INVESTIGATING THE EFFECT OF VERTICAL BARRIERS WALLS ON PHOSPHATE TRANSPORT THROUGHT LAYERED SOIL VIA NUMERICAL SIMULATION

Mohamed Galal Eltarabily[1], Abdelazim M. Negm[2], Oliver C. Saavedra Valeriano [3]

[1] PhD Student, Environmental Engineering Dept., School of Energy and Environmental Engineering, Egypt- Japan University of Science and Technology (E-JUST). New Borg Al-Arab City. Postal Code 21934, Alexandria, mohamed.eltarabily@ejust.edu.eg

[2] Chair of Environmental Engineering Dept.,School of Energy and Environmental Engineering, Egypt- Japan University of Science and Technology (E-JUST). New Borg Al-Arab City. Postal Code 21934, Alexandria, negm@ejust.edu.eg

3 Dr. of Eng., Associate Professor, Dept. of Civil Engineering, Tokyo Institute of Technology(2-12-1 Oookayama, Meguro, Tokyo 152-0033, Japan), Also at E-JUST saavedra.o.aa@m.titech.ac.jp

ABSTRACT

The contaminants, which are resulting from the wastes of agricultural lands, are considered among the sources of pollution of irrigation water in Irrigation and drainage network in Egypt. Due to the excessive use of fertilizers in agricultural processes and the traditional method of irrigation, they represent the largest component of agricultural residues.Fertilizers also affect the irrigation water quality leading to deterioration and degradation of water resources. This research aims to control the transport process of the extensive amount of phosphate, which applied to agricultural lands as a fertilizer in order to protect the irrigation water from being polluted. The behavior of phosphate transport through layered soil is tested when vertical walls of sheet piles are used as a protection method. The parameters are the change of the arrangement of soil layers, penetration depth of protection wall, location of walls from the pollution source, and the head difference of the water level between the agricultural lands and canals or drains side.This model has been simulated numerically by using two finite elements programs; SEEP/W and CTRAN/W as a part of GEOSLOPE software package. The results show that when the hydraulic conductivityof soil is less than 1×10^{-8} (m/sec), the flow velocity is small and the existence of sheet pile is insignificant.Also the order and numbers of soil layers play an important role in the extent and concentration of the phosphateso the vertical barrier will not be effective till it penetrates the impervious layer.The change in head difference has insignificant effect on the contaminant migration process. Finally, the best location is at the contaminant side and the penetration depth of the vertical barrier to reach the impervious layer is determined to reduce the proportion of the reached phosphateto attain the maximum possible protection of the irrigation water.

Keywords: Contaminants,Phosphate transport,Advection-diffusion process, Sheet pile, Finite element**.**

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1 INTRODUCTION

The extensive use of fertilizers and pesticides that modern agricultural activities are based on are considered the main source for the growth of crops. The contamination of the groundwater has occurred when some of the chemicals which applied to farm land move down with the deep percolating water from the root zone(Ratnojiand Shilpa 2001). The surface irrigation water in canals is also contaminated by the runoff of these contaminants from agricultural lands towards them alsomost of the phosphate (*P*) applied in the form of fertilizers may be adsorbed by the soil, and is not available for plants lacking specific adaptations(NaseriA. et al., 2011),(Balemi and Negisho2012).

The significance of phosphate (*P*) pollution from agricultural non-point sources (NPS) to surface waters has been an environmental concern for researchers and investigators in the past decades, due to its contribution to eutrophication, making the water unsuitable for drinking, industrial, recreational uses, and for fisheries (Sharply and Menzel, 1987).the phosphate is mainly lost from the field by surface runoff and soil erosion, Monitoring stations were installed to survey water quality from tile drained fields in southern Quebec. (Gollamudi, 2006); (Simard, 2005)showed that more than 40% of total phosphate (*P*) lost from the field is through subsurface runoff of drains.

The increasing use of plant phosphate in agriculture, mainly through inorganic fertilizers, contributes nutrients to water sources because plants do not absorb all of them applied on the land (Singh et al., 2000). The complication of the problem becomes more when dealing with different kinds of soil with varying properties.So, it is important to limit the application of fertilizers and monitor their movement in the unsaturated zone (Vadas P.A. et al., 2008). While many agricultural chemicals are generally beneficial in surface soils, their leaching into the deeper vadose zone and groundwater may pose serious problems. Thus, management processes are being sought to keep fertilizers and pesticides in the root zone alsothe concentration of the contaminant is decreased with depth and time(Jiri Simunek and Martinus Th., 2001); (Dike1B. U. et al., 2013)

The dispersion–advection equation is the most effective method for representation of contaminant transport through unsaturated soil which is affected by the volumetric water content of the soil, which, in turn, has an impact on the coefficients of diffusion and dispersion only in unsaturated flow and when the water flow rate is very low (Fityus, S.G. et al., 1999). Constant diffusion of a chemical substance in a free solution can be experimentally simulated by Ficks' first law (Fredlun, D. G. and Rahardjo, H.,1993). (Anderson, and Mesa, 2006) investigated the effect of vertical barrier walls on the hydraulic control of contaminated groundwater. They used impermeable circular arc wall with finite length where the center of curvature is downstream the arc. The domain is homogenous and the flow is steady and uniform. They found that there is a large region of low discharge which may be used to slow the movement of contamination. The rate of advective contamination transport can be significantly reduced when the wall placed up gradient of contaminant source rather than down gradient, where it reduces the plume width as reported by Mesa and Elizabth,(2005).

This study utilized numerical modeling program in simulating the phosphate fertilizers transport process through region consists of three layers of different physical and hydraulic properties of coarse sand, fine to medium sand, andsilty clay soil. This numerical simulation was performed using the finite element package of GEO-STUDIO by using sheet pile as a barrier wall with changing its location from the contamination source, penetration depth and the arrangement of the soil layers. Also changing groundwater level, in different seasons between the agricultural land side which consider the pollution source and the canal or drain side which contains the irrigation water. The phosphate fertilizer is considered one of the common fertilizers which are used in agricultures works, there for the phosphate anions are taken in consideration because they form different compounds of phosphate fertilizers such as mono ammonium phosphate, mono potassium phosphate, mono potassium phosphite, and phosphate acid.

2 NUMERICAL SOLUTION OF THE PROBLEM

Geo-Studio 2007 software is used. The modules which are used in this work are two. The first module (SEEP/W) is the flow module, which computes the water levels, and piezometer heads. The secondmodule (CTRAN/W) is the transport module, which uses the data from the flow module to determineadvective displacement, additional diffusion through dispersion, and chemical transformation. The flow studies were developed in SEEP/W to establish saturated and unsaturated conditions. The flow system established with SEEP/W was used in CTRAN/W to analyze contaminant movement. For each materials (coarse sand, fine to medium sand, and silty clay) model in SEEP/W, volumetric water content and hydraulic conductivity functions are required.

Two dimensions mesh is used for both SEEP/W and CTRAN/W programs to simulate the studied cases. The elements in the soil wereapproximately (0.5*0.5m) length with infinite element at both right and left sides. The mesh is 100 meters long and 18 meters depth. The dimensions of the agricultural land site are (20.0m) long submerged with 0.50m high of water. The canal cross section at right side is trapezoidal cross section with bottom width 3.0m and 1:1 side slopes. The sheet pile distances are 10.0m, 30.0m, and 50.0m from the end of agricultural land side and the penetration depths changed three times from five meters from the ground level to be ten meters to reach fifteen meters with constant width (0.25m). The arrangement of the three layers of soil used was changed to be coarse sand, fine to medium sand, and silty clay from the ground surface to bottom respectively, and to be coarse sand, silty clay, and fine to medium sand from the ground to bottom respectively. For each case, each layer has a thickness of (6.0 m). The domain is illustrated in Figure1.

For CTRAN/W variables, the average diffusion coefficient of phosphate anion (PO_3^{-3}) is ($1*10^{-12}$ m^2/sec) according to the volumetric water content of the soil. The adsorption function depends on the concentration of the phosphate. The initial concentration at the source of contamination is (10000 g/m³) of phosphate.The time step sequence consists of 20 steps. Time starts by Zero day ends by 200 days, the longitudinal dispersivity/transverse dispersivity = 2 and the decay- half life is ignored.

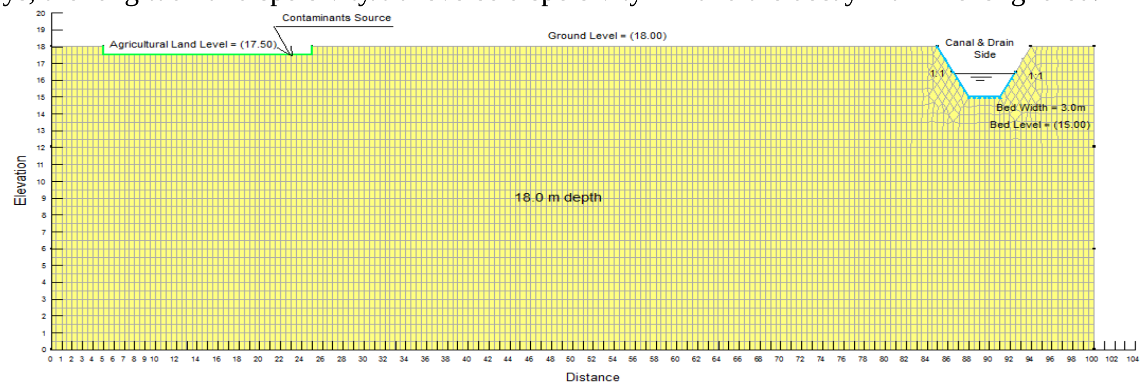

Figure 1. Model dimension and boundary conditions

3 MATERIALS AND METHODS

Three soils were used in this study namely, coarse sand and fine to medium sand which were collected from Bir al-Abd area near El-Arish city in Sinaiand silty clay from Sahl El-Tena area near Qantarah city. Some relevant properties of the soil samples is presented in Table 1.The numerical modelling for the transport process of phosphate is done three times. The first one is when the soil region considered to be all from coarse sand, the second is when the soil region consists of three layers(coarse sand, fine to medium sand, and silty clay) the third run is when the arrangement of the soil region is(coarse sand, silty clay, and fine to medium sand). For each case, the behavior of the phosphate transport as a fertilizer contaminant from agricultural land towards the parallel canal or drain is observed when using sheet pile as a vertical barrier wall at three different locations with different penetration depths.

Table 1. Parameters of hydraulic functions for soils used in the SEEP/W simulation.

Parameter	Coarse Sand	Fine to Medium Sand	Silty clay
Saturated water content *(θ_s)*	0.65[m^3/m^3]	0.41[m^3/m^3]	0.35[m^3/m^3]
Residual water content *(θ_r)*	0.32[m^3/m^3]	0.21[m^3/m^3]	0.12[m^3/m^3]
Saturated hydraulic conductivity *(K_s)*	0.001[m/s]	$1*10^{-5}$[m/s]	$1*10^{-8}$[m/s]

The sheet pile penetration depth is *(ds)*, and the total depth of soil region which equal 18.0m is *(Dt)*. The location of sheet pile from the end of agricultural land is *X(s.p)* and the net distance between the land and the canal or drain cross section is *X(total)*.

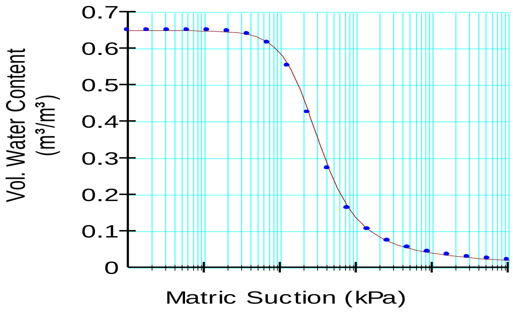

Figure 2. Vol. water content for coarse sand.

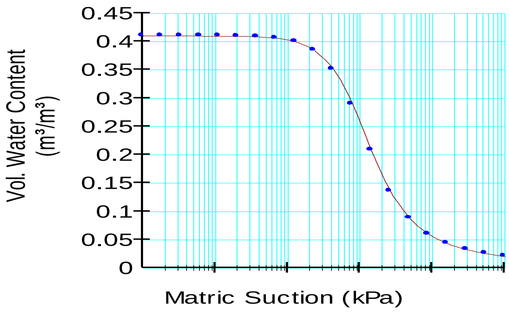

Figure 3. Vol. water content for fine to medium sand.

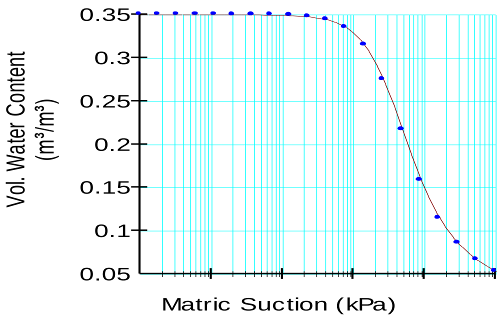

Figure 4. Vol. water content for silty clay soil.

4 RESULTS AND DISCUSSION

There are three models one is homogeneous from coarse sand and two are non-homogeneous with difference in the arrangement of the layers. For each model there are two cases, the original one without any controlling methods of transport process and the second by using the vertical barrier wall. The migration is reported as temporal variationof the contaminant concentration due to water percolation through the soil. Thered color indicates the maximum concentration while the blue indicates the minimum concentration.

4.1 Homogeneous Soil of Coarse Sand

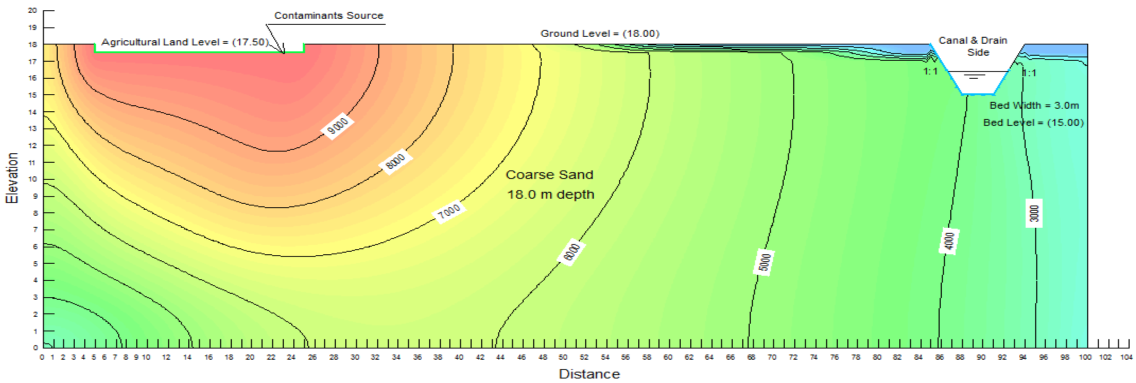

Figure 5. Contamination concentration without any sheet pile and t=100 days

4.1.1 Effect of sheet pile at the agricultural land side on contaminant transport

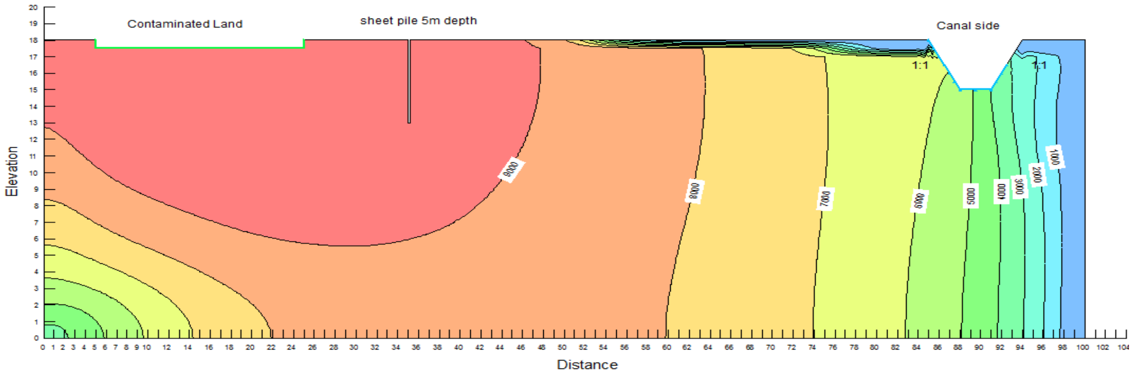

Figure 6. Contamination concentration with sheet pile, ds/Dt=0.278, X(s.p)/X(total)=0.20 and t=100 days

4.1.2 Effect of sheet pile at middle between land and the canal on contaminant transport

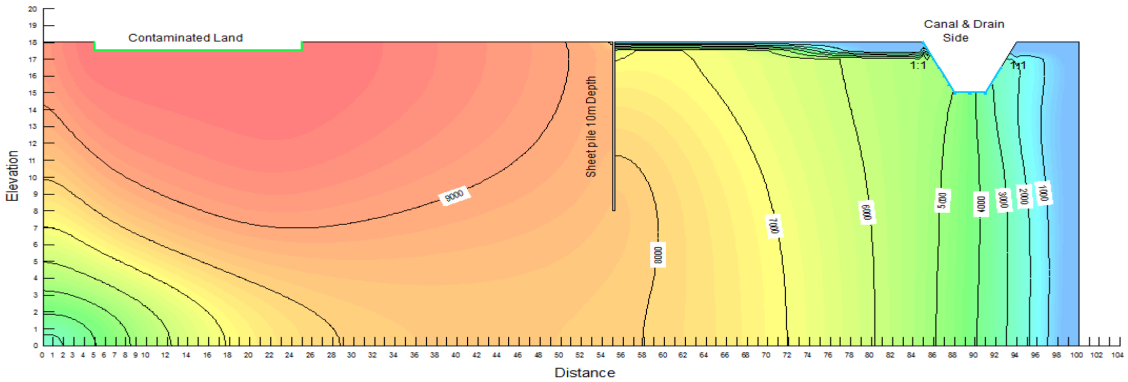

Figure 7. Contamination concentration with sheet pile, ds/Dt=0.556, X(s.p)/X(total)=0.50 and t=100 days

4.1.3 Effect of sheet pile at canal & drain side on contaminant transport

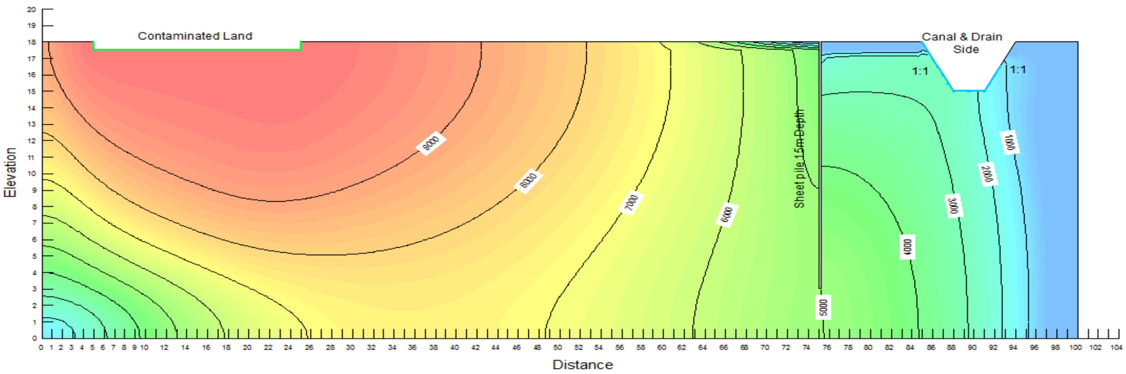

Figure 8. Contamination concentration with sheet pile, ds/Dt=0.833, X(s.p)/X(total)=0.80 and t=100 days

The concentration of phosphate at the beginning is equal 10000(g/m^3) at the agricultural land and after 100 days the contaminant reaches the toe of the slope with concentration as shown in Table 2.

Table 2. Phosphate contaminant at the slope toe after 100 days.

Contaminant Concentration in (g/m³)	Location of Sheet Pile / Net Distance Between Land & Canal *X(s.p) / X total*		
	0.2	0.5	0.8
ds/Dt =0.278	5622.33	5746.70	5745.0
ds/Dt =0.556	4656.69	4960.66	4868.86
ds/Dt =0.833	2534.56	3010.33	2781.23

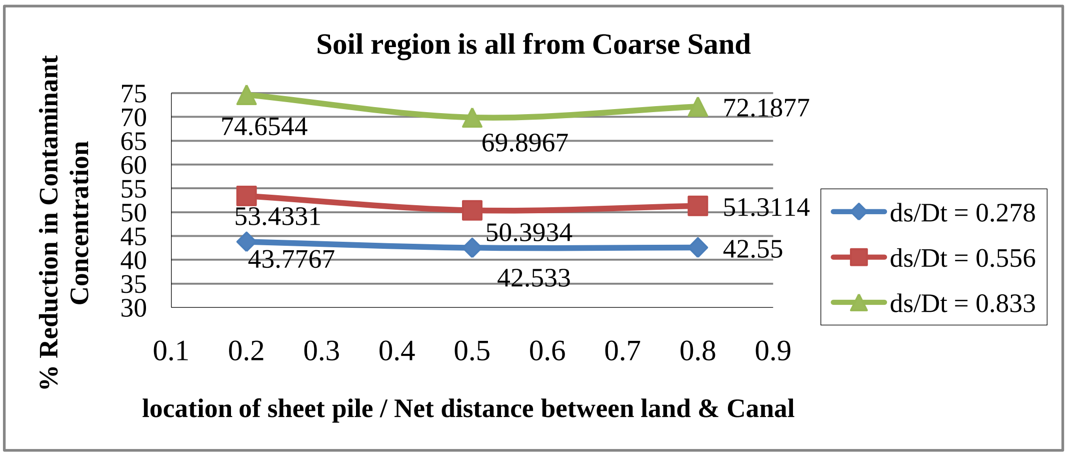

Figure 9. The reduction percentage in contamination concentration reach the toe of the slope

4.2 Layered soil (coarse sand, fine to medium sand, and silty clay)

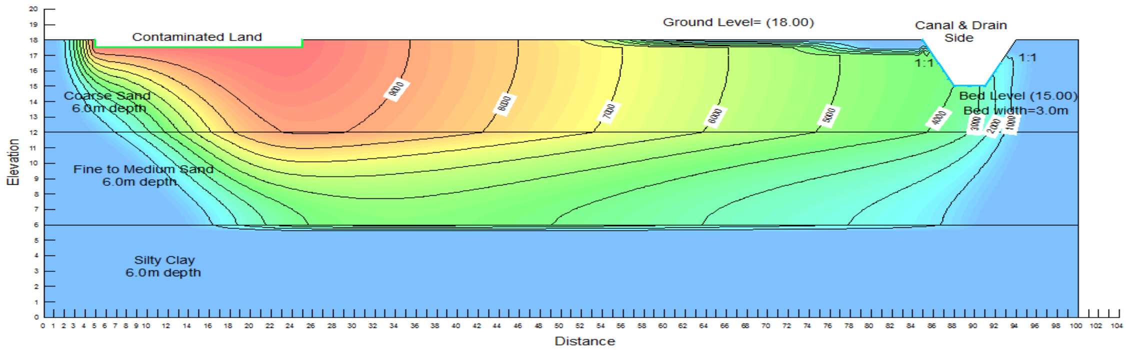

Figure 10. Contamination concentration without any sheet pile and t=100 days

4.2.1 Effect of sheet pile at the agricultural land side on contaminant transport

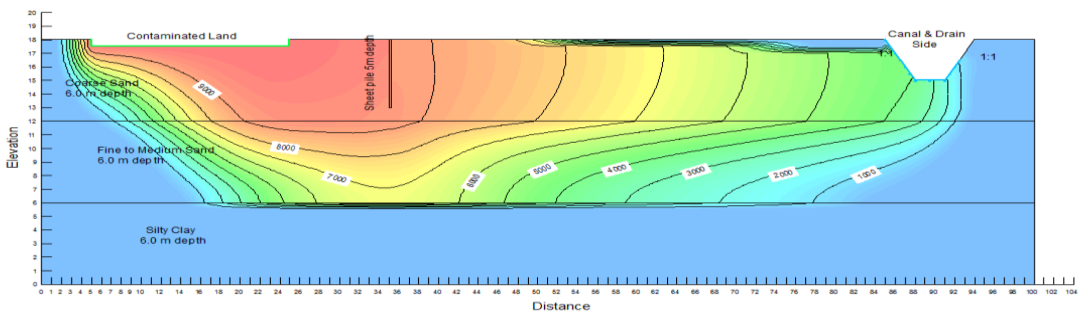

Figure 11. Contamination concentration with sheet pile, ds/Dt=0.278, X(s.p)/X(total)=0.20 and t=100 days

4.2.2 Effect of sheet pile at the middle between land and canal on contaminant transport

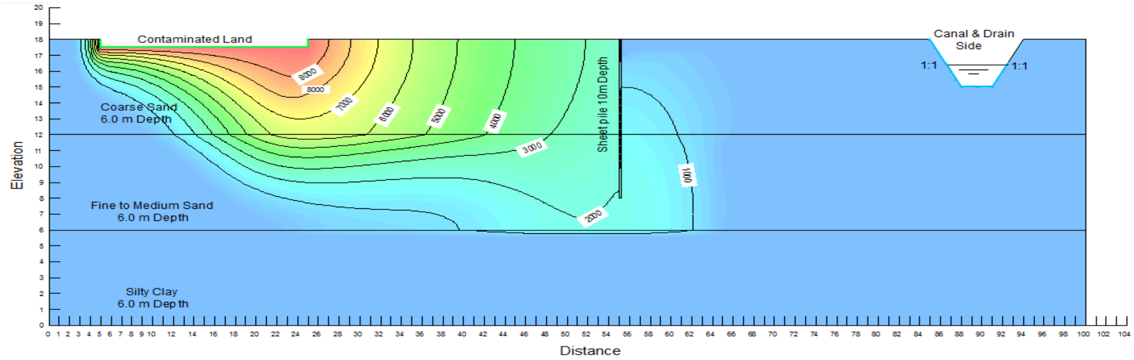

Figure 12.Contamination concentration with sheet pile, ds/Dt=0.556, X(s.p)/X(total)=0.50 and t=100 days

4.2.3 Effect of sheet pile at the canal & drain side on contaminant transport

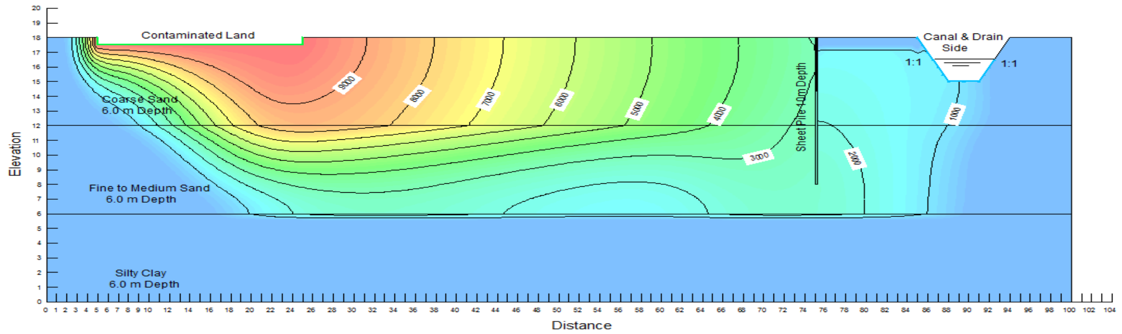

Figure 13. Contamination concentration with sheet pile, ds/Dt=0.556, X(s.p)/X(total)=0.80 and t=200 days

The concentration of phosphate at the beginning is equal 10000(g/m^3) at the agricultural land and after 100 days the contaminant reaches the toe of the slope when the sheet pile penetration depth/ total depth was 0.278, however when the sheet pile depth / total depth of the soil region was 0.556 or 0.833 the contaminant takes more time to reach the slope. Concentrations at the toe are shown in Table 3.

Table 3. Phosphate contaminant at the slope toe after 100days, 200 days.

Contaminant Concentration in (g/m³)	**Location of Sheet Pile / Net Distance Between Land & Canal *X(s.p) / X total***		
	0.2	0.5	0.8
ds/Dt =0.278 after 100 days	3893.35	3134.32	4166.82
ds/Dt =0.556 after 100 days	0.00	0.00	0.00
ds/Dt =0.556 after 200 days	1108.33	1206.30	1191.85

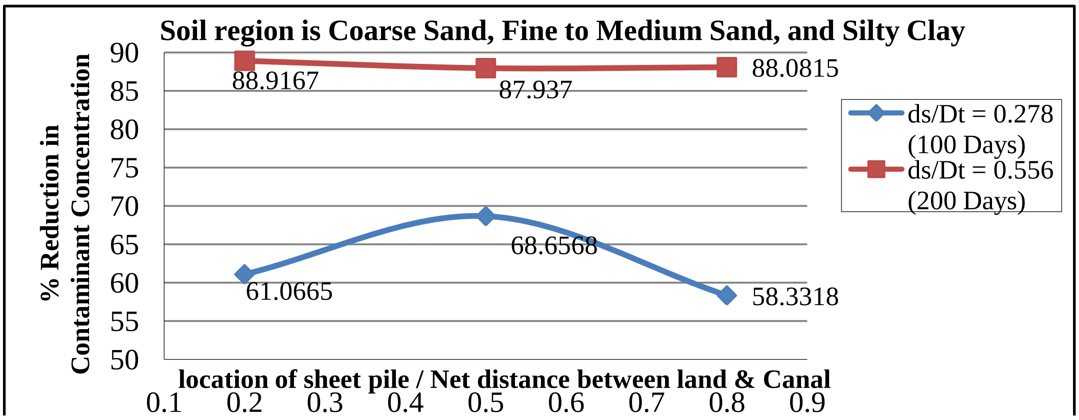

Figure 14. The reduction percentage in contamination concentration reach the toe of the slope

4.3 Layered soil (coarse sandsilty clay, and fine to medium sand)

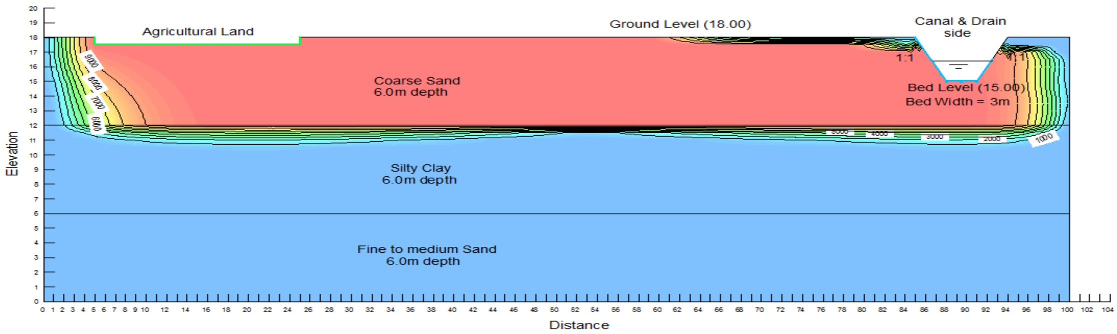

Figure 15. Contamination concentration without any sheet pile and t=100 days

4.3.1 Effect of sheet pile at the agricultural land side on contaminant transport

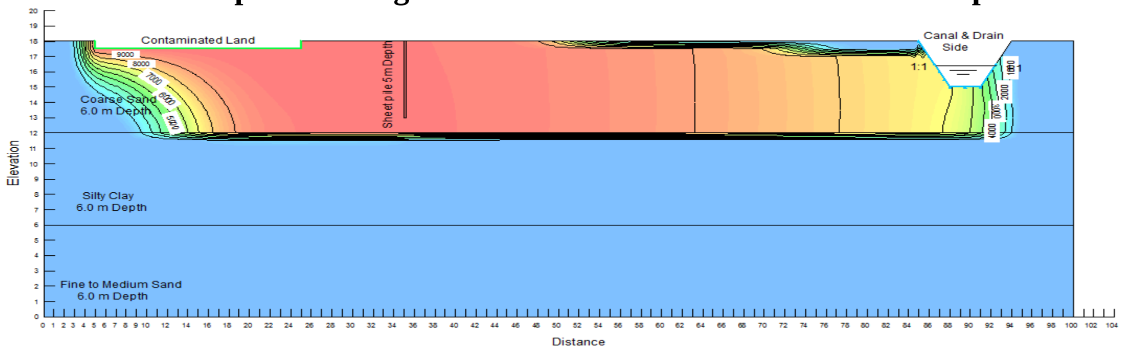

Figure 16. Contamination concentration with sheet pile, ds/Dt=0.278, X(s.p)/X(total)=0.20 and t=100 days

4.3.2 Effect of sheet pile at the middle between land and canal on contaminant transport

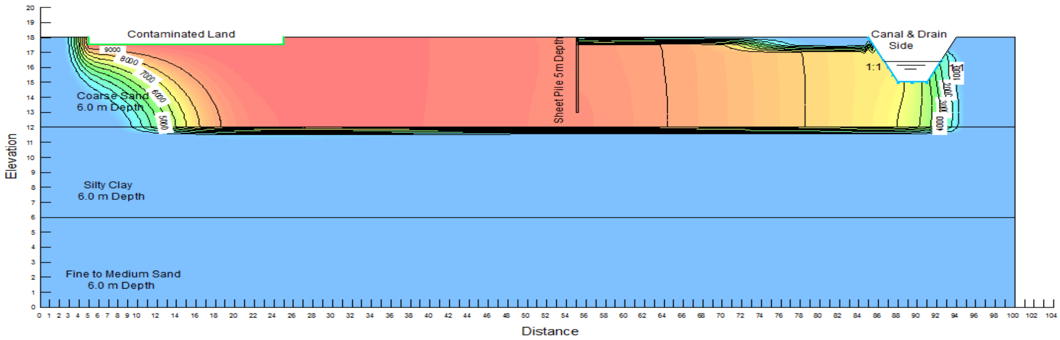

Figure 17. Contamination concentration with sheet pile, ds/Dt=0.278, X(s.p)/X(total)=0.50 and t=100 days

4.3.3 Effect of sheet pile at canal & drain side on contaminant transport

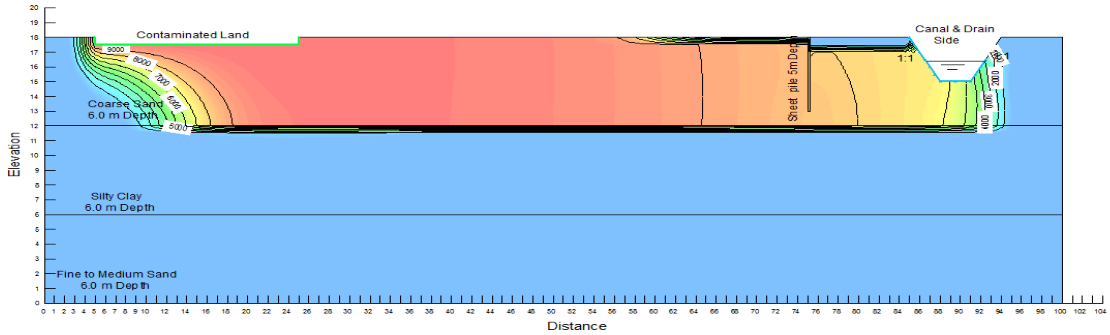

Figure 18. Contamination concentration with sheet pile, ds/Dt=0.278, X(s.p)/X(total)=0.80 and t=100 days

The concentration of phosphate at the beginning is equal 10000(g/m^3) at the agricultural land and after 100 days the contaminant reaches the toe of the slope with concentrations as shown in Table 4.

Table 4. Phosphate contaminant at the slope toe after 100days.

Contaminant Concentration in (g/m³)	**Location of Sheet Pile / Net Distance Between Land & Canal *X(s.p) / X total***		
	0.2	0.5	0.8
ds/Dt =0.278 after 100 days	7098.53	7223.10	7319.69

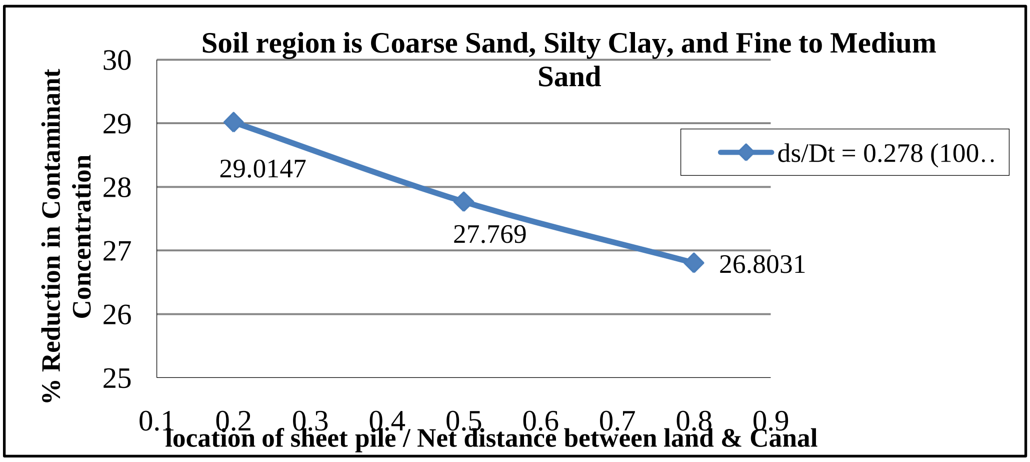

Figure 19. The reduction percentage in contamination concentration reach the toe of the slope

5 CONCLUSION

The following conclusions are reached, based on the discussion presented in this study:

- The order of soil layers and their properties especially hydraulic conductivity affect the transport process of the contaminant through them.
- In case of all soil region is from coarse sand, the best position of the sheet pile is at the agricultural land (contaminants source) with max penetration depth (depth of the layer).
- In layered soil (coarse sand, fine to medium sand, and silty clay) when the penetration depth of the vertical barrier not exceed the one-third of the total depth of layers, the middle is considered the best location, however to reduce the reached contaminants to the slopes, the depth of sheet pile must penetrate the low permeability soil; silty clay layer and to be at the agricultural land side.
- When the soil region is homogenous with high permeability, it is noticed that the transverse dispersivity has obvious effect as longitudinal dispersivity.
- While the hydraulic conductivity of the soil is lower, the contaminants take a long time to reach the toe of slope and it can be noticed in the case of the existence of the silty clay layer below the coarse sand layer.
- Existence of sheet pile has not any significant effect on contamination transport when the hydraulic conductivity of the aquifer is less than 1×10^{-8} (m/sec) because it is considered impermeable.
- Also, the study has shown that the existence of the vertical sheet pile causes an increase in the concentration of contamination below the lower edge of sheet pile.

Finally, it can be concluded that, the shape and spread of contaminants movement highly depends on their diffusion and adsorption function and the head of water submerged the agricultural land while the head difference in water between the contamination source and the canal side is not significantly affective.

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