Range of Contaminant Transport in Soil Under Saturated/ Unsaturated Conditions With Case Study

S. A. A. Khattab
Assistant professor
Mosul university

A. A. AL-Daood
Assistant lecture
Technical instate of Mosul

A. A. Khalil
Assistant lecture
Mosul university

Abstract

Contaminant movement through soil and groundwater contamination are one of the common environmental problems nowadays. Leakage of toxic fluids into the soil and groundwater could create a serious environmental problems. Most growing countries municipal use of open dumps directly without using lining for the solid waste disposal. The presence of groundwater near the waste landfill and its seasonal changes plays an important role in the contaminant transport on the surrounding sites. This necessitate studying the range of movement of contaminants in the soil.

This work aims to study the effect of some variables on the rang of contaminant movement in the saturated/unsaturated soils such as: soil type, contaminant type and concentration as well as the hydraulic condition of soil. Finite element GEO-SLOPE software was used in the analysis. Three soil types (CH,CL,SM) was considered as a waste disposal location. Analysis also was applied for the selected site of a landfill located in the Mosul city. The results show that the soil condition has a clear effect on the range of contaminated transmission through soil. It was also observed that the concentration of contaminants through a higher permeability soil is greater especially in the side of the landfill.

Keywords: Contaminant, finite element, unsaturated soil, diffusion, GEO-SLOPE.

مدى انتقال الملوثات في الترب المشبعة وغير المشبعة مع دراسة واقعية

سهيل إدريس عبد القادر خطاب
أستاذ مساعد

أسماء احمد علي الداؤود
مدرس مساعد

أمينة احمد خليل ال شمام
مدرس مساعد

الخلاصة

مع امتداد العمران وزيادة الكثافة السكانية، ظهرت في الآونة الأخيرة العديد من المشاكل البيئية ومنها تلوث المياه الجوفية. إن وجود المياه الجوفية قرب أماكن طمر الملوثات غير المبطنة و ارتفاع وانخفاض مستواها مع تغير المواسم، يؤدي إلى انتشارها وانعكاس ذلك على المواقع المحيطة بها. من هنا ظهرت الحاجة إلى تحديد مدى انتقال الملوثات في التربة المشبعة وغير المشبعة. أستخدمت في هذا البحث حزمة العناصر المحددة لبرنامج SLOPE-GEO. أخذا بنظر الاعتبار نظرية انتقال الملوثات في التربة المشبعة أي تحت تأثير الانحدار الهيدروليكي، وكذلك نظرية الانتشار في حالة التربة غير المشبعة إلى جانب تأثير انحدار المص. اختيرت ثلاثة أنواع من الترب مرشحة لان تكون مواقع لطمر الملوثات، وهي CH,CL,SM. أكدت النتائج أن لنفاذية ودرجة تشبع التربة تأثير على سرعة حركة الملوثات، كما أن انتشار الملوثات باتجاه جريان الماء يكون أكثر من الانتشار بالاتجاه العمودي للجريان.أخيرا تم إجراء تحليل لأحد مواقع طمر النفايات مقترحة في مدينة الموصل، ومدى انتقال الملوثات خلال المنطقة.

Received 18 March 2009 **Accepted 9 July 2009**

Introduction

Solid waste dumping sites are usually constructed around cities to preserve the environment. These sites should be constructed to met the specifications in order to prevent spreading pollution throughout movement of contaminants through the soil. Solid waste management in the world is essential to protect the public health and safety of the waste disposal in a safe environmental manner. The increasing number of urban population and rising of standards of living and industrial, and agricultural progress must followed by an appropriate methods for collection, transport and dumping of solid waste.

A simulation model was constructed to study the infiltration rate from solid waste site of Kahrizak (one of dumping sites of Tahran city). Results indicated that the leachate quantity was within the range of 500 -700m^3/day which is within the safe limits of the Organizaon of Waste, Reuse and Composing (ORWC) [1].

There are two basic contaminant transport processes that: advection and dispersion. Advection is the movement of contaminant with the flowing water. Dispersion is the apparent mixing and spreading of the contaminant within the flow system. Processes can be represented as a steady flow of water in a long tube filled with sand, as shown in Figure(1). Transfers of contaminate through the soil can be represented mathematically by the laws of flow.[2]

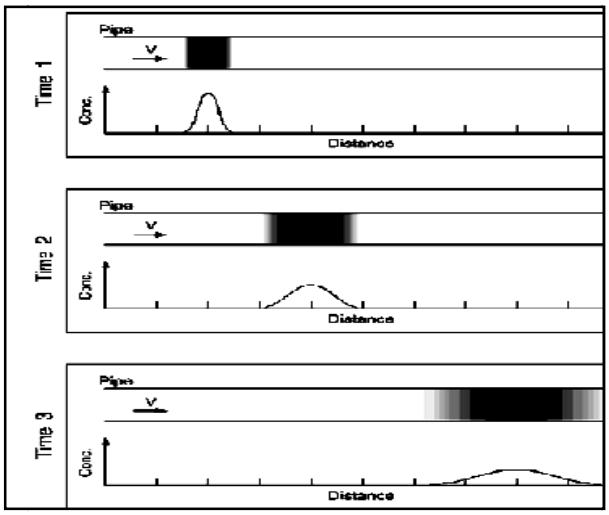


Figure (1): Representation of Migration and the Spread of Contaminated With the Fluid Through a Tube Long [2]

The choice of the dump site or landfill and its capacity depends on: depth, soil permeability, ground water depth and the possibility of post-closure. Recently the landfills design has been regulated by the relevant authorities to ensure that the appropriate performance criteria are met.

Leakage and diffusion of the toxic fluids resulting from the decomposition of organic material into soil and groundwater and must be studied thoroughly to protect the environment from contaminaon. [3]

This research aims to study the range of movement of contaminants through three types of soils in saturated/unsaturated condition. Effects of soil type, physical characteristics as well as hydraulic gradient and the use of contaminant transport process was performed using finite element package of SEEP/W and CTRAN/W.

Theory

Transport Processes

Evaluation and prediction of the migration of contaminants in groundwater is commonly performed using advection-dispersion based models. These processes are mathematically described in the advection one-dimensional form of advection-dispersion equation for non-reactive, dissolved constituents in saturated, homogeneous, isotropic media is:[2]

$$n_e \frac{\delta C}{\delta t} = D_h n_e \frac{\delta^2 C}{\delta x^2} - v n_e \frac{\delta C}{\delta x} \qquad \text{.....(1)}$$

where: n_e = effective porosity, C = solute concentration in pore fluid, t = time, D_h = coefficient of hydrodynamic dispersion along the flow path, x = distance along the flow path, and v = average linear groundwater velocity.

$$v = q / n_e \qquad \text{.....(2)}$$

where: q = the Darcy velocity

Hydrodynamic dispersion is the combination of mechanical dispersion and

molecular diffusion and can be expressed as:

$$D_h = \alpha_l v + D_e \quad \text{.....(3)}$$

where: α_l = dispersivity, and *De* = coefficient of molecular diffusion of a solute in the porous media.

Mechanical dispersion occurs during advective contaminant transport due to the different groundwater flow paths and velocity variation within and between pores. Molecular diffusion refers to further spreading of a contaminant front that is caused by concentraon gradi ents. [4]

Diffusion Dominated Transport

In the absence of advection, diffusion is often considered to be the dominant contaminant transport process. As advective flow becomes less significant, the average linear groundwater velocity approaches zero and D_h becomes dominated by D_e.[5]

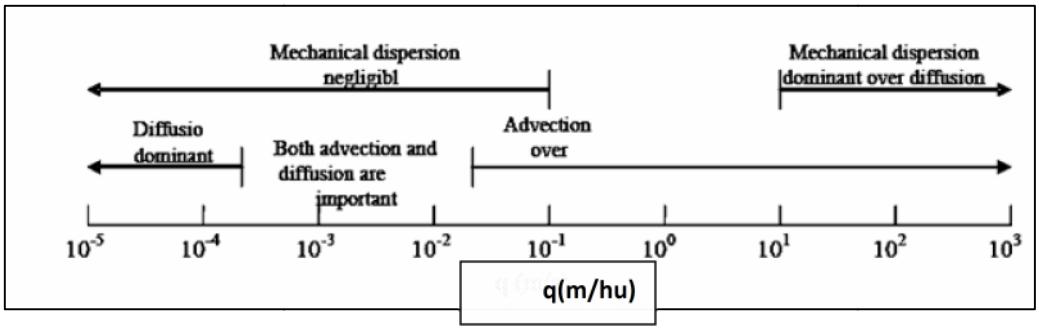


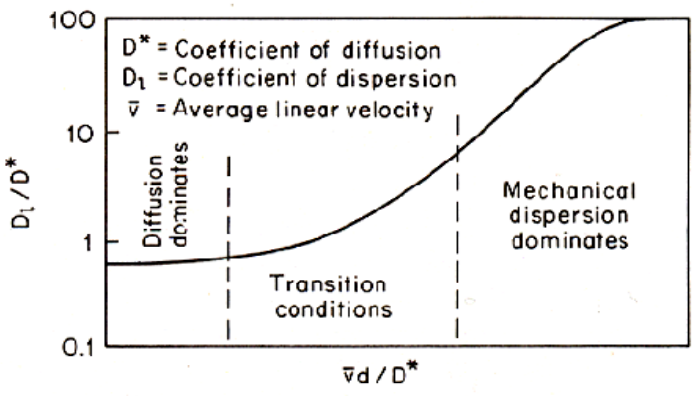
Figure (2) Range of Darcy Velocities Over which Diffusion or Mechanical Dispersion[5]

The relative contribution of diffusion and mechanical dispersion to the transport process is commonly expressed in terms of the dimensionless Peclet number *Pe*.

$$Pe = \frac{vd}{D_e} \quad \text{.....(4)}$$

where: *d* = characteristic length of the medium

The characteristic length is generally taken as the mean grain-size diameter. At low P_e values, molecular diffusion will dominate, while at high P_e values of mechanical dispersion which is define as D_m dominates as shown in Figure (3).[5]



Figure(3) Graph of the Dimensionless Dispersion Coefficient Versus the Peclet Number (Adapted From Freeze and Cherry, 1979).[5]

Theory of Diffusion

Molecular diffusion is a process whereby dissolved mass is transported from a higher chemical energy state to a lower chemical energy state through random molecular motion. Steady-state diffusion of a chemical or chemical species in free solution can be described empirically using Fick's first law.[5]

$$J = -D_o \frac{\partial C}{\partial x} \qquad \text{.....(5)}$$

where: J = the solute mass flux, Do = the diffusion coefficient of the solute in water, C = solution concentration, x = the direction of transport, and $\partial C/\partial x$ = concentration gradient. The negative sign in equation(5) indicates that the net mass flux of contaminant is from areas of high concentration to areas of low concentration. The rate of molecular diffusion is

$$D_o = \frac{k_B T}{6\pi\eta a}$$

controlled in part by the frictional force between molecules in solution. The diffusion coefficient of a molecule in solution can be calculated from using the Stokes-Einstein equation:

.....(6)

where: k_B = Boltzmann constant, T = absolute temperature, η = viscosity of the solution, and a = hydrated radius of the ion.[5]

Diffusion in Soil

Solute diffusion is slower in soil than in free solution because the soil particles restrict the fluid filled cross-sectional area, the diffusion pathways for the solute are more roundabout, and other factors attributed to the presence of soil particles. In a saturated soil system the reduced cross-sectional area for solute movement is accounted for by including the porosity of the medium in Fick's first law: [4]

$$J = -nD_e \frac{\partial C}{\partial x}$$

.....(7)

where: n = soil porosity, and D_e = effective diffusion coefficient. This equation is called Fick's second law and written as follows:

$$\frac{\partial C}{\partial t} = D_e \frac{\partial^2 C}{\partial x^2}$$

.....(8)

where: $\partial C/\partial t$ = change in concentration with time.

Diffusion Functions

A diffusion function defines as relationship between volumetric water content and coe□cient of molecular di□usion. This relaon defined by Kemper and Van Schaik (1966) has shown in Figure (4). Generally from the amount of molecular di□usion of salt water between ($6.2*10^{-5}$-$2*10^{-5}$) m^2/sec [8]. Function effective in unsaturated soil when the speed run low.

$Dp=D_o \alpha \gamma (L/L_e)^2 \Theta$ .....(9)

where: D_o=coefficient of diffusion in salt water, α=decreased fluidity, $(L/Le)^2$=redaction in velocity ,Y=electronic exchange ,Θ=Volumetric water content.[7]

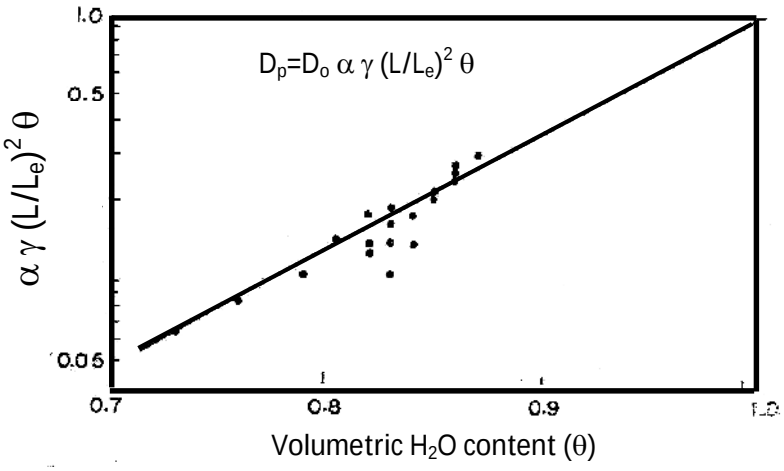


Figure (4): Relation Between Volumetric Water Content and Molecular Diffusion[7]

Moisture conditions beneath a landfill

There are many situations where the soil beneath a landfill is partially saturated. Many landfills are constructed in arid or semiarid environments, where the soil is usually partially saturated to a great depths.

The fundamental difference between saturated /unsaturated soil is that the unsaturated soils composed of four phases (water, air, solid material and the contractual skin), It should be noted that the level of underground water represents the boundary between positive and negative pore water pressure. The soil above the groundwater level is divided in to two regions, a region of soil being saturated with capillarity, ranging from less than one meter thick and up to ten meters depending on the nature of the soil.[8]

Numerical Modeling

Numerical modeling was performed using the finite element package of SEEP/W and CTRAN/W. These programs could be used to simulate both transient and steady-state condition to simulate contaminant movements in a groundwater system. Two-dimensional or three dimensional problems that are symmetrical about a vertical axis can be simulated.

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 (soil, landfill) model in SEEP/W are required: volumetric water content and hydraulic conductivity functions. Boundary conditions in SEEP/W can be entered as head values. While CTRAN/W solute concentration or solute flux values can be specified.

Numerical Model Description

The same two-dimensional mesh was used for both the SEEP/W and CTRAN/W. The elements in both the soil and landfill were approximately (1*1m) length with infinite element at both right and left sides. The geometry of problem is shown in Figure (5). The soil domain extends as (48m) length, and (22m) depth. Landfill located from (1 m to 6 m) depth below soil surface with (17m) length. Ground water table was assumed to be at (10m) depth from surface. Seepage velocities were set to zero in CTRAN/W to ensure a diffusion-dominated system as one of the cases.

The boundary condition using in SEEP/W was taken as the total head equivalent to the elevaon head which is equal to (19m) , with zero flux boundary at the boom of soil body. While the boundary condition using CTRAN / W, assumed the concentration (C) uniform throughout the landfill site for each type of contaminant concentration studied in research. Selected contaminants concentration were chosen from a typical values shown in Table (1) [11]. To ensure the control of coe□cient of di□usion in the media, the flow speed was run close to zero, effects of adsorption and decay were neglected.

Table (1): Material Concentration[9]

Material	Concentration (mg/L)

Nitrate	25
Chloride	500
Sulfate	300

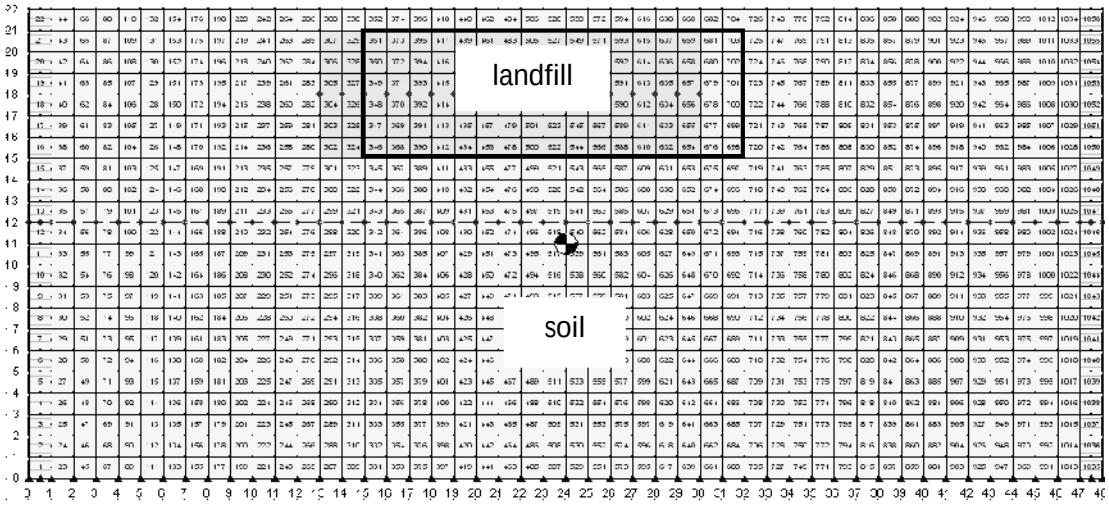


Figure (5):Finite Element Mesh of Proposes Studied Area

Three types of soils were considered as landfills in this study have properties shown in Table (2).[11]

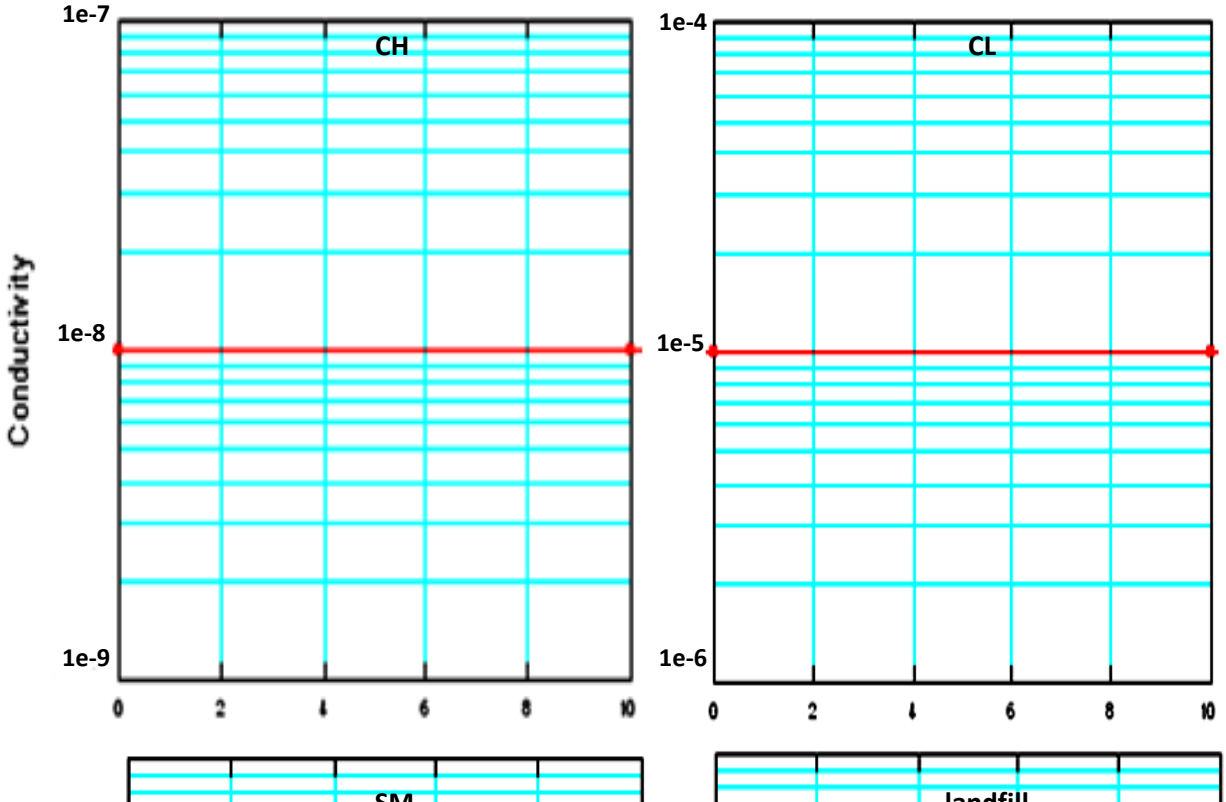
Table.(2): Soils Type[13]

Soil type	Soil 1	Soil 2	Soil 3
Soil classification	CH	CL	SM
	sand(5%)	sand (16%)	sand (66%) silt (30%)

Grain size	silt (51%) clay (44%)	silt (52%) clay (32%)	clay (4%)
Hydraulic conductivity (K)	0.00001E-3	0.01E-3	1E-3
Porosity (n)	0.31	0.39	0.5
Volumetric water content (Θ)	0.31	0.39	0.5

Hydraulic Conductivity, volumetric water content, and diffusion functions for the three soils and landfill obtained from presented study are shown in Figures (6) to (10) and the coefficient of diffusion was set to zero for the steady state in saturated and unsaturated cases . the dispersivity distance was selected to be 2 m in the long direcon and 1 m in the perpendicular direction.

Numerical model was considered to simulate contaminant transport through saturated/unsaturated soils using CTRAN/W and SEEP/W for GEO-SLOP computer program. The data sets that incorporate characteristics of the soil in its saturated and unsaturated states as well as the established parameters involved in determining the movement of contaminated: soil type and condition of the steady state of saturated and unsaturated, as well as the type and concentration of contaminant materials. Finally, the flow of contaminated through soil is predicted for a me of up to 25 years. Contaminant types and concentrations are illustrated in Table (1). Three types of soils (one layer) were selected in this study (clayey soils of medium and high plasticity, and silty soil). The soil properties are shown in Table(2).



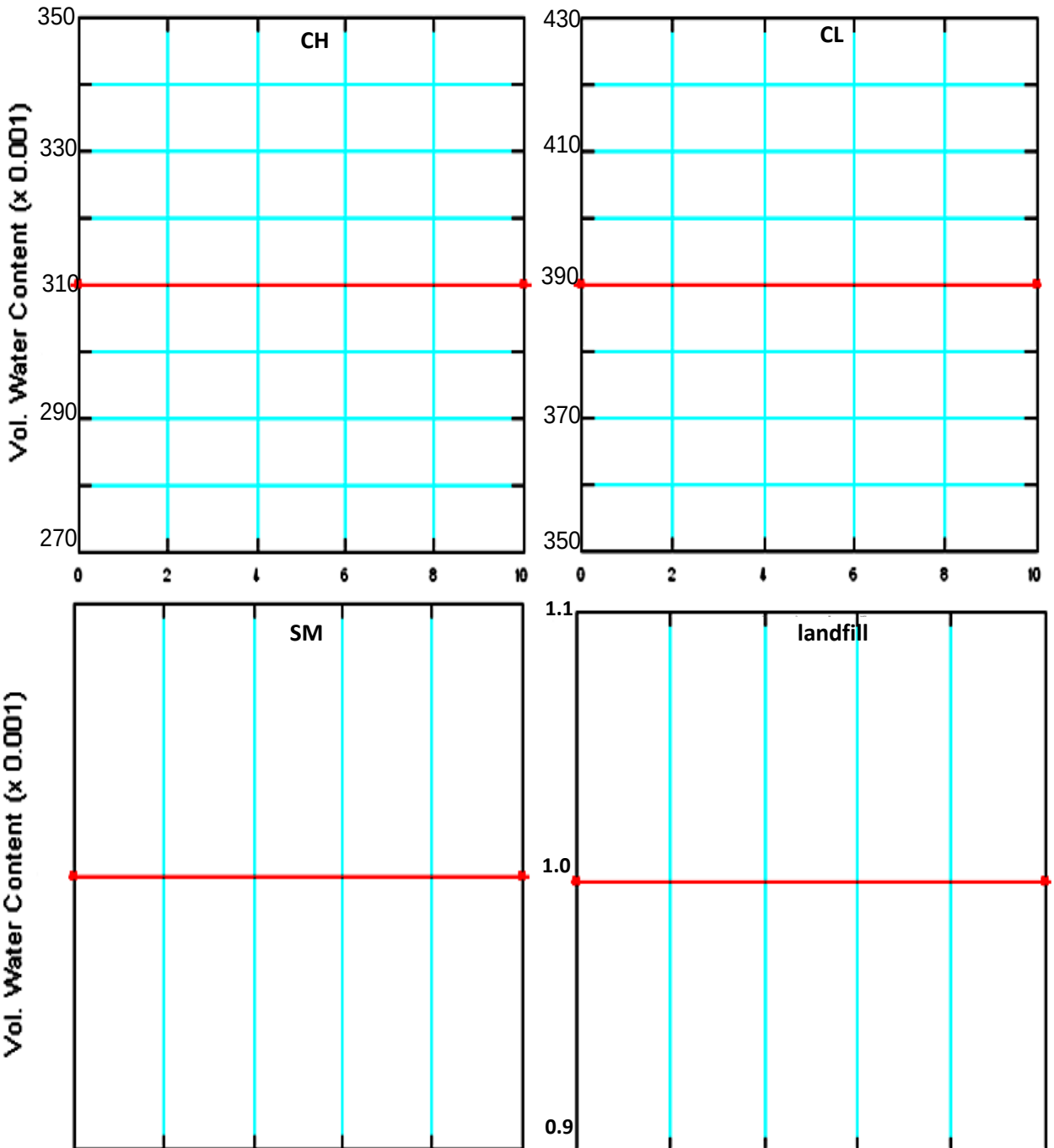

CH
CL
SM
landfill
Vol. Water Content (x 0.001)
Vol. Water Content (x 0.001)
350
330
310
290
270
430
410
390
370
350
1.1
1.0
0.9
0
2
4
6
8
10

Figure (7): Soil Water Characteristic Curve for the Saturated Soils Used

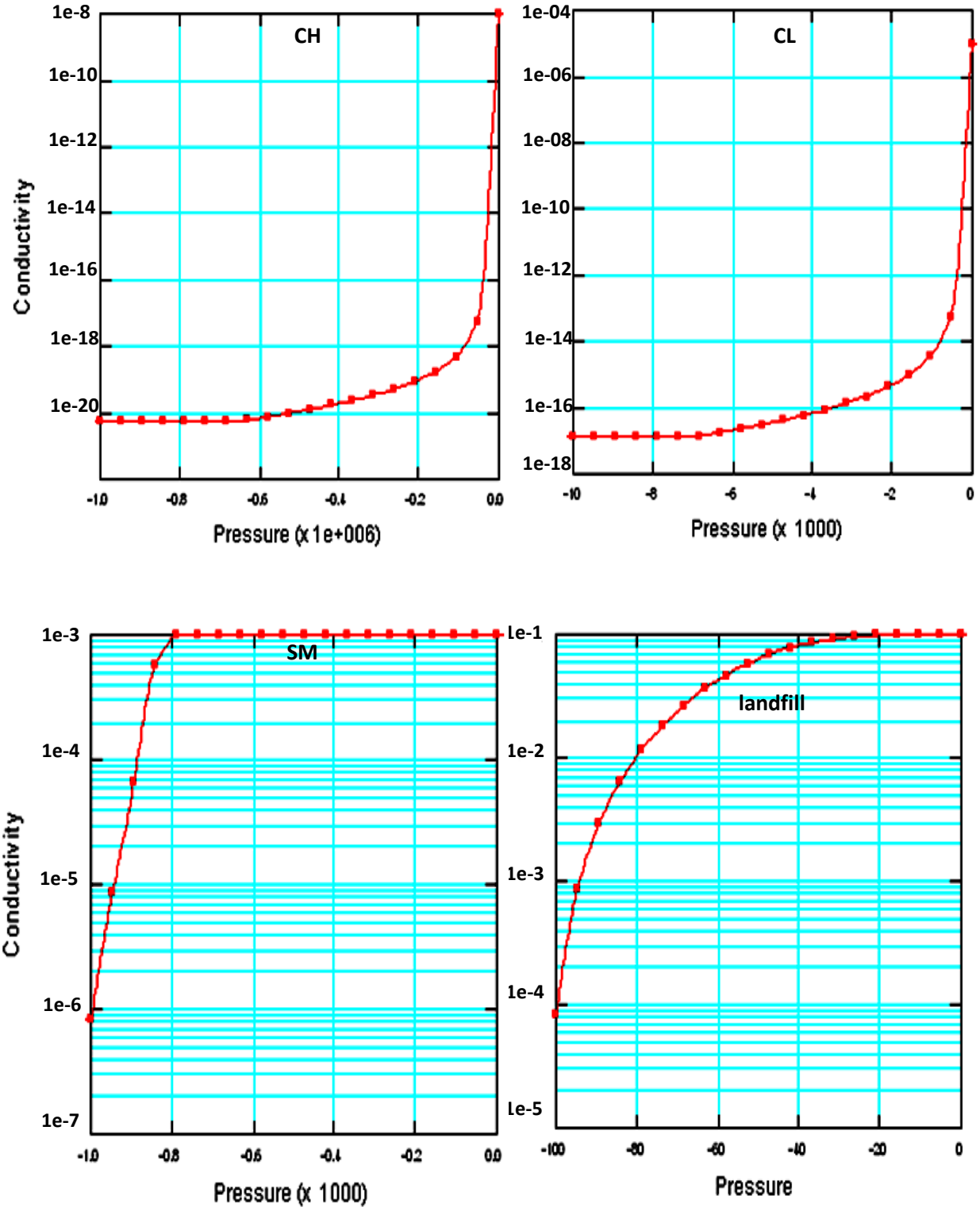

CH
Conductivity
1e-8
1e-10
1e-12
1e-14
1e-16
1e-18
1e-20
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
Pressure (x 1e+006)
CL
1e-04
1e-06
1e-08
1e-10
1e-12
1e-14
1e-16
1e-18
-10
-8
-6
-4
-2
0
Pressure (x 1000)
SM
Conductivity
1e-3
1e-4
1e-5
1e-6
1e-7
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
Pressure (x 1000)
landfill
1e-1
1e-2
1e-3
1e-4
1e-5
-100
-80
-60
-40
-20
0
Pressure

Figure (8): Conductivity Function for the Unsaturated Soils Used

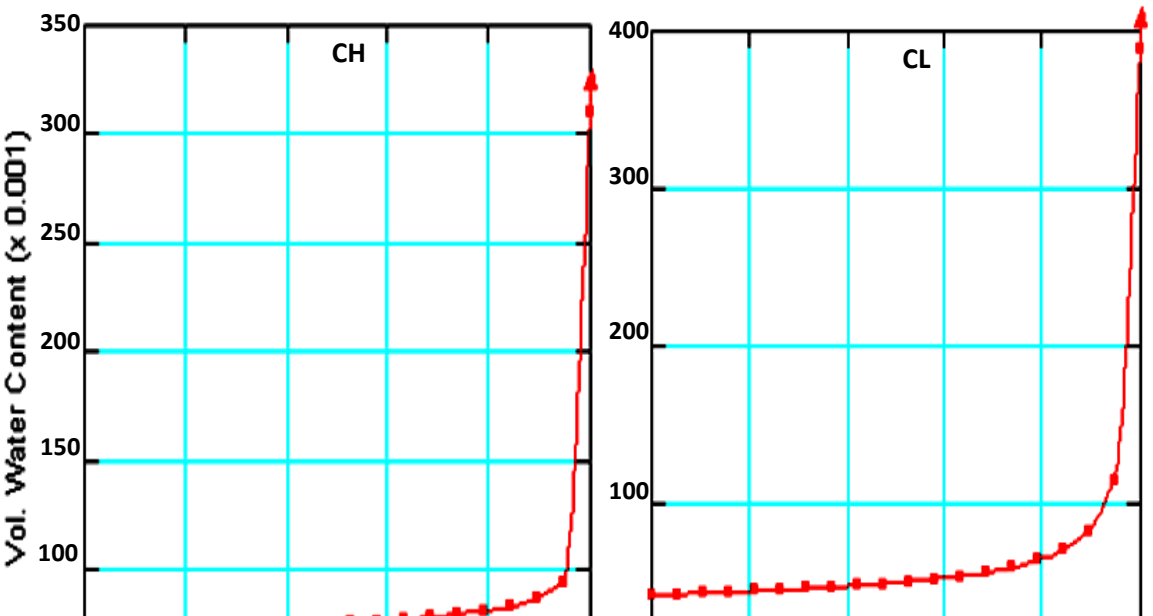


Figure (9): Soil Water Characteristic Curve for the Unsaturated Soils Used

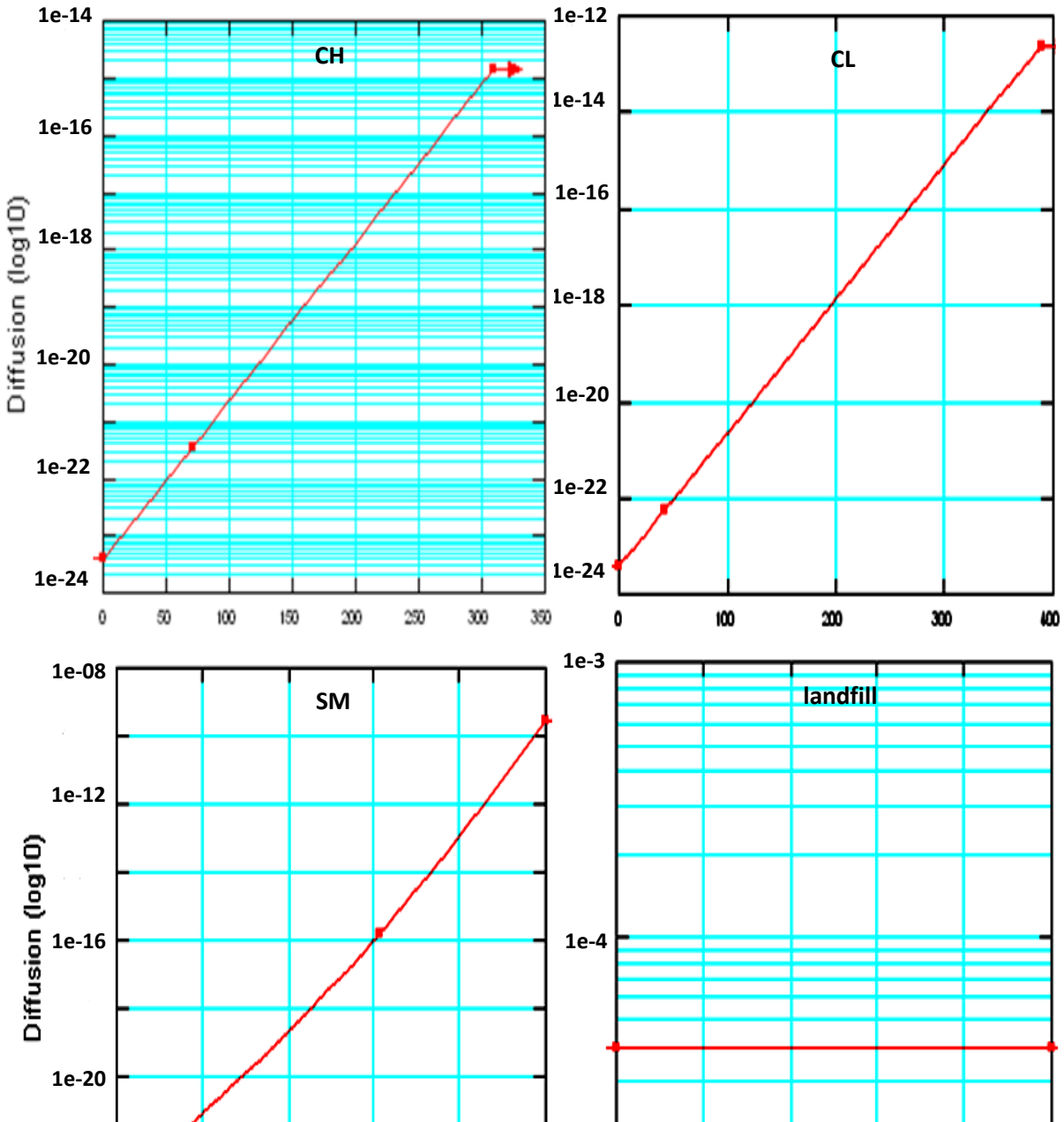
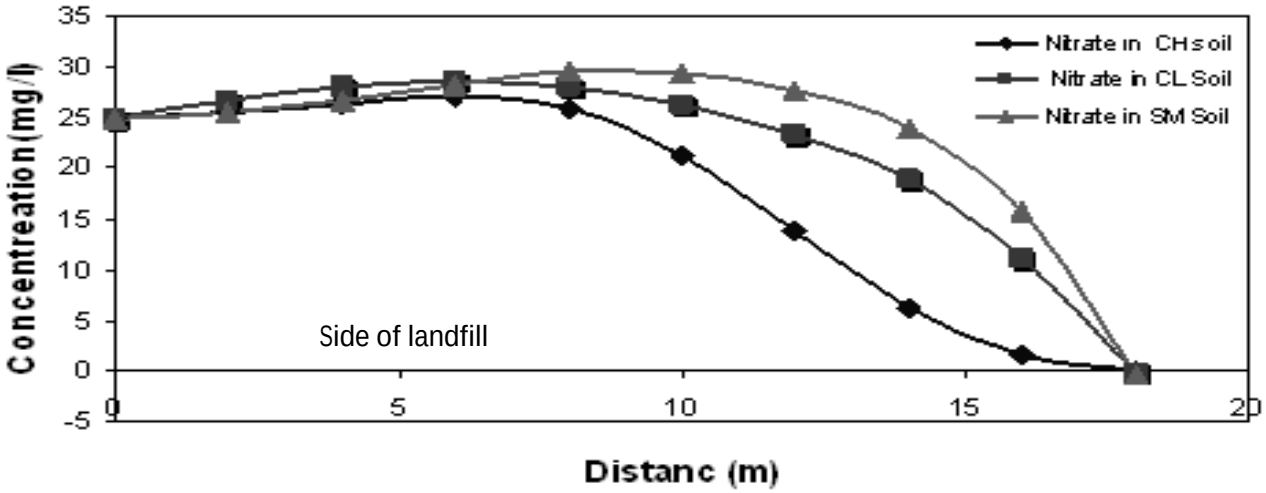


Figure (10):Diffusions Curve for Soil Used

Results And Discussion

Figure (11) shows the e□ect of soil type on contaminant movement (Nitrate for example). A highest concentration of contaminant was recorded through silty soil (SM) which have a highest permeability compared with the other two selected soil types (CH, CL). This finding is obvious in the ditch sides while it is not very clear in the soil below the ditch.

Figure (11) also shows a limited initial increase in concentration in the side and bottom distances followed by a reduction in the contaminant concentration. This could be attributed to the accumulative increase in the range of concentration with the transition and then contaminant dispersion and the spread of contaminants along the bottom and the sides of the landfill site [2]. It could also be noted that the highest contaminant concentration was found at the base of the landfill compared with the sides. This difference may be due to the rapid downward movement for contaminant as shown in Figure (12). According to the manual Re.[2] the biggest size of arrows indicate a higher speed of contaminant as it is clear from the Figure (12).



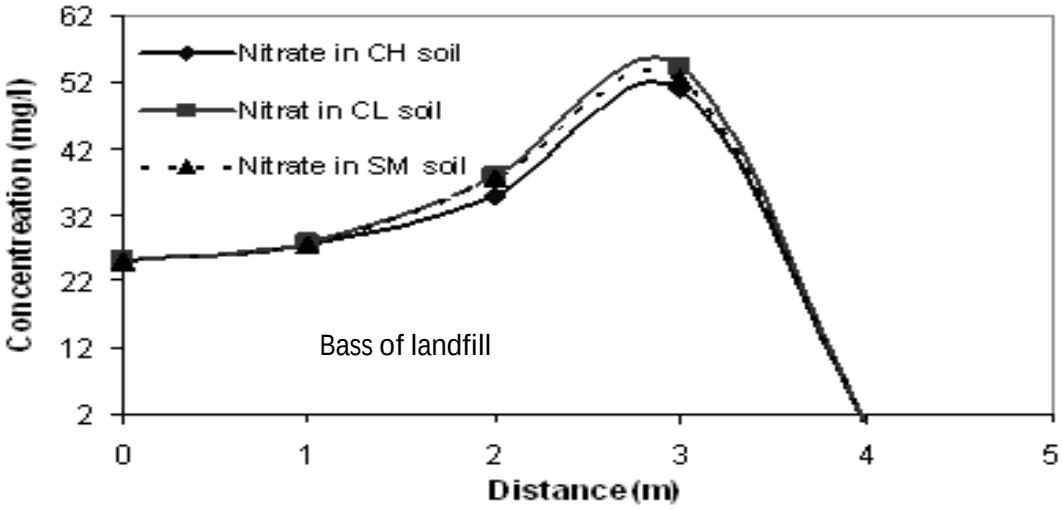


Figure (11): Range of Movement of Nitrates at the Bottom and Side of Landfill Site Through the Selected Soils.

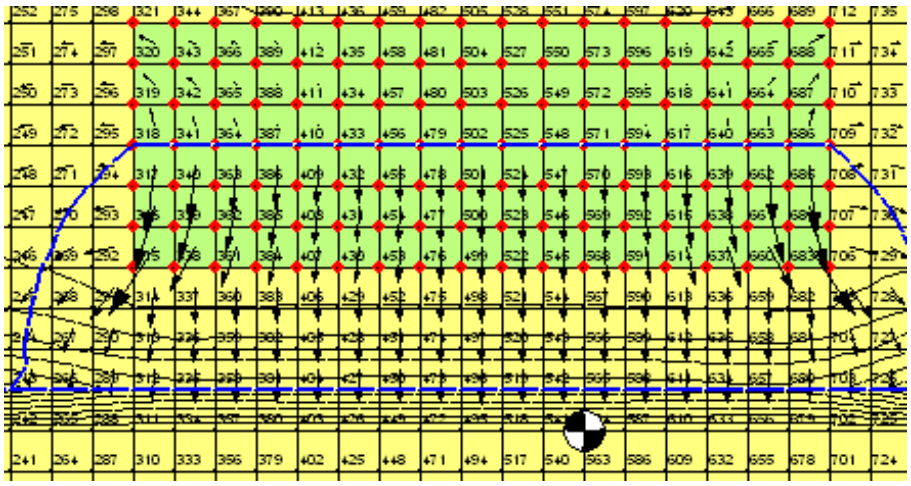


Figure (12): Contaminant Transport Base and Side.

Figure(13) shows the effects of four consecutive periods of (6, 9, 15, & 30) months which indicates an increase in the concentration of contaminant with time. The highest concentration was found at the level of the water table level, then it decreases due to the dilution in the water table. This could be explained again by the accumulatively increase of contaminants transported and concentrated by dispersion and advection processes followed by concentration reduction caused by the ground water dilution.

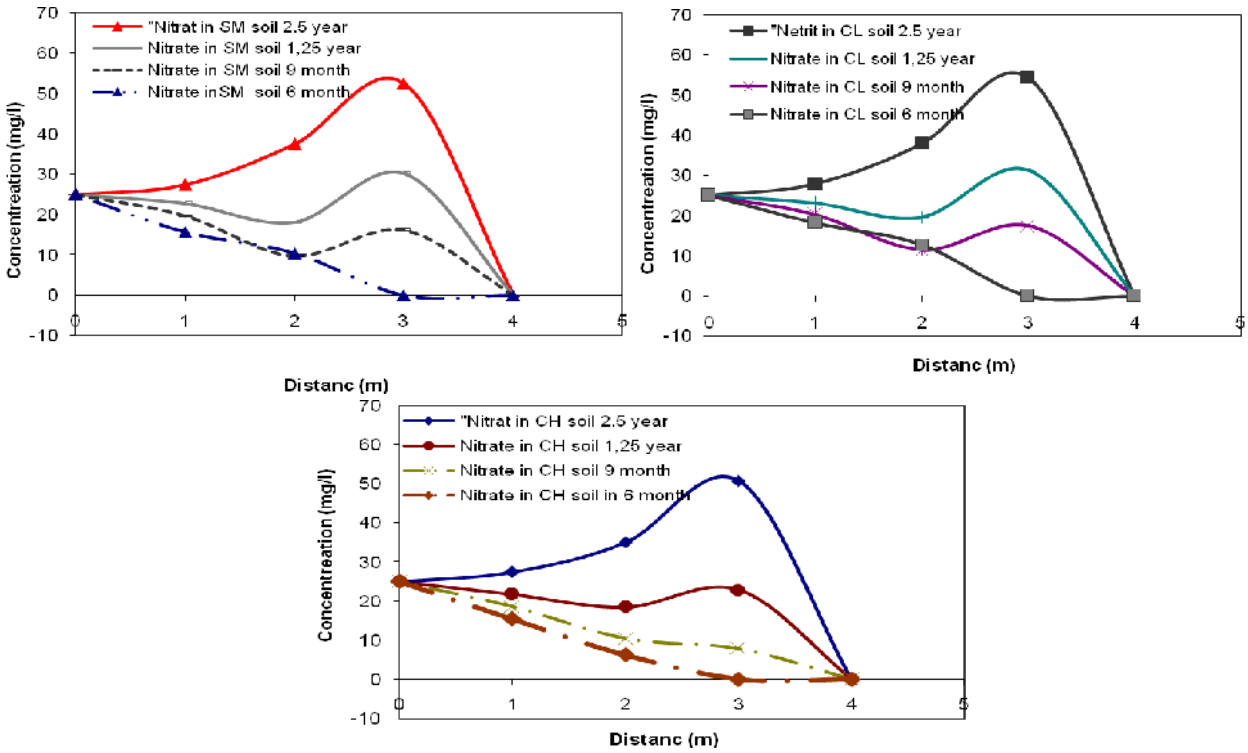


Figure (13): The Range of Movement of Nitrate Through the Soils at the Base of Landfill for Different Period.

The effect of hydraulic conductivity on the rang of contaminant movement is presented in Figures (14),(15), and (16). Results in Figure (14) indicate a very limited variation in concentration and distance of contaminant movement through the soil at the base of landfill through clayey soil (CH). This result coincides with that concluded by others (manual SEEP/W (application program as an example, deals with cases found difference 4%).[2]

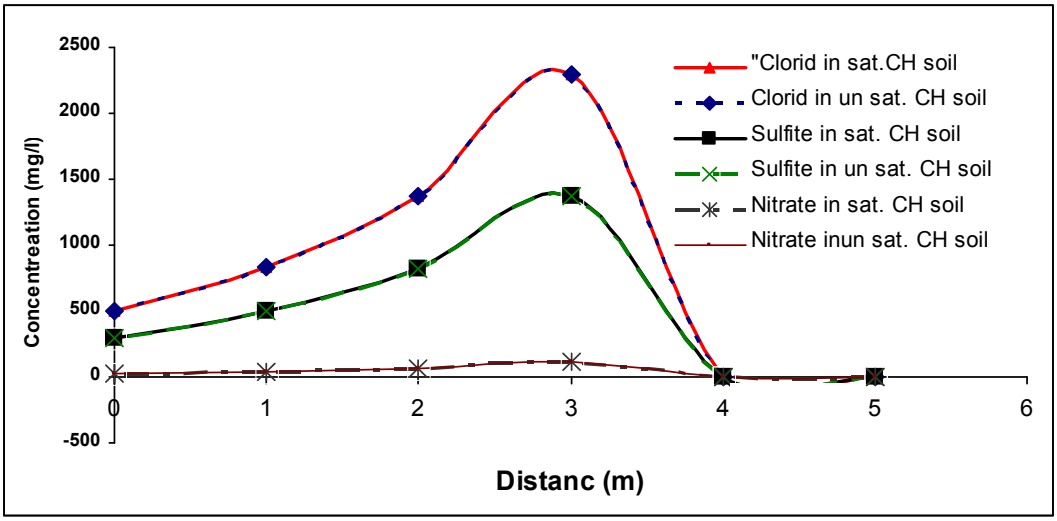


Figure (14): Contaminant Transmission Range Through

Saturated /Unsaturated Soil After 25 Years.

Figure (15) shows the range of (Nitrate) movement at the base of landfill for soils (CL, SM) which pointed out that the concentration, extending of contaminant movement are less for unsaturated condition (at zero speed rang).

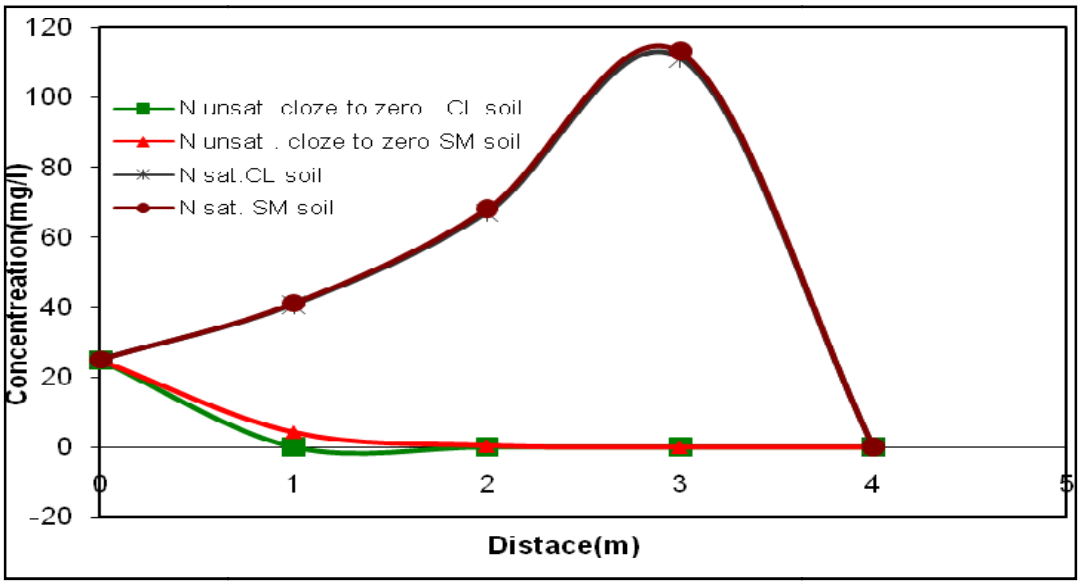


Figure (15): Nitrate Contaminant Transmission Range of Solid Waste Through Saturated /Unsaturated Soil (Speed Run Close to Zero) at the Base of Landfill

Figure (16) shows the range of movement of nitrates at the side of landfill for CH soil. This Figure shows nitrates extension over a distance of (20m) through soil for both saturated/unsaturated cases. On the other hand, the extended distance is over (2m) through the third case (seepage velocity close to zero). Also, a gradual increasing in concentration could be noted followed by a sudden decrease until reaching to zero at saturated condition. This is due to fragmentation and movements flow of contaminated water as mentioned previously.

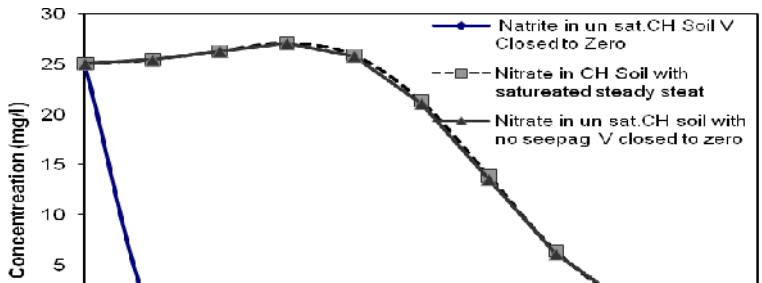
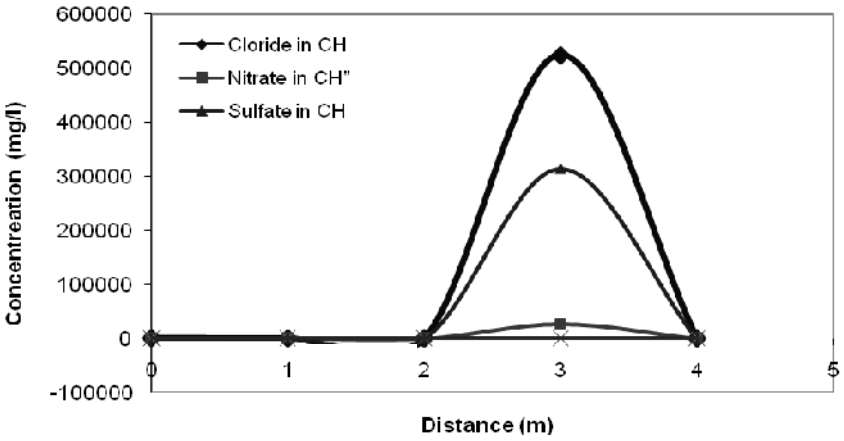


Figure (16): The Range of Movement of Nitrates at the Side of the Landfill Through Saturated / Unsaturated Soil When the Speed Run Close to Zero.



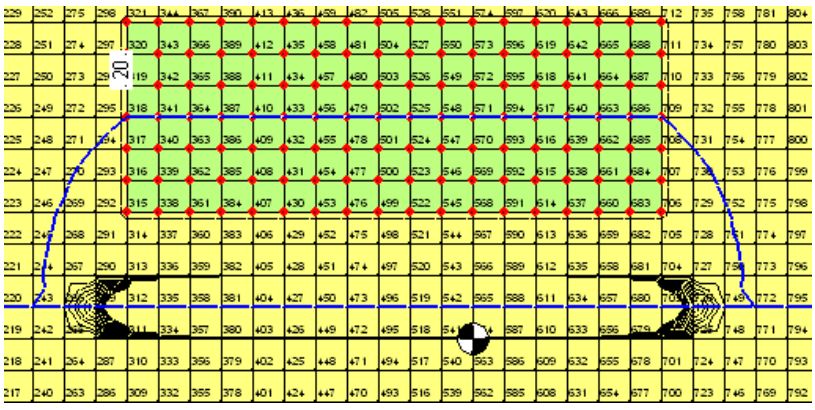


Figure (17): The Range of Movement of Nitrates, Chloride and Sulfate Contaminant Solid Waste Through Unsaturated Soil (for the Rapid Flow of Close to Zero)

From other side, a higher contaminant concentration was noted on the base of dumping place (3 m distance) for clayey soil and the case of flow speed approaching to zero (Figure 17). This could be explained by the ar acon nature of negavel y charged surface of clay minerals.

The effects of type and concentration of each contaminant (Nitrate, chloride, sulfate, stated in Table(2)) were studied. The movement of these materials through the soil, after a period of time, reached a maximum distance of contamination (which extends close to (20m)) for both saturated/unsaturated cases. It could be noted that, the maximum recorded concentration was for silty soil comparing with that of clayey soil within limited (600mg/l) for chloride as shown in Figure (18).

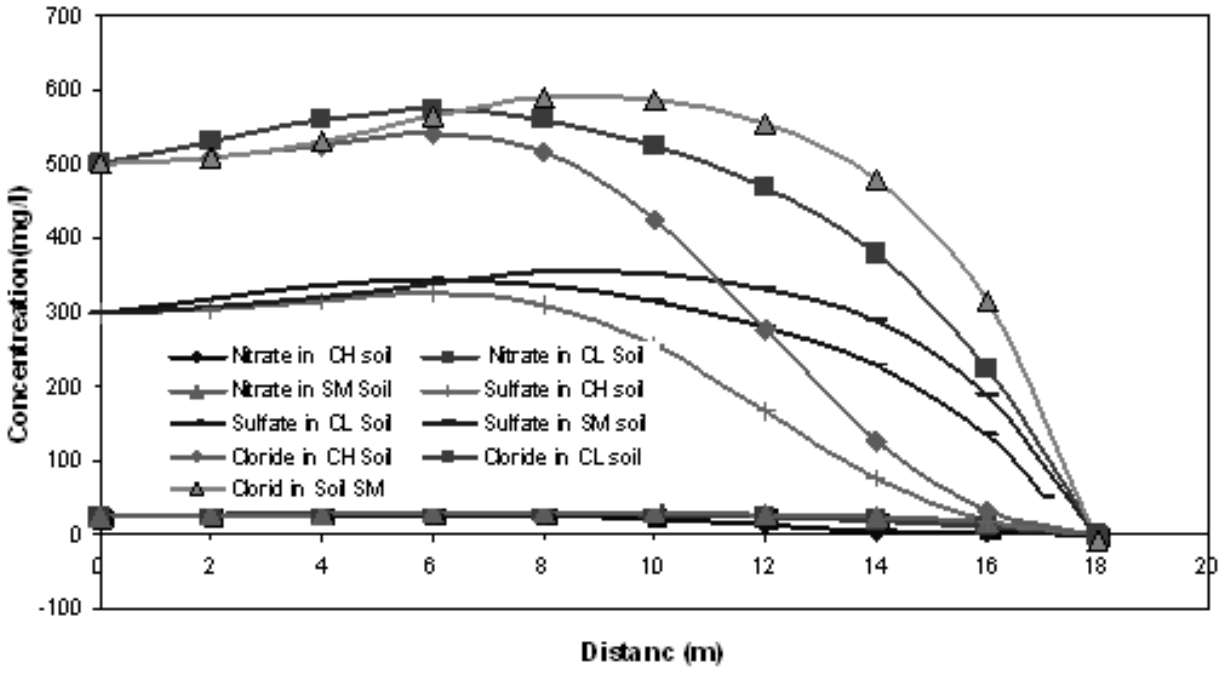


Figure (18): Range of Solid Waste Contaminants Transmission Through the Selected Soils Saturated Soils After 25 Years of Burial.

CASE STUDY

Site Description

A proposed landfill sites by municipality of Mosul is located in the left side of the Mosul city, 13 kilometers away from city center. This site covers an area of about 375000 m^2 (full distribuon of soi ls layer and extended shown in Figur e (19)), groundwa t er level is about 15 m below the soil surface. Numerical modeling was performed using the finite element package of SEEP/W and CTRAN/W to determine the range of movement of one of a typical contaminant, nitrates for example, through the soil. Table(3) summaries some obtained physical properties of soil during site investigation.

Table:(3) Some Physical Properties of Soil Which Using for Landfill Site[10]

Soil type		Layer 1	Layer 2
Atterberge limit	L.L%	48	51
	P.L%	22	23.9
	P.I%	26	27.9
Soil classification		CL	CH
Grain size		26% sand, 36% silt, 38% clay	10% sand, 46% silt, 44% clay

Hydraulic conductivity m/sec (K)	1 E-8	0.83 E-8
Porosity (n)	0.37	0.31
Volumetric water content saturated	0.37	0.31

Numerical Model Description

The same two-dimensional mesh was used for both the SEEP/W and CTRAN/W. The elements in both the soil and landfill were approximately (1*1m) length with infinite element at both right and le sides. The studied site dimensions of 300m length and 42m depth with a dumping site (landfill site) of 100m length and 4m depth under the ground level as shown in Figure (19).

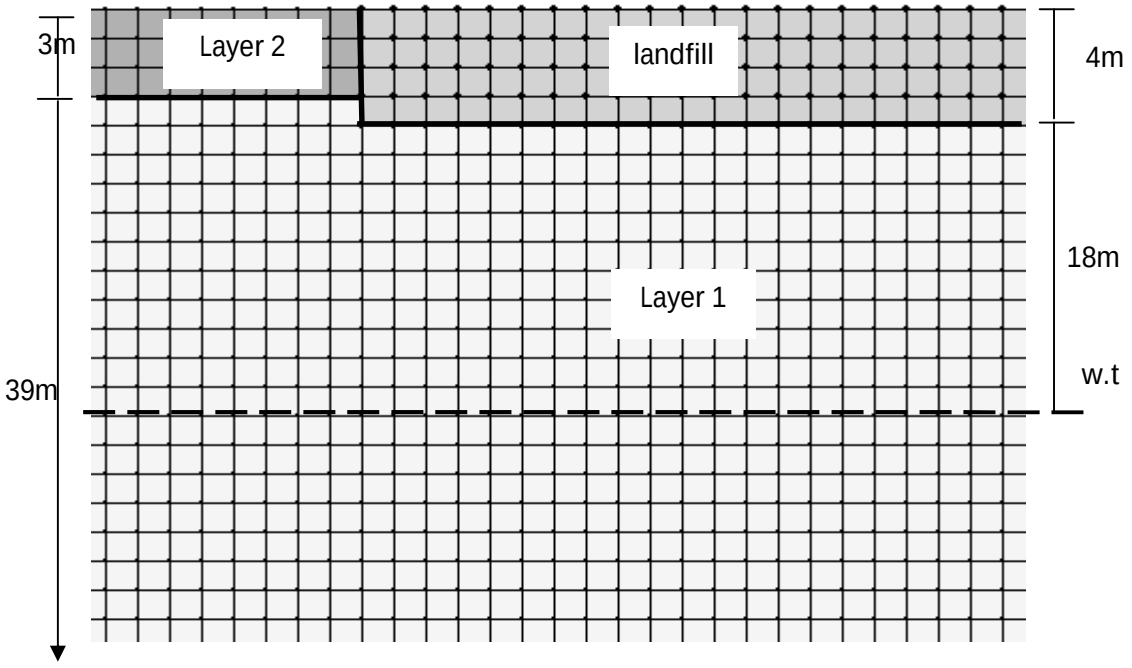


Figure (19):Numerical Model Description

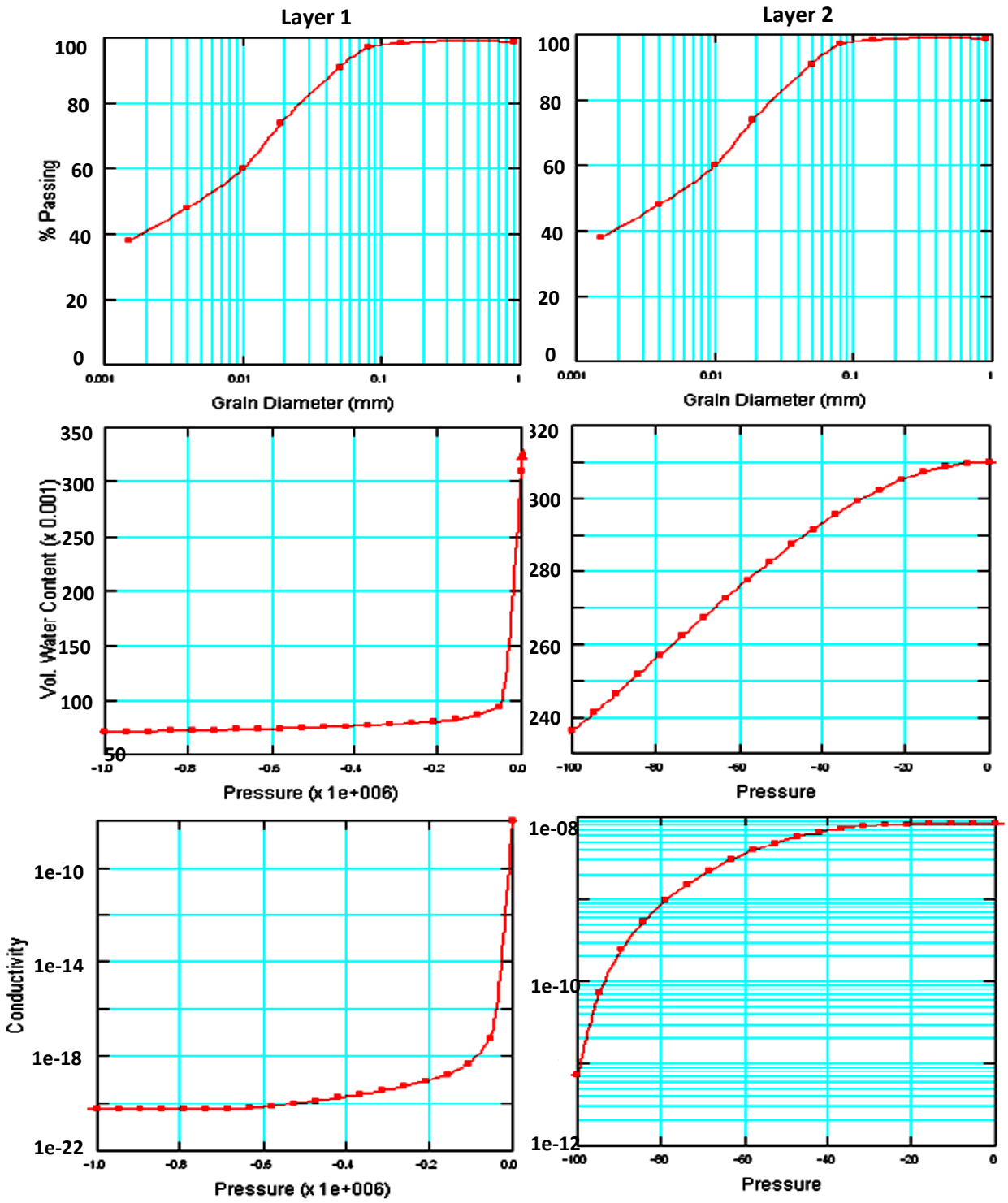


Figure (20): Volumetric Water Content and Diffusion Function in the Cases of Saturated /Unsaturated Soil

Boundary conditions using SEEP/W Model were taken as: the total head (H) equivalent to the Elevation head in the middle of the landfill site, with zero flux boundary at the bottom of soil body. The level of groundwater was 18 m depth from the ground surface,

the steady state flow through soil (saturated/unsaturated) was considered. Other boundary conditions of Model in CTRAN/W were fixed as mentioned above in the study. Hydraulic conductivity function, Volumetric water content and Diffusion function of soil in the cases of saturated and unsaturated shown in the Figure (20). A dispersivity (α) of 2m in long direcon and 1m in vercal direcon were consi dered.

Results

The results indicated that there is an increase in contaminants concentration of the steady state saturated flow through soil (below dumping site). The maximum value is obtained just above the water table. On the other hand, the contaminants concentration is limited to 1 m below the dumping site in the case of di□usion as indicated in Figure.(21). Concerning of the flow along the dumping side, Figure.(22) shows that there is a gradual decrease in contaminant concentraon wi th its fbw that connued to 22m and 1mi nthe saturated /unsaturated (flow control) successively.

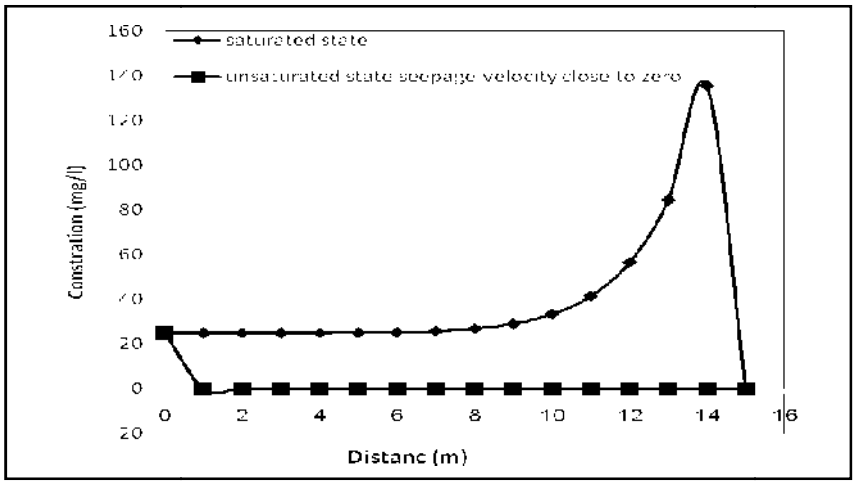


Figure (21): Concentration Movement at Beneath of Landfill

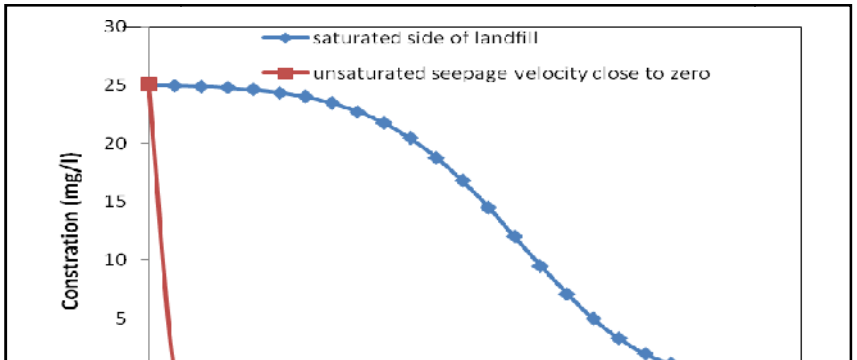


Figure (23) shows stages of contaminant transion during the successive periods of time beneath the landfill site. It was illustrated that there is an increase in the range of concentrations with the transition of contaminant and increase the period after the landfill. The range of contaminant transmission in the first five years was extended to (13m) of the landfill base of the site and reach the level of groundwater after ten years.

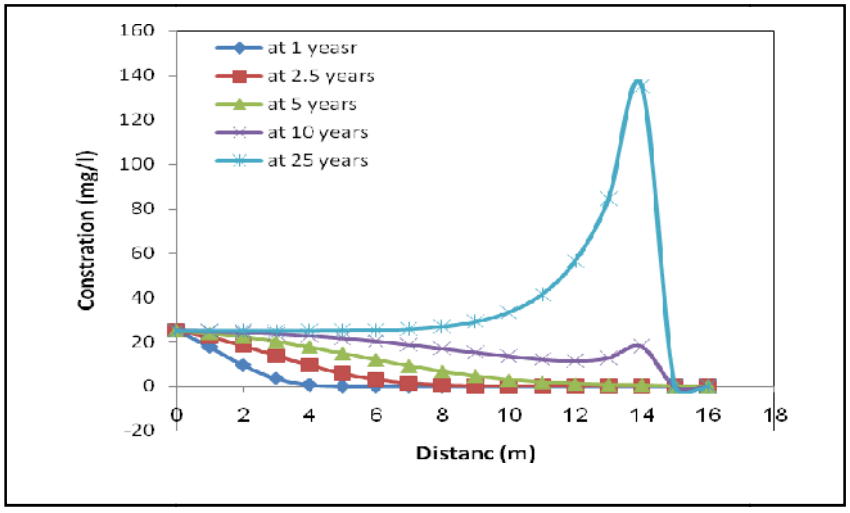


Figure (23): Range of Contaminant Movement during periods of time

Conclusions

1- Effect of soil type on the contaminant concentration movement was found to be related to its permeability. The maximum contaminant concentration was noted to be for the soil of highest permeability. The percentage increase in contaminant concentration was 18%, 14%, and 8% for SM, CL and CH soils respectively.
2- Concerning the distance and concentration of contaminant, a matching values were found between the steady state flow of saturated and unsaturated cases. The only difference was noted in the case of steady state unsaturated flow when seepage velocity approaches to zero (diffusion case) where, the obtained values are less than mentioned in the above cases.
3- Contaminants concentration play a very limited role in the infiltrate movement distances through soils. The accumulated percentage of concentration increase was about 18% at a distance of 8 m in the side of dumping side.
4- Contaminant concentration is higher in the direction of movement comparing with the perpendicular to flow direction.
5- Results of the studied case "Mosul dumping site" indicate that a (contaminant area around the landfill area spread about 176400m^2) during the 25 years. It could be noted that extend of contaminant to reach the level of underground water Table during the first 10 years.

References

1. Safari, E., and Baronian, C., (2002), "Modeling Temporal variations in Leachate Quantity Generated at Kahrizak Landfill ", http://www.iemss.org/iemss2002/proceedings/pdf/volume%20uno/22_safari.pdf .
2. GEO-SLOP User's Guid, (2002) , "GEO-SLOPE OFFICE For Finite Element Analysis", Ver. 5.
3. Row,K.R.,C,,J Caers, ,and F, Barone., (1988),Laboratory determinaon of diffusion and distribution coefficients contaminants using undisturbed clayey soil Canadian.
4. Fredlun, D. G. and Rahardjo, H. , (1993), "Soil Mechanics For Unsaturated Soils", John Witey & Son, Inc..

5. Freeze, R.A. and J.A. Cherry .Groundwater, (1979), prence -Hall,Inc. ,Englewood Cli□s, New Jersey, pp 604.
6. Shackelford ,C.D. Daniel, (1991). "Di□usion in saturated soil. I: Background" , Journal of Contaminant Hydrology, pp 177-217.
7. Kemper ,W.D., and Van Shaik, J .C., (1966), Di□usion of salts in Clay-Water Systems, Soil Science of America proceedings, Vol.30.
8. Fredlund, D. G. , (1995), " Scope of Unsaturated Soil Mechanics : an Overview", IstInt. Conf. on Unsaturated Soils, Paris ,Sept. Vol.3, pp.1155-1177, eds, E.E. . Alonso & P .Delage, Bakema.
9. "Solid-Waste Management", Mc Graw-Hill International Editions Civil Engineering Senses.
10. AL-Rawi, S.M., (2008), "Selecon, Design ,and Management of Solid Waste Sanitary Landfills for Mosul City", study presented to ASTF.
11. Jor G. , (1977), "internaonal Society for Ecological Tetra Tech Inc. "Handbook of Environmental Date and Ecological Parameters".
12. Row, K. R., (1987), "Pollutant transport through barriers", Geotechnical Pracce for Waste Disposal, Special Rub. No. 13, R C Woods(ed), ASCE, New York, N. Y., pp. 159-181.
13. AL-Omary, A. M. A., (2007), "Effect of Soil Type & Compaction Condition on Behavior of Soil-Water Characteristic Curve for Soil Selected From Mosul", un published M Sc. Thesis, Civil Engineering, University of Mosul, Iraqi.

The work was carried out at the college of Engg. University of Mosul