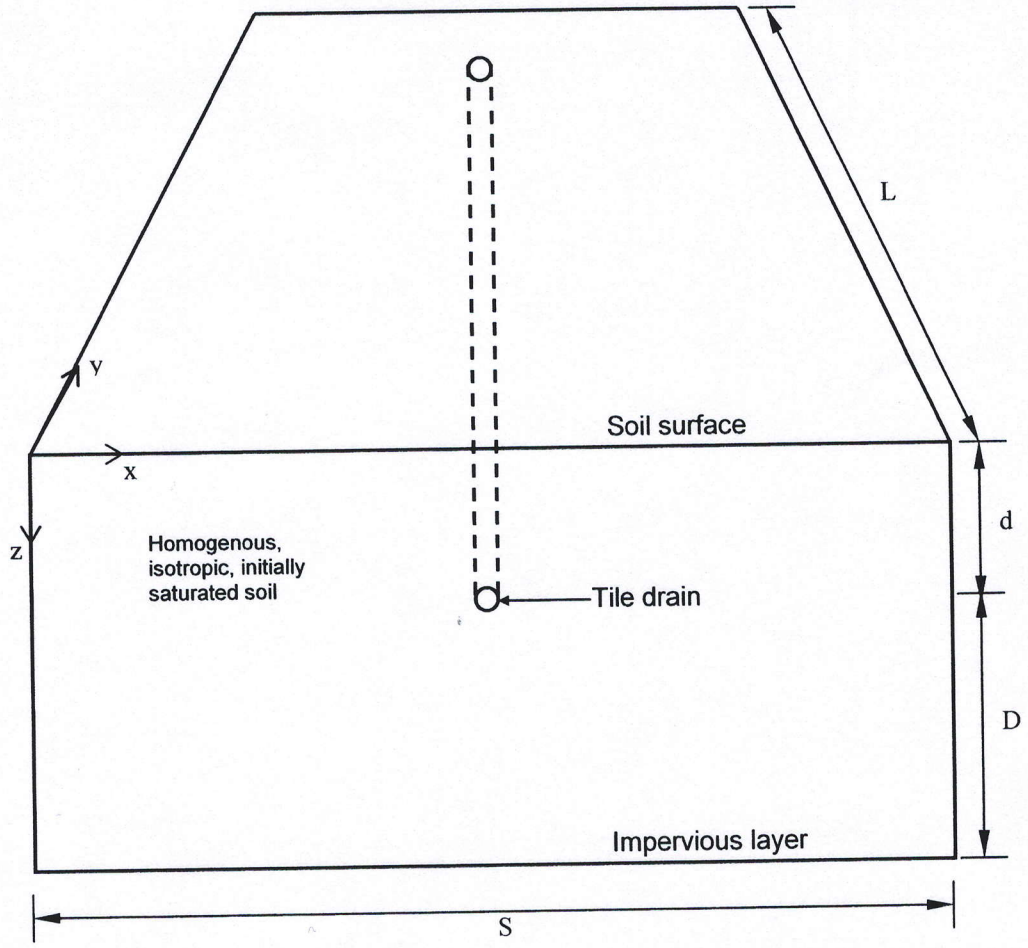


Figure 1. Numerical domain used in the simulations

RESULTS AND DISCUSSIONS

The effect of soil texture on drain flow rate is given in Figure 2. The highest drain flow rate belongs to loamy soil, followed by silt loam and silt. In other words, heavier soils are draining slowly. Generally, coarse-textured soils drain more readily than fine textured ones. The hydraulic conductivity plays an important role in drainage. The highest drain flow rate was obtained from the loamy soil which has the highest hydraulic conductivity. The results of the model are consistent with intuition.

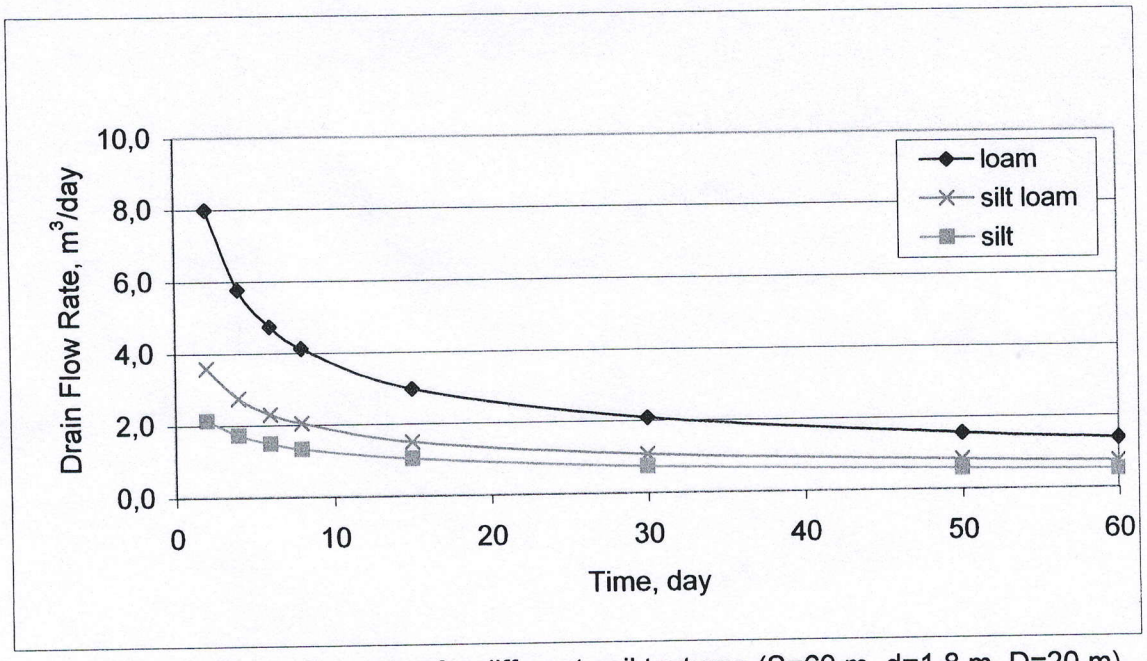


Figure 2. Drain flow rates for different soil textures (S=60 m, d=1.8 m, D=20 m)

The effect of drain spacing on drain flow rate is presented in Figure 3. Initially, drain flows for different drain spacing are almost equal to each other because the hydraulic head above the drain level is the same. As time progress, drain flow rate is getting higher for wider drain spacing because larger volume of soil has to be drained out and the hydraulic head is changing as a results of differences in matric and gravitational potential in the profile. However, increase in drain spacing is not proportional to the drain flow. Hillel (1998) points out that the discharge per drain might become constant when the drains were spaced far apart. Then, the total drainage discharged from a field becomes proportional to the number of drains installed.

The effect of drain depth on drain flow rate is shown in Figure 4. Increase in drain depth causes also increase in drain flow rates. Contrary to the case of drain spacing, the hydraulic head is different for each drain depth, resulting variations in drain flow rate. The depth of the tile drains is often controlled by the depth of outlet. Crop requirements should also be taken into the consideration.

By reducing drain depth and spacing, less ground water is collected from deep in the soil profile, and in cases where the water quality declines with increased depth in the soil profile, less poor-quality water will be extracted (Grismer 1993). The reduction in drain depth will also lead to smaller volume of water being discharged from the drains and more water being used by the crop. Including crop water use in the design, although not considered in this study, will increase the lateral spacing for a specific drain depth. Such a mechanism may be possible if the shallow ground water quality is suitable for crop use (Ayars et al., 1997).

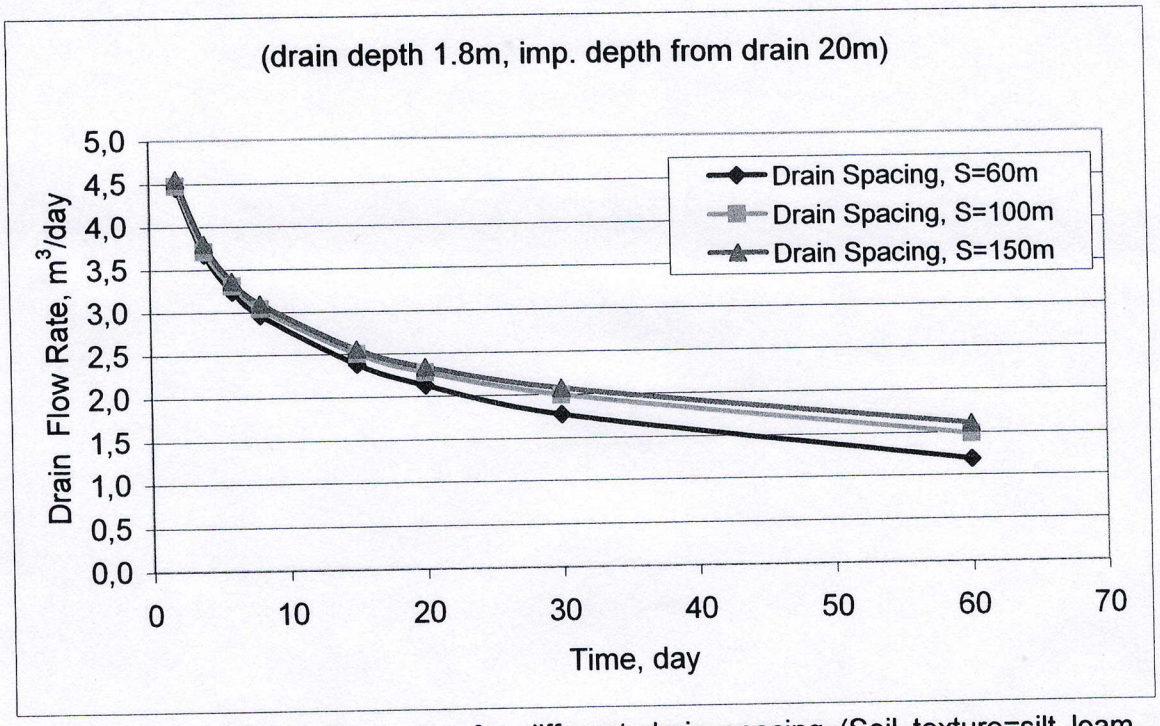


Figure 3. Drain flow rates for different drain spacing (Soil texture=silt loam, d=1.8 m, D=20 m)

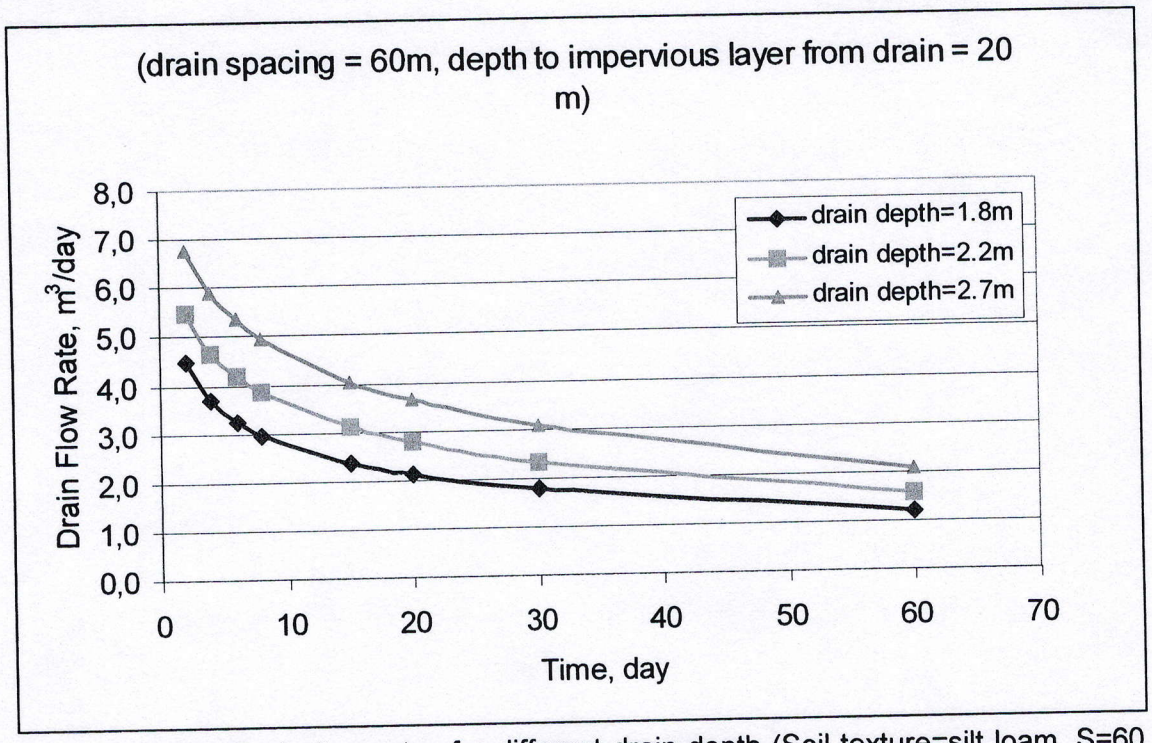


Figure 4. Drain flow rates for different drain depth (Soil texture=silt loam, S=60 m, D=20 m)

The effect of impervious layer depth on drain flow rate is given in Figure 5. Initially, the drain flow rates are not equal because the hydraulic head is changing depending on the depth of impervious layer. Drain flow rates are increasing as the depth of impervious layer below the drain increased. However, increase in the drain flow is not proportional to the increase in the depth of impervious barrier. The depth of impervious layer does not affect drain flow rate if it is more than 10 m deep.

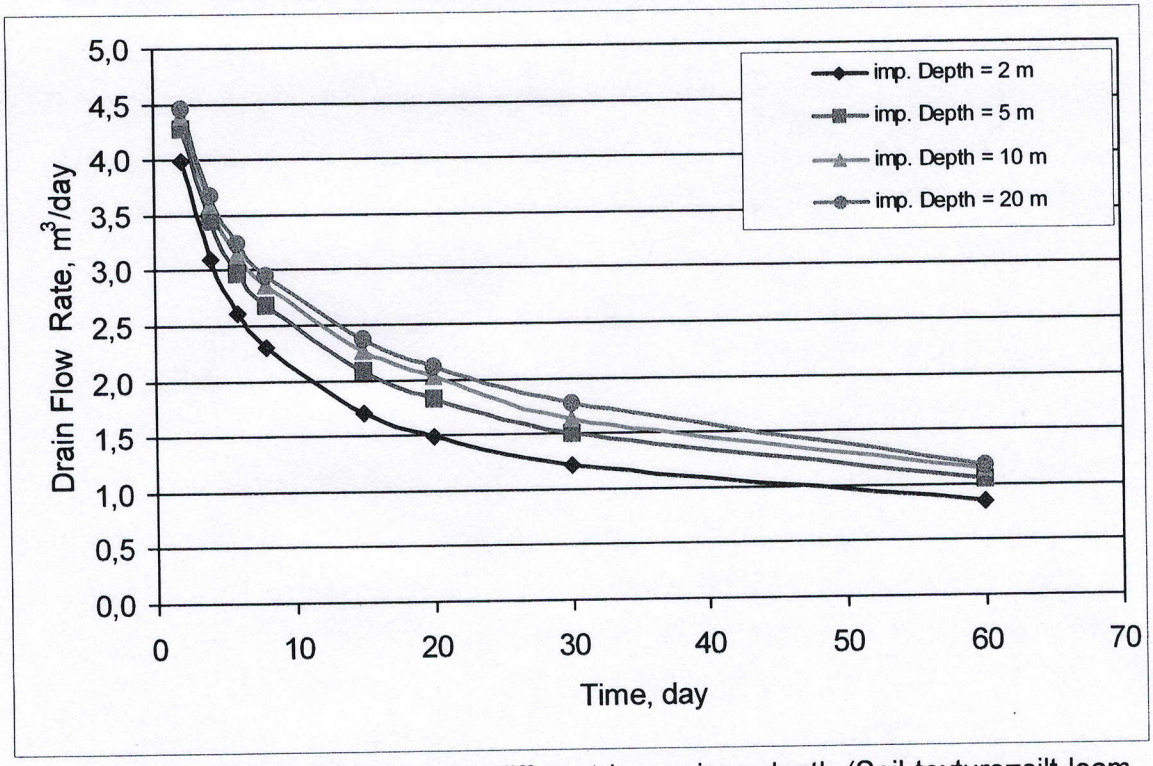


Figure 5. Drain flow rates for different impervious depth (Soil texture=silt loam, S=60 m, d=1.8 m)

Evolution of water table depth for the impermeable depth of 2 m is given in Figure 6. The shape of the water table looks like an ellipse. This shape of water table is encountered in the field. Water table depth in the middle of the drains is decreasing about 60 cm at the end of the simulation period of 60 days for a silt loam soil.

Evolution of water table depth above drain level for different depth of impervious layers is shown in Figure 7a, b, c, d and e. The drop in water table depth at the end of simulation period is slightly higher than 60 cm for impervious depth of 2 m, whereas it is about 1 m for impervious depth of 20 m (Figure 7e). As the depth of impervious layer increased from 10 m to 20 m, the drop in water table is about 6 cm. In other words, as the bottom boundary condition is far apart from the drain, its effect on water table depth is not pronounced well.

Water table depths are also in accord with drain flow rates given in Figure 5. Deep water table depths corresponds to higher drain flow rates because the volume of water stored in soil is decreasing.

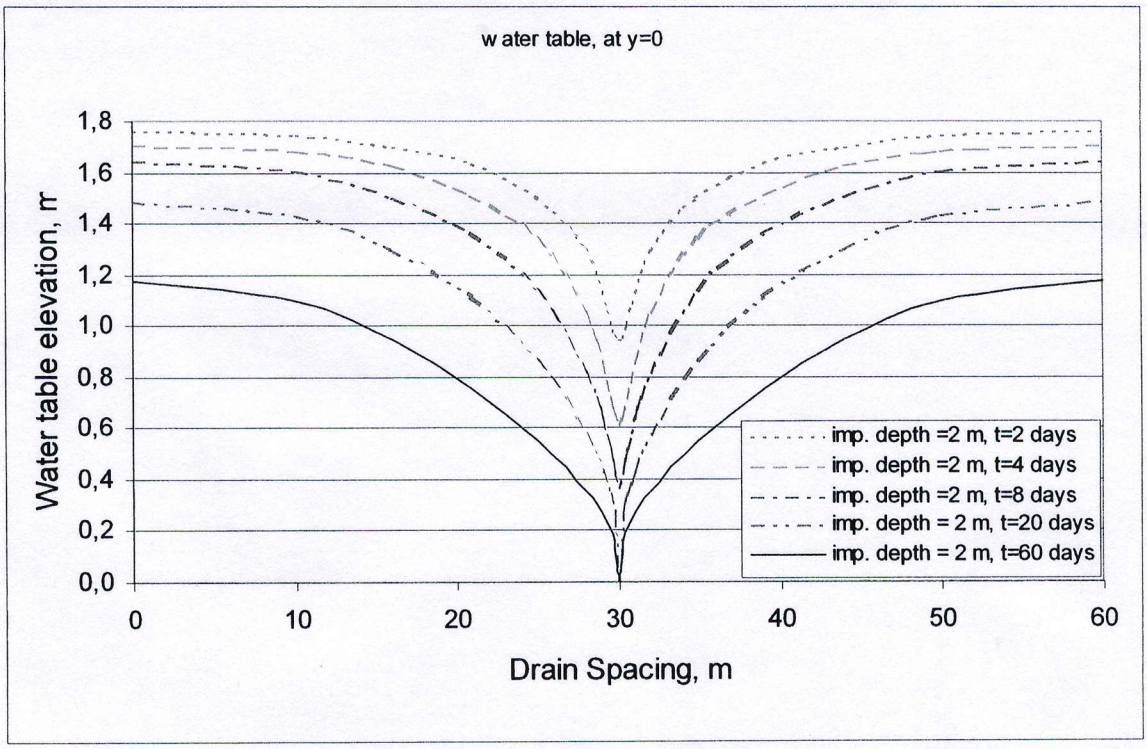
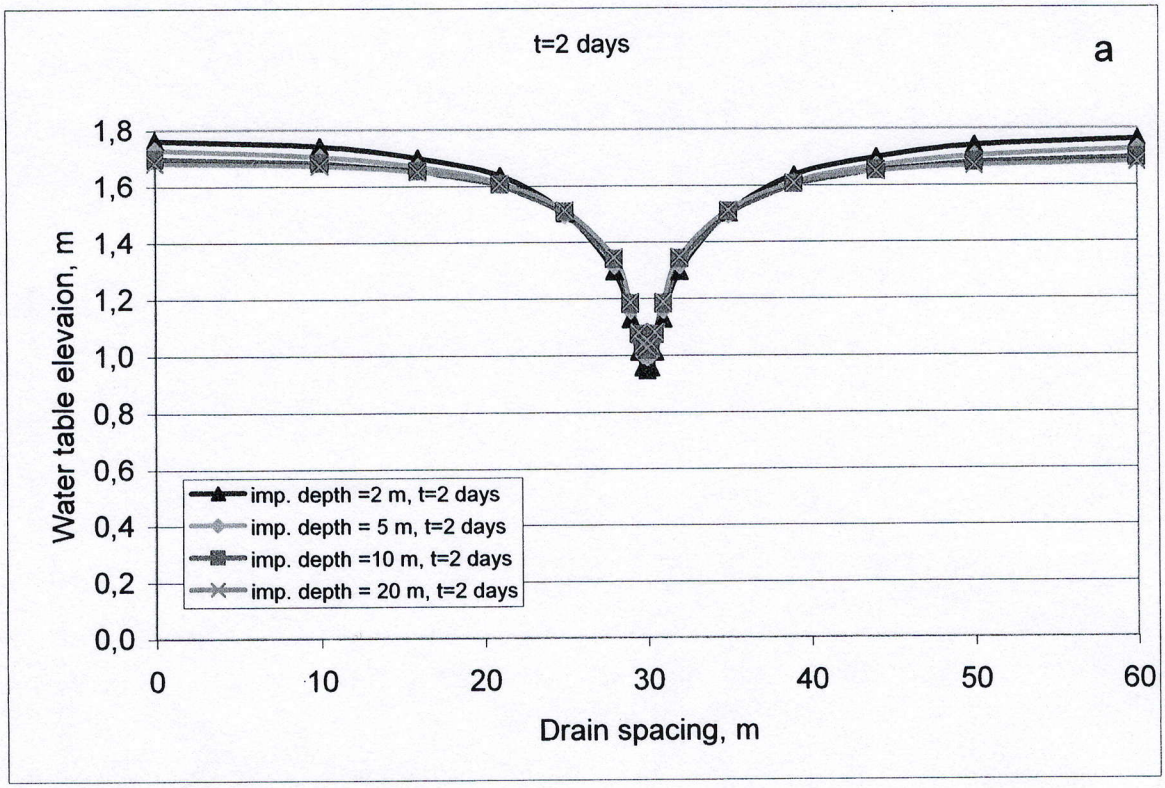
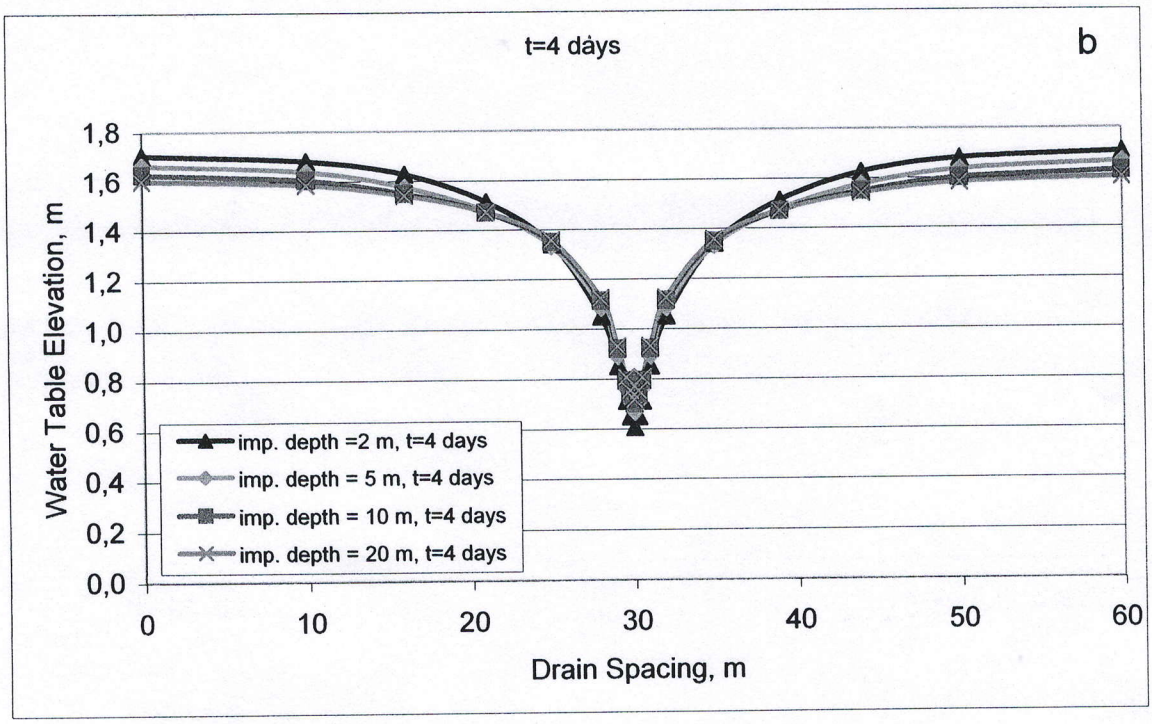
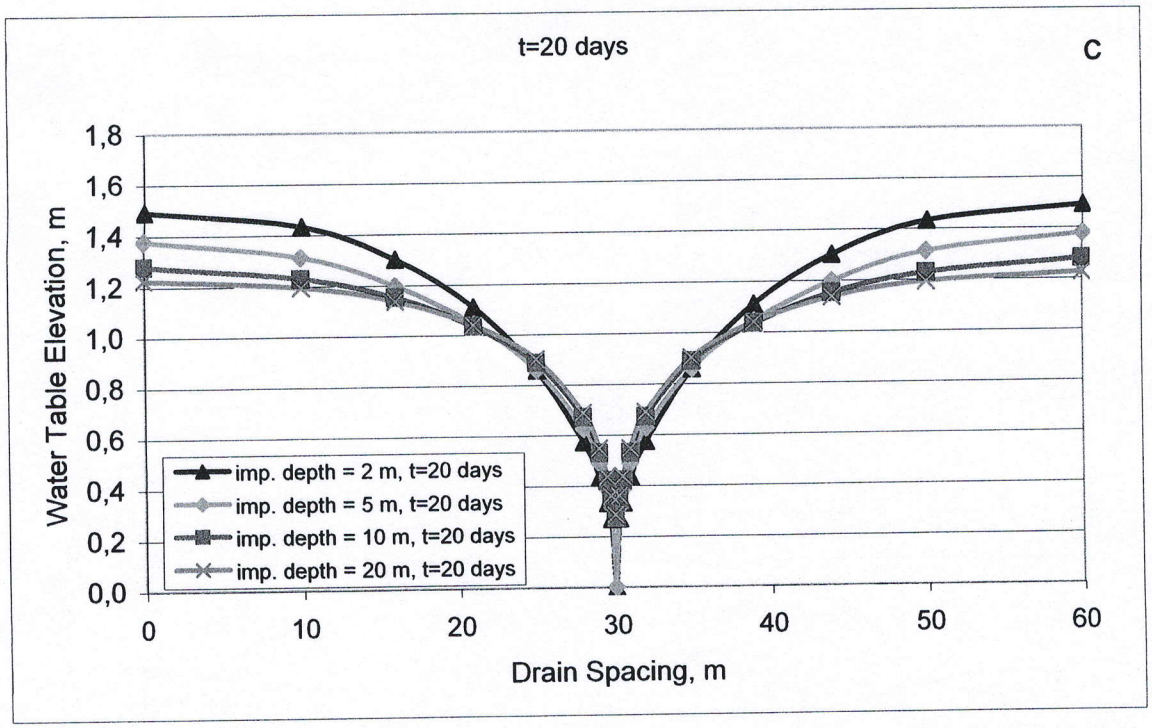
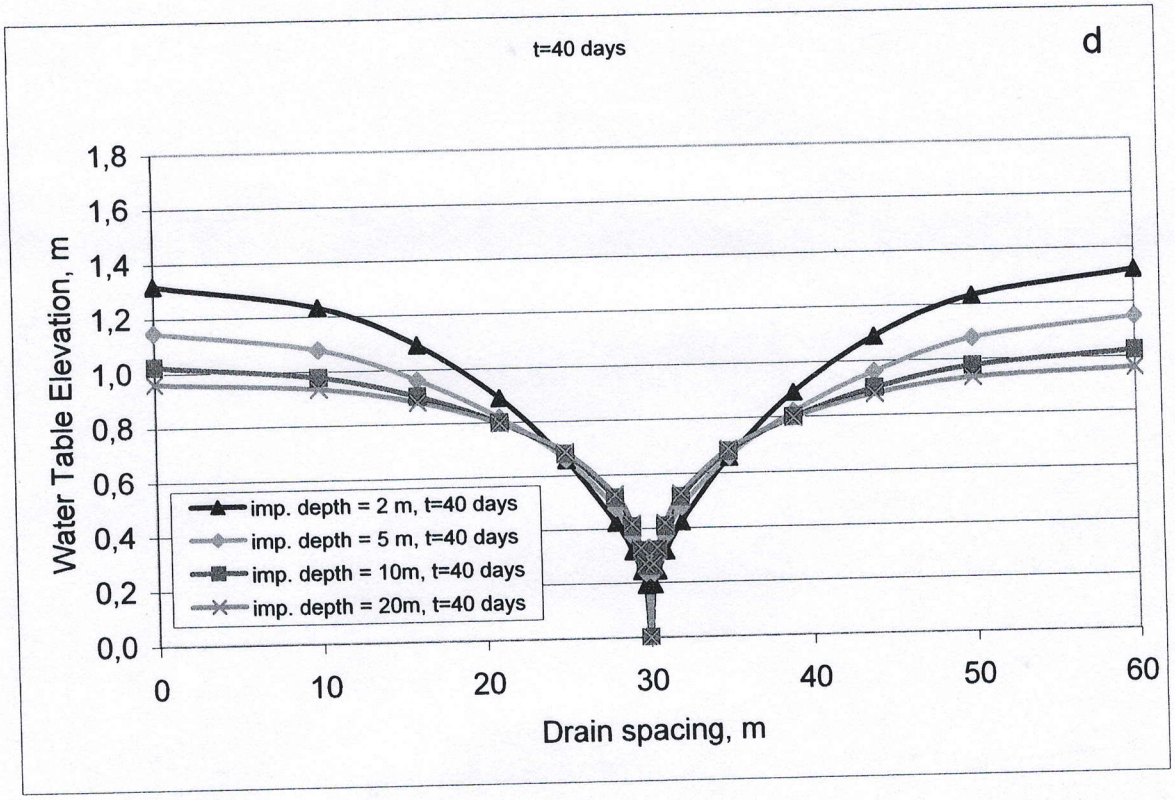


Figure 6. Evolution of water table depth for the impervious depth of 2 m. (Soil texture=silt loam, S=60 m, d=1.8 m)




t=4 days
b
Water Table Elevation, m
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
0
10
20
30
40
50
60
Drain Spacing, m
imp. depth =2 m, t=4 days
imp. depth = 5 m, t=4 days
imp. depth = 10 m, t=4 days
imp. depth = 20 m, t=4 days


t=20 days
c
Water Table Elevation, m
1,8
1,6
1,4
1,2
1,0
0,8
0,6
0,4
0,2
0,0
0
10
20
30
40
50
60
Drain Spacing, m
imp. depth = 2 m, t=20 days
imp. depth = 5 m, t=20 days
imp. depth = 10 m, t=20 days
imp. depth = 20 m, t=20 days



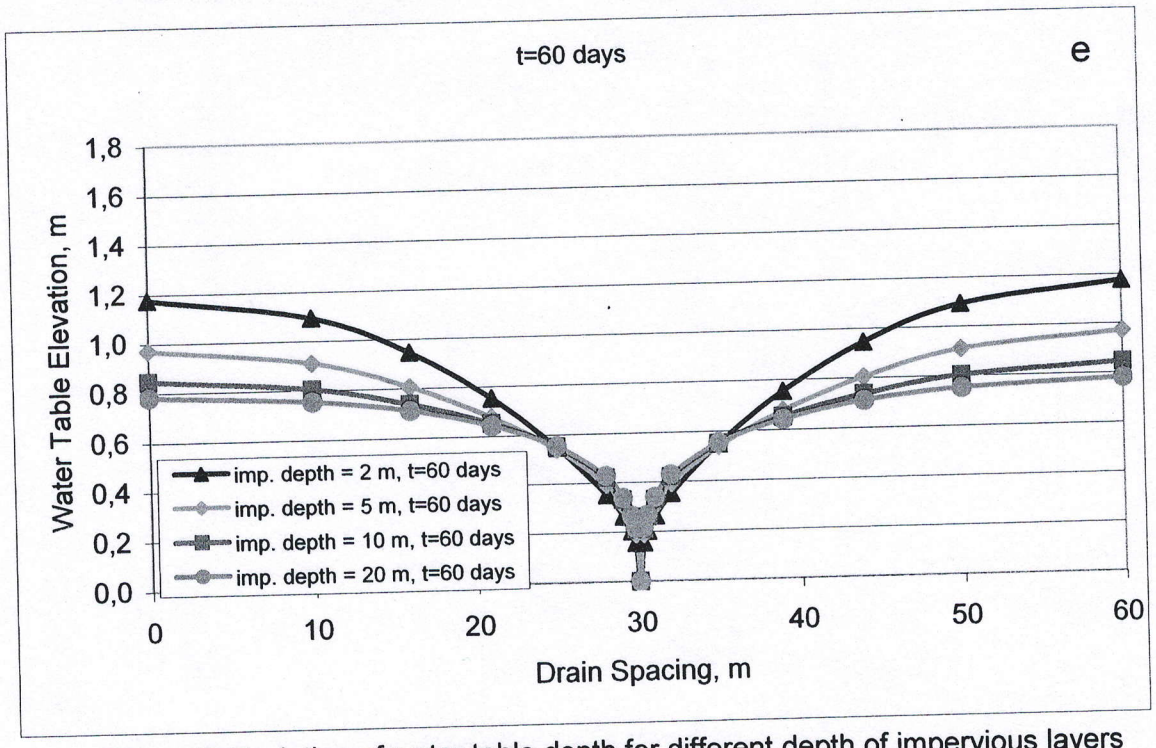


Figure 7. Evolution of water table depth for different depth of impervious layers (Soil=silt loam, S=60 m, d=1.8 m).

CONCLUSION

Results for a simple domain given above demonstrate that the numerical simulation models can be used to analyze performance of alternative drainage systems and to optimize the drainage design. Such analyses are often not possible in practice because of time constraints, absence of meteorological and other input data.

This study also can be extended to include the effect of drainage on crop yield and water quality.

REFERENCES

Ayars, J.E., Grismer, M.E. and Guitjens, J.C. 1997. Water quality as design criterion in drainage water management systems. *ASCE J. of Irrig. And Drain. Engng.*, 123: 154-158.

Buyuktas, D. and Wallender, W.W. 2002. Enhanced subsurface irrigation hydrology model. *ASCE J. of Irrig. And Drain. Engng.*, 128: 168-174.

Carsel, R.F. and Parrish, R.S. 1988. Developing joint probability distributions of soil water retention characteristics. *Water Resour. Research*, 24: 755-769.

Feddes, R.A., Kabat, P., Van Bakel, P.J.T., Bronswijk, J.J.B. and Halbertsma, J. 1988. Modelling soil water dynamics in the unsaturated zone-state of the art. J. *of Hydrology,* 100: 69-111.

Fipps, G., Skaggs, R.W. and Nieber, J.L. 1986. Drain as a boundary condition in finite elements. *Water Resour. Research,* 22: 1613-1621.

Grismer, M.E. 1993. Subsurface drainage system design and drain water quality. *ASCE J. of Irrig. And Drain. Engng.*, 119: 537-543.

Hillel, D. 1998. Environmental Soil Physics. Academic Press, London, 768 pp.

Madramootoo, C.A., 1999. Planning and design of drainage systems. In: agricultural drainage, ed. R.W. Skaggs and J.van Schilfgaarde, Agronomy Monograph of ASAE No 38, p. 871-892.

McWorther, D.B., Marinelli, F. 1999. Theory of soil water flow. In: Agricultural Drainage, ed. R.W. Skaggs and J. van Schilfgaarde, Agronomy Monograph of ASAE No 38, p. 111-144.

Nieber, J.L., Feddes, R.A. 1999. Solutions for combined saturated and unsaturated flow. In: Agricultural Drainage, ed. R.W. Skaggs and J. van Schilfgaarde, Agronomy Monograph of ASAE No 38, p. 145-212.

SCS (Soil Conservation Service). 1973. Drainage of Agricultural Land. Water Information Center, Inc. New York, pp 430.

Simunek, J., Huang, K. and van Genuchten, M.Th. 1995. The SWMS_3D Code for Simulating Water Flow and Solute Transport in Three-dimensional Variably Saturated Media. USSL/ARS, Report No 139.

Somma, F., Hopmans, J.W. and Clausnitzer, V. 1995. Transient three-dimensional modeling of soil water and solute transport with root growth, root water and nutrient uptake. *Plant and Soil*, 202: 281-293.

Srivastava, R. and Yeh, T.C.J. 1992. A three-dimensional numerical model for flow and transport of chemically reactive solute through porous media under variable saturated conditions. *Adv. in Water Res.*, 15: 275-287.

Vimoke, B.S., Tyra, T.D., Thiel, T.J. and Taylor, G.S. 1963. Improvements in construction and use of resistance networks for studying drainage problems. Soil Sci. Soc. Am. J., 26: 203-207.