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Computer Aided Assessment of Contaminant Transport in Landfill*

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Abstract. Migration of contaminants from a landfill poses considerable attention to environmental scrutiny. Some experience practitioner has made calculated guesses in the contaminant transport through varies material. This paper presents the use of software modelling as a tool to study the sensitivity of the pollutant leachate movement with response to the shallow but complex site geology. The geometry, contaminant transport parameter as well as the properties of sub-soil was varied. The resulting dispersion of the leachate in the subsurface was predicted. Sensitivity analysis also suggested that changes in aquifer hydraulic conductivity, landfill geometric and dispersivity have the most significant impact on model output indicating that these parameters should be carefully selected when similar modelling studies are performed.

Keywords: landfill, leachate, contaminant transport, computer modelling, advective and diffusive flow

1 Introduction

The reliance on landfill for the ultimate disposal of treated or untreated waste will inevitably remain for a considerable number of years. On one hand, the "not-in-my-backyard" syndrome confronts every siting of a new landfill site, while, on the other hand, the "out-of-sight-is-out-of-mind" philosophy incessantly contributes to the local landfill. Owing to this distinctive behaviour in the present society, as well as effective pollution control through the proper design of landfill and waste management facilities; the need to understand the leachate migration characteristics with associated spatial and temporal variations becomes a necessity[7, 19, 22].

Landfill is a very complex heterogeneous environment and present many modelling difficulties[9, 11]. Attempts to develop models that reflect these complexities generally involve the use of large numbers of spatially dependent parameters. The major drawback with this approach is that these parameters cannot be properly characterized. In this regard, vast majority of past modelling efforts reported in the literature have tended to model flow through waste using either a simple compartmental conceptualization or deterministic methodologies, resulting in both oversimplified or very complex and hence unidentifiable results [18].

Pollution of groundwater resources by landfill leachate is a significant environmental problem throughout the world and recognized since the 1970s[1, 4, 8, 10, 12, 14, 18, 24, 27, 28]. Despite the evolution of landfill technology from uncontrolled disposal sites into highly engineered facilities, the generation of leachate remains an inevitable consequence. The factors controlling the mobility of contaminant within the landfill are individually sound understood and can be simulated reasonably well in a laboratory setting, however their interaction in landfill are still not fully comprehended[2, 5, 21].

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2 Modelling concepts

The theory and governing equations of flow and transport in porous media has been the subject of extensive research, particularly in the past two decades, in response to problems arising from subsurface contamination[3, 16, 18, 25, 26, 28]. Analytical or numerical models have been developed to simulate subsurface leachate flow and transport. Though all these models solve mass, momentum and heat transport equations, the individual model capabilities and solution schemes can differ widely[6, 13, 15, 17, 20, 23]. Inclusion of the detailed discussion on these is beyond the scope of this paper. The four different processes of contaminant migration are:

- Advection; the movement of the contaminant with the seepage of the groundwater.
- Dispersion; the apparent mixing and spreading of the contaminant within the flow system.
- Adsorption; the process by which chemical dissolved in the groundwater clings to a solid surface which decreasing the concentration of the solute.
- Degradation or known as radioactive decay, which will reduce the concentration of radionuclide in both the dissolved and sorbed phases.

The cumulative one dimensional effect of these contaminant processes is expressed in the following partial differential equation:

$$D_x \frac{\partial^2 c}{\partial x^2} - \overline{v}_x \frac{\partial c}{\partial x} - \lambda_1 c - \frac{\lambda_2 \rho_d c^*}{\theta} - R = \frac{\partial c}{\partial t},$$

where, D_x is the hydrodynamic dispersion in x-direction (L^2T), v_x is the average linear velocity in x-direction (L^2T^{-1}), $_1$ is the dissolved half-life (T^{-1}), $_2$ is the sorbed half-life (T^{-1}), c is the dissolved concentration (L^3M^{-1}), c^* is the sorbed concentration (ML^{-3}), $_d$ is the bulk density (ML^{-3}), is the volumetric water content and R is the retardation factor of soption isotherm.

This can be extended to the case of two and three-dimensions by simply adding the corresponding terms for hydrodynamic dispersion and advection in the y and z-direction.

3 Results and discussion

3.1 Advective contaminant transport

Contaminant transport in soils involves the processes of both advection and dispersion. Early in a contaminant transport analysis it is often useful to isolate the magnitude of purely advective transport without the extra data input and computational requirements of including dispersion. It is necessary to mention that it is near impossible to numerically solve the advection-dispersion equation when the dispersive component is small relative to the advective component because the numerical solution becomes unstable in these cases. For simplicity, the MODEL I of Table 1 was set in a steady state condition and with constant influent flux; the input data of sub-soils' hydraulic conductivity was varying from the wide range of 1×10^{-5} to 1×10^{-14}m/s; the effect of contaminant flux migrated through a 20m thick geological layer was observed at a relative depth's interval of 0.1; other input parameter can be found in the Tab. 1.

Fig. 1 presented an output of a purely advective contaminant transport analysis. The rainbow lines represent varies of hydraulic conductivity, and the relative depth of each compliance points also indicated in the family curve. As far as the result is concerned, the time required for contaminant to migrate from a particular elevation to the compliance point through the geological layer is highly susceptible to its hydraulic conductivity. The different values of hydraulic conductivity yield the different in shapes of curves and corresponding times. The S-shape curves flatten out with decreasing in hydraulic conductivity. Theoretically speaking, a higher hydraulic conductivity will increase the speed of groundwater velocities, and hence tend to reduce the time of migration.

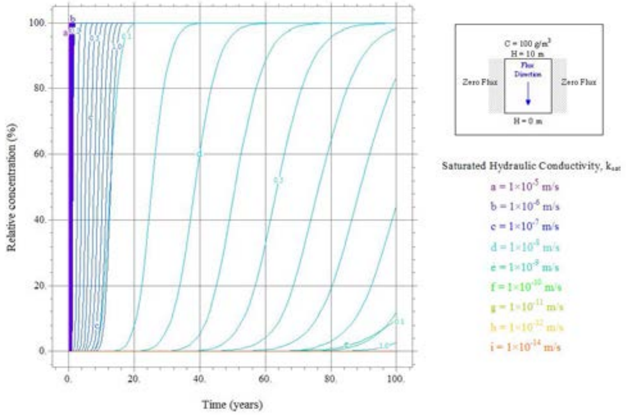
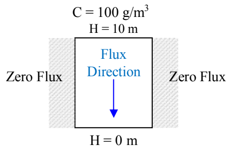
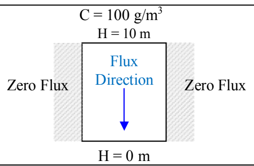
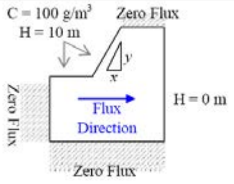
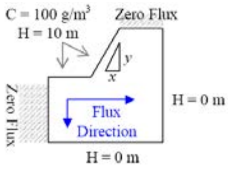


Fig. 1: Advective contaminant transport for model i at difference value of hydraulic conductivity

Table 1: Modelling domain

Model	Exploratory	Boundary Condition	Parameter
I	Hydraulic Conductivity		$k_{sat} = 1 \times 10^{-5}\ 1 \times 10^{-14} m/s$
II	Diffusion		$k_{sat} = 1 \times 10^{-5}\ 1 \times 10^{-14} m/s$ $D^* = 1 \times 10^{-7}\ 1 \times 10^{-12} m^2/s$ $\alpha_L = 5 \times 10^{-1} m$ $\alpha_T = 5 \times 10^{-3} m$
III	Geometry		$x = 1\ 5$ $y = 1\ 5$ $k_{sat} = 1 \times 10^{-8} m/s$ $D^* = 1 \times 10^{-9} m^2/s$ $\alpha_L = 5 \times 10^{-1} m$ $\alpha_T = 5 \times 10^{-3} m$
IV	Boundary Condition		$x = 1\ 5$ $y = 1\ 5$ $k_{sat} = 1 \times 10^{-8} m/s$ $D^* = 1 \times 10^{-9} m^2/s$ $\alpha_L = 5 \times 10^{-1} m$ $\alpha_T = 5 \times 10^{-3} m$

3.2 Advective-dispersive contaminant transport

Quantification of the magnitude of advective flow is useful as a preliminary analysis of contaminant transport. However, a more realistic analysis is needed to include the effect of hydrodynamic dispersion. Hydrodynamic dispersion causes dilution of contaminants both longitudinally (in the direction of groundwater flow) and transversely (perpendicular to the direction of flow) is a very significant component of contaminant transport and therefore cannot usually be ignored. A general rule-of-thumb used for estimating the mechanical dispersion coefficient is based on equating the Longitudinal dispersivity, $\alpha\alpha_L$ to the distance of transport, L as $\alpha_L = 0.1L$. and Transverse dispersivity, $\alpha_T = 0.01\alpha_L$.

An advective-dispersive analysis was conducted to assess the effect of effective diffusion coefficient variation on simulation result. The common range of variation of effective diffusion coefficient, D^* of some chemical species was varying from the wide range of 1×10^{-7} to 1×10^{-11} m^2/s; other input parameter and boundary condition was remained unchanged as MODEL I.

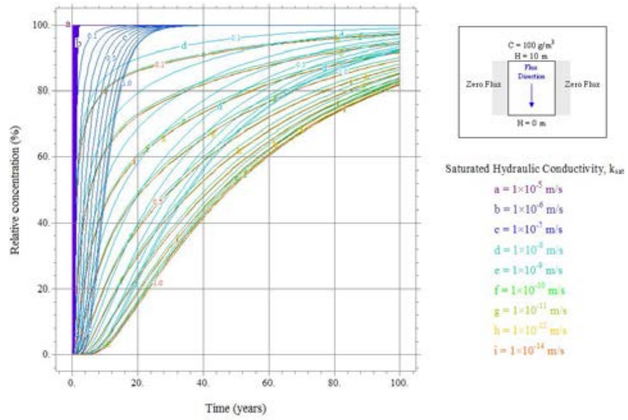


Fig. 2: Advective-Dispersive Contaminant Transport for model II at effective diffusion coefficients, $D^* = 1 \times 10^{-7}$ m^2/s and difference value of hydraulic conductivity

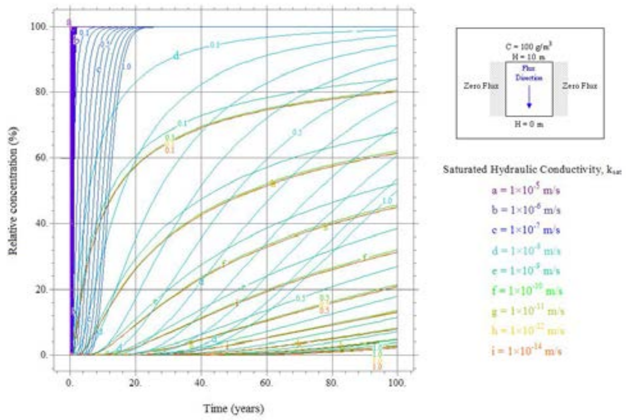


Fig. 3: Advective-dispersive contaminant transport for model II at effective diffusion coefficients, $D^* = 1 \times 10^{-8}$ m^2/s and difference value of hydraulic conductivity

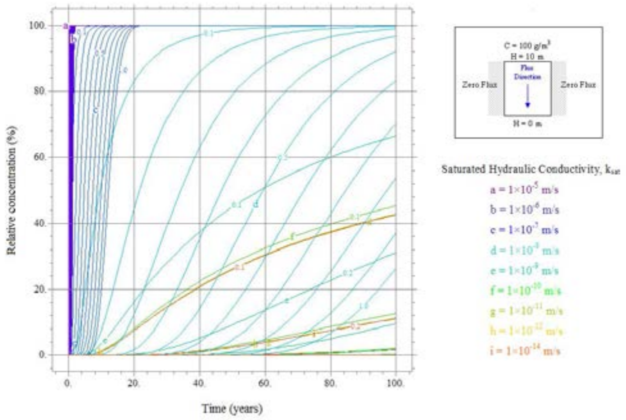


Fig. 4: Advective-Dispersive Contaminant Transport for MODEL II at effective diffusion coefficients, $D^* = 1 \times 10^{-9}$ m^2/s and difference value of hydraulic conductivity

The potential affect by taking account into the consideration of dispersion was noticeable. Fig. 2 presented an extreme case where effective diffusion coefficients of 1×10^{-7} m^2/s. A more rapid migration of contaminant was generated at the downstream, while this higher flow also induces higher dilution and hence reduces the concentration in the long term. The simulation in Fig. 3 shown the impact of effective diffusion coefficients decreasing in an order of magnitude. Aforesaid variation resulted in an opposing pattern of contaminant distri-

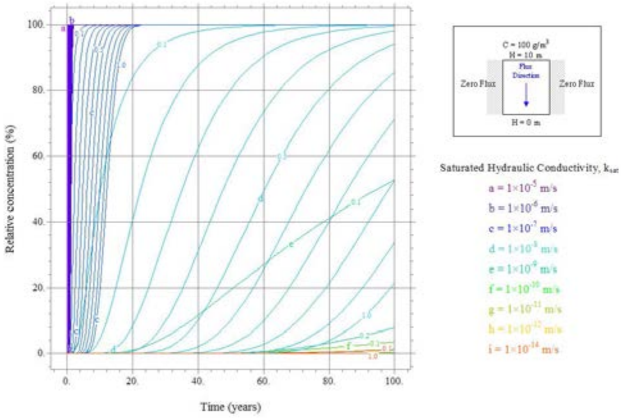


Fig. 5: Advective-Dispersive Contaminant Transport for MODEL II at effective diffusion coefficients, $D^* = 1 \times 10^{-10}$ m^2/s and difference value of Hydraulic Conductivity

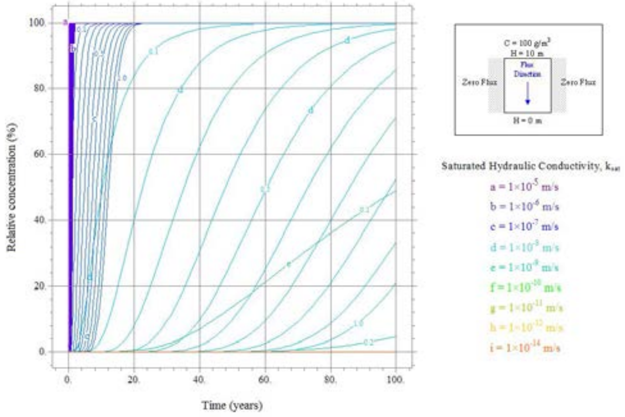


Fig. 6: Advective-Dispersive Contaminant Transport for MODEL II at effective diffusion coefficients, $D^* = 1 \times 10^{-11}$ m^2/s and difference value of Hydraulic Conductivity

bution. For hydraulic conductivity greater than 1×10^{-8} m/s, the relative concentration decreases as the distance from the source point increases. In contrast, the full concentration arrival time for hydraulic conductivity greater than 1×10^{-7}m/s was reduced. Typical range of effective diffusion coefficients from 1×10^{-9} $1 \times 10{-}10$ m^2/s in aqueous phase was point up in Figs. 4 and 5. The results have shown the influences of diffusion parameter start to play a role when hydraulic conductivity is drop down to 1×10^{-9} m/s.

On the basis of the overall results, the effective diffusion coefficients become significant for contaminant transport through soil if, and only if, advection transport is low. Diffusion starts to play the predominant role in the total contaminant flux when hydraulic conductivity value is lower than 1×10^{-9}m/s as evidenced in Figs. 2 to 6. For hydraulic conductivity value lower than 1×10^{-10}m/s, it becomes more negligible because of the predominance of diffusive transport. This is particular useful in sighted when related to the situation where hydraulic flow is relatively low, i.e. through barrier systems.

3.3 Influences of geometric and boundary condition

All Slope stability of a landfill site is of great concern for engineers. However, their influences on the contaminant migration were not being attended. In the regard with this, MODEL III and IV of Tab. 1 was simulated to study the influences of geometric and boundary condition in the contaminant transport. Input parameter can be found in the same table. Fig. 7 present the result in a contour plot of contaminant flux migration and the magnitude of the concentration can be found in the left and right margin respectively. Despite the seepage flowing pattern, variation in the slope's gradient could delay the occurrence of peak pollution within the vicinity of the landfill site as evidenced in Fig. 7(a) and 7 (b). As the gradient flatten out, the models clearly shown a greater concentration of plume in the right margin of the geological layer. In conversely, the plume will have reduced when the gradient was increased.

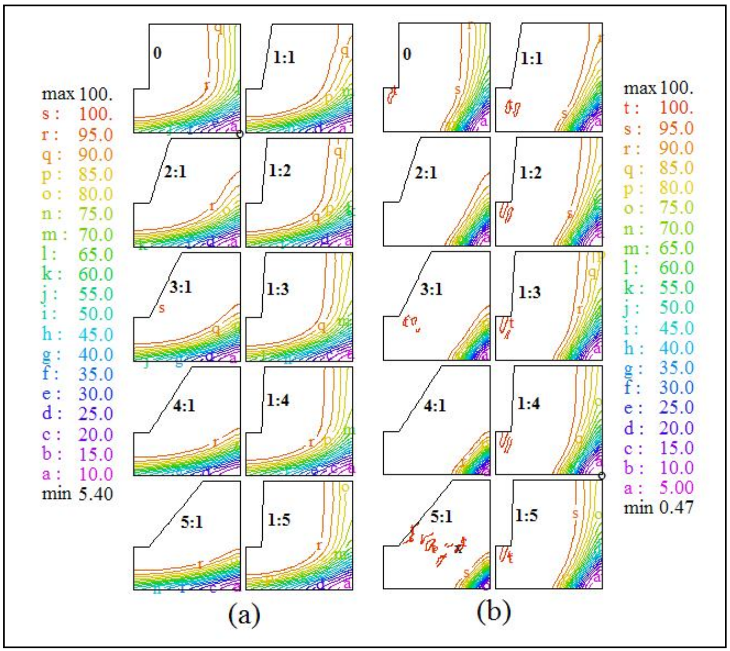


Fig. 7: (a) Influences of geometric and (b) Boundary condition in the contaminant transport at 100 years

Model IV present a more realistic case where the contaminant is migrating in both longitudinal and transverse direction, the simulated result was presented in Fig. 7(b). The concentration contours clearly shown a great diversion of large amount of plume in vertical direction; however, the magnitude of relative concentration was not significantly affected by the slope gradient.

4 Conclusions

Achieving an understanding of the scientific basis to contaminant transport was essential to improve long term prediction of the leachate migration characteristic and controlled landfill design. This paper presents an investigation into the parametric sensitivity of contaminant transport as well as demonstrating the efficiency on computer aided modelling. The simulation included variations in model parameter such as hydraulic conductivity, diffusivity, boundary condition and geometry. Some of the prime conclusions are:

- The time required for contaminant migration is highly dependent on the hydraulic conductivity of the geological layer;
- For a purely advective contaminant transport; the flux is a function of Darcy velocity that, in turn, is proportional to the hydraulic conductivity, provided that the gradient is constant;
- The diffusivity significantly affected the contaminant transport through soil. Diffusion starts to play a predominant role in the total contaminant flux when hydraulic conductivity value is lower than 1×10^{-9}m/s;
- Geometry of the landfill slope evidently factors controlling contaminant migration. Performance in leachate containment increases as the slope gradient increases.

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