MODELING THE MOVEMENT OF NITRATES THROUGH THE SANDY SOIL CONSIDERING HOMOGENOUS SOIL PROFILE

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Nitrate is one of the most common chemical contaminant found in groundwater because it is a moderate solute in soils and could move quickly through the soil profile leading to plant nutrient loss and groundwater pollution. The intensive application of nitrogen fertilizers in agriculture can cause nitrate contamination of ground water above the 50 mg NO3-/L (WHO guideline value for drinking water).This paper reports an application of a model in order to investigate the migration process of nitrates through the sandy soil under different pore water velocities. The tests were carried out using two dimensional numerical models SEEP/W and CTRAN/W with homogeneous soil. SEEP/W computes the water flow velocity, volumetric water content, and water flux and CTRAN/W uses these parameters to compute the contaminant migration. These models are useful tools in predicting the effects of measures and can be used to optimize agricultural practice aiming to minimize the impact on the environment. For the sandy soil, the amount of nitrate adsorbed into the soil is higher than any other soil types such as loam or clay. Nitrate sorption in the sand is influenced by environmental Conditions such as temperature, humidity, type of natural soil and common irrigation practices. The results also show that water pressure and nitrate concentration was highly affected by soil type and water application boundary conditions. All of these variables are contributing to the migration process of nitrate in soil.

Keywords: nitrate concentration, Advection-dispersion Process, Two-dimensional Model, Homogeneous soils.

INTRODUCTION

The leakage of agriculture wastewater through vadose zone to the groundwater is considered a massive problem to the public health because of possible contaminants of drinking water in case of groundwater is the source of drinking. Agricultural wastewater is mainly consists of Nutrients (nitrogen and phosphorus) that is typically applied to farmland as commercial fertilizer (inorganic nitrogen fertilizers) and animal manure. Nitrates are mainly produced for use as fertilizers in agriculture because of their high solubility and biodegradability (Wang and Wang, 2008).

The infiltration of N- containing pollutants from surface water and the transport of nitrate contaminants through soil and groundwater occur via a series of complex chemical and hydraulic phenomena (Wang and Wang, 2008). Therefore, in many agricultural areas the values of nitrate in groundwater are higher (Bonton et al., 2012) than the 50 mg NO3-/L guideline value for drinking water of World Health Organization (WHO, 2011).

The groundwater pollution by nitrate is an international problem (Roberts and Marsh, 1987; Meybech *et al.*, 1989; Spalding and Exner, 1993; Zhang *et al.*, 1996; Lerner, 1999; Wakida and Lerner, 2002). Nitrate (NO3-) is a leaching pollutant from fertilizer application in soil and groundwater (Chotpantarat *et al.*, 2011). The pollution of groundwater by nitrate (NO3-) has been a frequent matter in aquifers in the world (UNEPE, 1991).

The transport process of nitrate contaminants through soil and groundwater occurs via a series of complex chemical and hydraulic phenomena (Wang and Wang, 2008). The high doses of nitrogenous/phosphorous fertilizer applied to the soil immediately followed by massive irrigation water causes some nitrogen losses and risk of nitrates penetration to subsoil, Thus once ecosystems are contaminated by these elements, they become potential threat for many years (Shivasharanappa *et al.*, 2013; Novakova and Nagel, 2009). The choice of using two software, CTRAN/W is used in conjunction with SEEP/W, makes it possible to analyze problems varying from simple particle tracking in response to the movement of water, to complex processes involving diffusion, dispersion, adsorption, radioactive decay and density dependencies.

METHODS - NUMERICAL SOLUTION OF THE PROBLEM

There are many numerical solution methods such as Finite Differences (FDM), Finite Elements (FEM) and Boundary Elements (BEM). The FEM is an effective numerical technique because of its numerous applied fields such as groundwater flow, multiphase flow, and mass flow through pours medium. It is flexible in simulation.

General Description of SEEP/W and CTRAN/W Models

SEEP/W is a finite element software product for analyzing groundwater seepage and excess pore-water pressure dissipation problems within porous materials such as soil and rock. SEEP/W can model, in addition to traditional steady-state saturated flow, both saturated and unsaturated flow, that makes it possible to analyze seepage as a function of time and to consider such processes as the infiltration of precipitation.

CTRAN/W is a finite element software product that can be used to model the movement of contaminants through porous materials such as soil and rock. CTRAN/W utilizes the SEEP/W flow velocities to compute the movement of dissolved constituents in the pore-water. The following is the one-dimensional form of the advection-dispersion equation (Geo-Slope User’s Guide). Where C is the concentration, θ is the volumetric water content, D is the hydrodynamic dispersion coefficient, U is the Darcy velocity, S is the adsorption, ρd is the bulk mass density of the porous medium, t is the time, and x is the distance in the x direction. The first term in the equation represents transport by dispersion, the second represents transport by advection, the third represents decayed mass loss in the fluid phase, and the fourth represents decayed mass loss in the solid phase. The term on the right side of the equation represents storage of mass in the fluid phase and in the solid phase due to a change in concentration.

The aim of this study is to model the movement of nitrates as a fertilizer applied in agricultural lands towards drain side and the risk which may be occurred when this contaminant reach the drain's water in sand soil. The flow is considered to be steady-state, two dimensional in a homogeneous isotropic porous media.

MODEL DESCRIPTION

The self-diffusion coefficient for representative anion (NO3-) at infinite dilution in water at 250C is D0=19*10-10 (m2/s). The model is two dimension, the hydraulic conductivities Kx/Ky =1, the porosity (n) = 50%, the longitudinal dispersivity / transverse dispersivity =2 and the time step sequence consists of ten steps. Time starts in zero days and ends in 100 days.

Table 1. Parameters of hydraulic functions for sand used in the simulation

Parameter	Value
Saturated water content (θ_s)	(0.65 m^3/m^3)
Residual water content (θ_r)	($1.01*10^{-4}$m/s)
Saturated hydraulic conductivity (K_s)	(0.30 m^3/m^3)

Table 2. The adsorption capacity for sand at 15°C, 25°C, and 35°C

C_0 (mg/L)	15°C *Qeq* (mg/g)	25°C *Qeq* (mg/g)	35°C *Qeq* (mg/g)
25	0.038	0.040	0.027
50	0.091	0.087	0.060
100	0.199	0.186	0.131
200	0.425	0.412	0.300
500	1.249	1.132	0.851

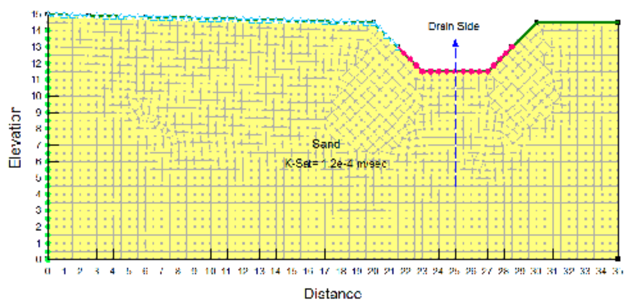


Figure 1. The domain mesh showing the boundary conditions for SEEP/W analysis

MODEL RESULTS AND DISCUSSION

In order to model the contaminant migration in unsaturated soil, SEEP/W was firstly run. After set the geometry (35 m in length x 15 m in depth soil) and the grid (mesh 0.5x 0.5 m) as shown in figure 1.

The SEEP/W contour function allows one to graphically view the results by displaying velocity vectors that represent the flow direction. A vector is drawn in each element. The vector represents the average velocity within the element. The seepage flow velocities computed from SEEP/W are then used by CTRAN/W for the contaminant transport analysis.

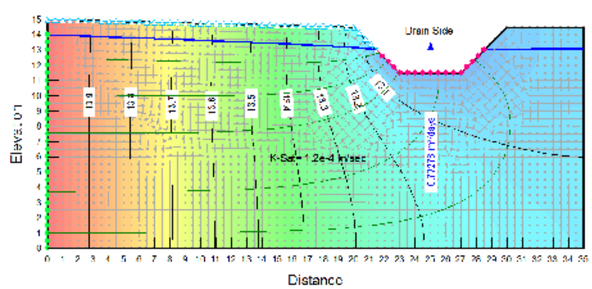
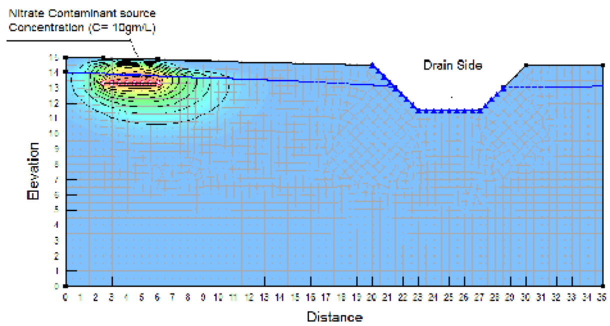
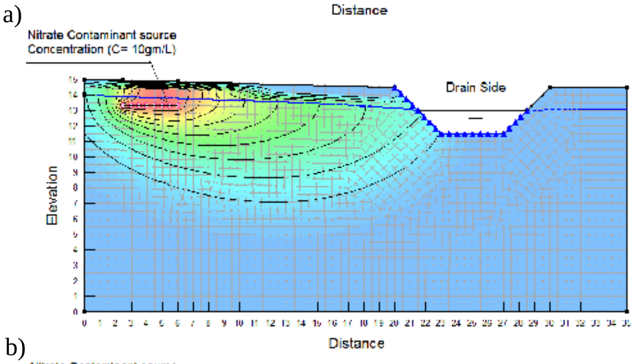


Figure 2. Total head distribution and flux section at the drain side

In the advection-dispersion analysis, adsorption of contaminant on the soil particles is linearly related to concentration. This is the concept of chemical partitioning between the fluid and solid phases. This means that the chemical partitioning coefficient, (which is the slope of the adsorption/concentration function), can be specified as a function of concentration. Figures 3(a-d) are graphical representations of advection-dispersion of nitrate; starting concentration (10 gm/l) = (10000 gm/m^3).



a)



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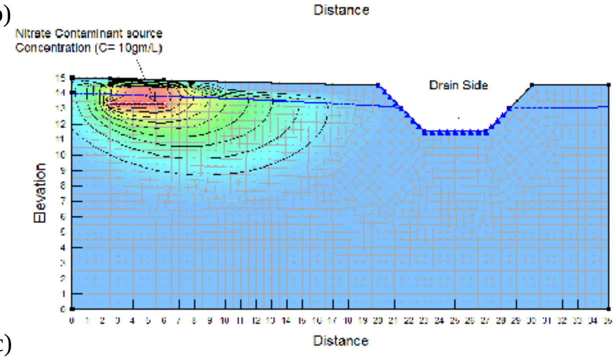
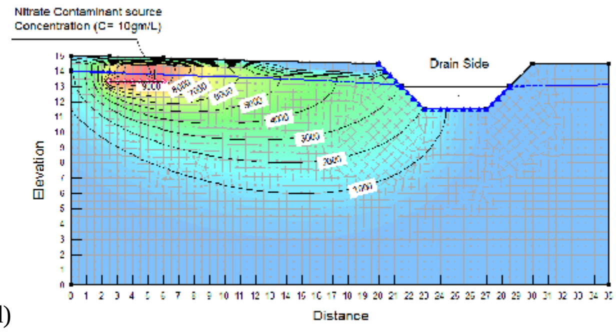


c)



d)

Figure 3. Advection-dispersion analysis after: a) 10 days, b) 30 days, c) 60 days, d) 100 days

In case of using sheet pile, the water flux at the drain side equals (0.62258 m3/days) this value is less than the flux without using the sheet pile, this reflects that the water flow velocity has decreased.

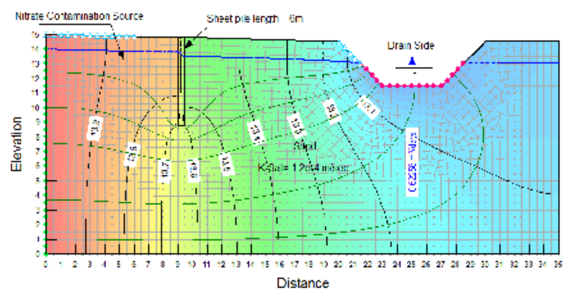


Figure 4. Total head distribution and flux at the drain side in case of using sheet pile

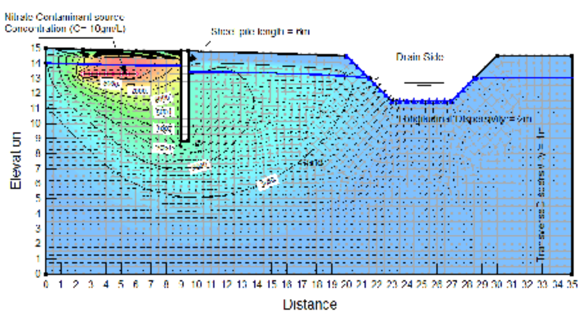


Figure 5. Advection-dispersion analysis after 100 days using sheet pile

CONCLUSION

The following conclusions are made, based on the studies in the literature and on the discussion presented in this study:

The movement velocity of contaminants in course soils (gravel and sand) is greater than its movement in fine soil (silt and clay). In case of increasing time, the existence of the contaminants is in a far distance in the soil media.

The distance of contaminant transport significantly depends on the hydraulic conductivity of the soil and the diffusion coefficient (D_0) of contaminant Anion or Cation.

The average particles tracking velocity in the soil significantly depends on the water velocity and their total distance traveled depends on the time.

The total flux at drain side is decreased in case of using the sheet pile rather than the useless of the sheet pile because the velocities magnitudes have decreased.

The head of water above the contaminant source affects significantly on the contaminant transport process rather than the difference in water level between the agricultural land and the drain side.

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REFERENCES

Akosman, C., Ozdemir, T. (2010), “Adsorption Dynamic and Equilibrium Studies of Nitrate onto Various Soils”, *Fresenius Environmental Bulletin*, 19(10).

Chotpantarat, S., Limpakanwech, C., Siriwong, W., Siripattanakul, S. and Sutthirat, C. (2011), “Effect of Soil Water Characteristics Curves in Simulation of Nitrate Vertical Transport in Thai Agricultural Soil”, *Sustainable Environmental Resources*, 21(3), 187-193.

GEO-SLOPE User’s Guide, CTRAN/W and SEEP/W: http://www.geoslope.com.

Gunatilake, S.K., Iwao, Y. (2010), “A Comparison of Nitrate Distribution in Shallow Groundwater of Two Agricultural Areas in Sri Lanka and in Japan”, *Sabaramuwa University Journal*, 9(1), 81-95.

Jassam, M., Khattab, S., Bouasker, M., Dufour, A., Jozja, N., Defarge, C. and AL-Mukhtar, M. (2014), “Transport of Nitrate through Saturated-Unsaturated Soils Considering non homogeneous Soil Profile”, *International Journal of Geology, Earth & Environmental Sciences*, 4(1), 8-22.

Meybeck, M., Chapman, D. and Helman, P. (1989), “Global Freshwater Quality: A first assessment, global environment monitoring system”, UNEP/WHO.

Novakova, K. and Nagel, D. (2009), “The Influence of Irrigation on Nitrates Movement in Soil and Risk of Subsoil Contamination”, *Soil & Water Resources*, 4(2), 131-136.

Roberts, G. and Marsh, T. (1987), “The Effect of Agricultural Practices on the Nitrate Concentrations in the Surface Water Domestic Supply Sources of Western Europe”, *IAHS*, 164, 365-380.

Shivasharanappa, Padaki Srinivas and Srinivas Kushtagi (2013), “Adsorption Studies of Nitrate by Geo-Physical Environment (Lateritic soil) of the Study Area Bidar Urban & its Industrial Area, Karnataka State, India”, *International Letters of Chemistry, Physics and Astronomy*, 6, 66-76.

Siracusa, G., La Rosa, A.D., Musumeci, L. (2007), “Modeling of Contaminant Migration in Unsaturated Soils”, *WIT Transactions on Ecology and the Environment*, 102.

Spalding, R.F. and Exner, M.E. (1993), “Occurrence of Nitrate in Groundwater - A review”, *Journal of Environmental Quality*, 22, 392-402.

Van Dam, J.C., Feddes, R.A. (2000), “Numerical Simulation of Infiltration, Evaporation and Shallow Groundwater levels with Richards's equation”, *Journal of Hydraulic*, 233, 72–85.

Wakida, F.T. and Lerner, D.N. (2002), “Nitrate Leaching from Construction Sites to Groundwater in Nottingham, UK, urban area”, *Water Sci. Technology*, 45, 243-248.

Wang, C. and Wang, P.F. (2008), “Migration of Infiltrated NH4 and NO3 in a Soil and Groundwater System Simulated by a Soil Tank”, *Journal of Soil Science Society of China*, 18(5), 628-637.

Zhang, W.I., Tian, Z.X., Zhang, N. and Li, X.Q. (1996), “Nitrate Pollution of Groundwater in Northen China”, *Agricultural Ecosystem Environment*, 59, 223-231.