Quality of Groundwater, **Proceedings of an International Symposium, Noordwijkerhout, The Netherlands, 23–27 March 1981, W. van Duijvenbooden, P. Glasbergen and H. van Lelyveld (Eds.),** *Studies in Environmental Science*, **Volume 17**

THE INFLUENCE OF SOIL HETEROGENEITY ON THE SIMULATION OF THE DEVELOPMENT OF GROUND-WATER QUALITY

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INTRODUCTION

The threat of pollution sources to the quality of ground-water as a resource for drinking water has been long recognised. More recently attention has tended to shift towards the role of chemical pollution in the degradation of any sort of ground-water as the close integration of this and the biosphere as a whole has become apparent. Furthermore there has been a shift from passive to active and preventitive pollution management strategies which in turn has tended to highlight the necessity of effective simulation of the mobility of the contaminants in any given practical situation. These simulation techniques are widely available and a vast literature has grown up around the numerical and mathematical problems associated with them. Usually these techniques have not been applied to structured or heterogeneous soils. Often the problem didn't warrent the extra effort but unfortunately many of the cases under current study have length and time scales that are comparable to the heterogenity scale and this aspect has to be carefully considered. It is the purpose of this paper to examine some of the consequences of heterogeneity.

PROBLEM FORMULATION

Taking as the starting point the continuum approach the governing equations for steady state saturated water flow are

$$\nabla\cdot(K\nabla\phi) = 0 \qquad (1)$$

and

$$\frac{\partial c}{\partial t} + \frac{\partial s}{\partial t} = -\nabla\cdot c\bar{v} + \nabla\cdot(D+\mathbf{D})\nabla C + \Psi \qquad (2)$$

where K is the permeability, ϕ the potential, C and S the concentrations of dis-solved and absorbed components respectively, t the time, $\bar{v}$ the in pore velocity

($\bar{v} = K \nabla\phi/n$, by definition, with n the porosity) and ($D + \mathbb{D}$) the dispersion tensor. Ψ is a pollutant source or sink term, such as first order decay for radio-nuclides.

For cases of simple geometry and coefficients that don't vary in space [i.e. homogeneous porous media], many analytical solutions are available [see for example Bear, 1972]. In more complicated cases numerical methods have to be applied, the type of method depending upon the value of the coefficients in equation (2). For problems where the Peclet number (= $^{VL}/_{D}$, where L and V are a characteristic length and velocity for the particular problem) is large, then the equation takes an hyperbolic character and the point tracing method is the better. On the other hand for a small Peclet number, the form is parabolic and numerical integration of both time and distance derivatives is necessary. Both these methods will be illustrated in the two case studies given below.

CASE 1 - Infiltration of polluted river water into adjoining ground.

This case taken from a major simulation study for a proposed dyke modification in North Holland, who's consequence was an increase of salt water penetration into the surrounding ground. In this case the equations to be solved are (1) and the point trace simplification of (2), i.e.

$$\frac{\partial c}{\partial t} = - \nabla \cdot c\bar{v} \qquad (2a)$$

The solutions were obtained using over-relaxation techniques for (1) and direct integration along the resulting flow lines for (2a) . Both capabilities being provided by the institutes SEEP code. The results are illustrated in figure 1. These should be contrasted to those in figure 2 which is a similar calculation using homogeneous coefficients.

An important practical result of this study was that whereas in the homogeneous case, the simulation predicted that a drainage ditch behind the dyke would have prevented salt water intrusion, the more sophisticated heterogeneous simulation indicated that this would not be the case and that serious degradation of the ground-water was inevitable with this option.

CASE 2 - Toeing phenomina from a chemical waste disposal site.

As part of an on-going study for the environmental impact of a chemical waste dump on the quality of the local ground-water a calculation was made for the distance of penetration at which the polutant concentration became 10% of the source concentration (toe effect). For similar geohydrological situations the calculations were performed for the case of a homogeneous soil and for soils with increasing degrees of heterogeneity or differentiation (around the same average).

In order to make the heterogeneous simulations the flow field was divided into elements to which the media properties were assigned values according to the required distribution in a random manner. Equations (1) and (2) were then solved for this field using finite difference techniques contained in the code GEOVEEN. The results are shown in figure 3. The value for the inverse Peclet number taken from literature correlations for this problem was about 0.10, giving a relative break through time of 0.53.

In fact for 16% differentiation [16% of the volume randomly non-homogeneous] the break-through at the 10% level occurs at relative time 0.40 and with 28% differentiation, at 0.16. From figure 3 it would appear that a system with 28% differentiation is behaving as though the inverse Peclet number was 0.9 are almost a factor 10 greater than predicted, but with 16% differentiation only twice as high!

As in case 1 the conclusion is that not taking heterogeneity into account can lead to very serious errors in predicting the impact of pollution sources on the quality of ground-water.

REFERENCES

1 J. Bear, Dynamics of Fluids in Porous Media, Elsevier Pub. C., Inc., New York, 1972.

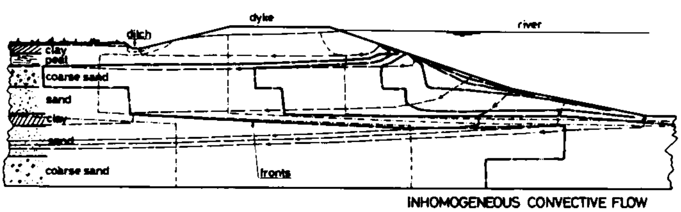

Fig. 1

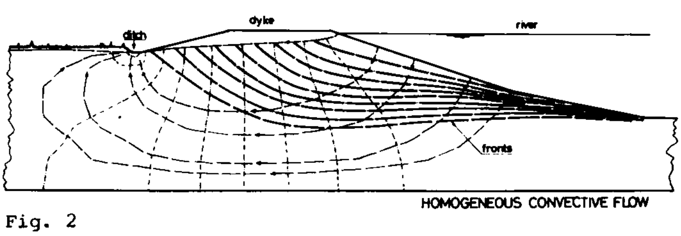

Fig. 2

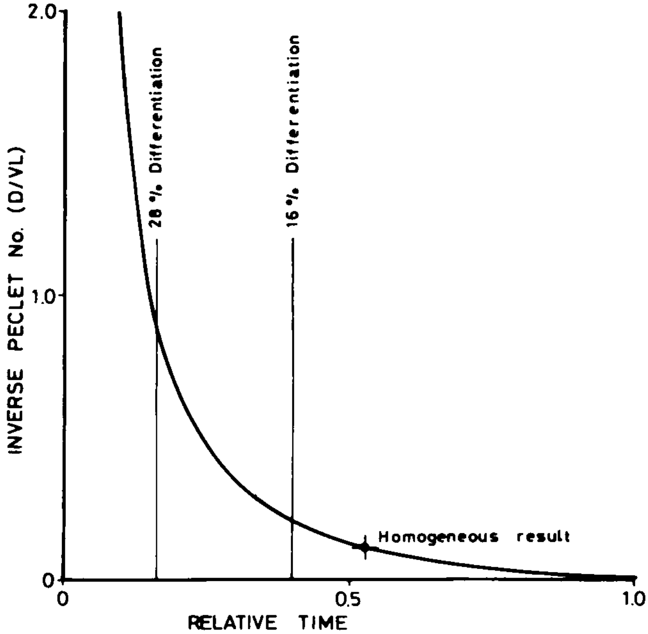
2.0
1.0
0
INVERSE PECLET No. (D/VL)
28 % Differentiation
16 % Differentiation
Homogeneous result
0
0.5
1.0
RELATIVE TIME

FIG. 3.