Effective porosity values used in calibrated transport simulations in a fissured and slightly karstified chalk aquifer

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Abstract In fissured and slighly karstified chalks, the main difficulty for modelling groundwater flow and transport consists in finding a good approximation of the highly heterogeneous reality by a REV concept. No major problem is encountered for groundwater flow simulations when the high contrast in hydraulic conductivity can be given to the cells/elements of the model. The Darcy's law is applied in terms of specific flow rate, through the REV. When considering transport, it is often assumed that the calibrated field of hydraulic conductivity should be kept unchanged. Consequently, 'physically non acceptable' values of the effective porosity are often needed to obtain a match between modelled and measured breakthrough curves. The model becomes, to some extent, a black-box model.

INTRODUCTION

The previous studies of the Hesbaye aquifer (located near Liège in Belgium) were mainly made for assessing the piezometric heads and base-flow in function of the withdrawal flow-rates (collecting galleries and pumping wells). A 3D groundwater finite element model was built, calibrated and validated, to investigate several production scenarios. Recently, for purposes of assessing the protection zones, it was necessary to study in detail the transport behaviour in the different vulnerable zones of this chalk aquifer. Since the studies made by Biver & Dassargues (1993), it was known that the double porosity effect should be taken into account when dealing with the transport behaviour in such a micro-fissured, fissured and/or slightly karstified aquifer. The high chalk hydraulic conductivity values are due to fissure flow systems using preferential dissolution along discontinuities and zones of weakness, such as bedding phases and tectonic fractures. In the chalk matrix, however, the hydraulic conductivity value is much lower although the total porosity can be very high.

MULTI-TRACER TESTS

Thirty-five injections of tracers (11 sites) were performed under convergent flow conditions to pumping wells or under cylindrical flow conditions towards the collecting gallery. The morphostructural and geophysical studies provided information on the main fracturation axis where advective transport was expected to be very important. Interpretation and modelling of each of these local situations have allowed to observe three kinds of breakthrough curves:

(1) transport with a dominant advective component (Fig. 1-A): narrow and symmetrical observed breakthrough curves showing maximum velocity of tracer included between 10 and 110 m h^{-1} (for distances between 5 and 130 m and for fluorescent dyes as well as ionic tracers); the first arrival (arbitrary fixed at a concentration of 10 ppb) is followed very rapidly by the peak. The concentration tailing is also rapid as nearly no retardation (adsorption/desorption) and nearly no diffusion into the porous

chalk matrix are observed. Groundwater flow occurs mainly in the preferential fissured (or slightly karstified), channels which can often be deduced from the morphostructural analysis and the shallow geoelectrical prospections;

(2) transport with advective and dispersive components (Fig. 1-B): more spread-out breakthrough curves are observed with maximum velocity of the tracer from 1 to 10 m h^{-1}. Retardation effects can affect the breakthrough curves creating a non-symmetrical trend. This type of transport behaviour occurs in micro-fissured/ fractured zones of the chalk matrix;

(3) transport with a dominant dispersive component, advection remains but can be considered slow in comparison with (1) and (2) (Fig. 1-C): the breakthrough curve is flat and the maximum recorded velocities are lower than 1 m h^{-1}. Retardation and immobile water effects induced a low decrease of the concentration after the peak. This transport behaviour can be considered as typical for the chalk matrix.

MODELLING THE TRACER TESTS

In each site, the calibration of the local (2D, quasi-3D or full 3D) flow and transport models on the results of the pumping and tracer tests have allowed to deduce values for the transport parameters. If no particular problems were encountered for modelling flow and transport behaviours in cases (2) and (3), on the contrary, cautious approach must be adopted when simulating transport behaviours, such as described in type (1). After calibration of the flow model, high contrasts in hydraulic conductivity values were introduced in the model. Keeping these K-values unchanged, extremely low values of the effective porosity (n_e) must be introduced in order to reproduce breakthrough curves of type (1). Attempts have been made to accentuate the contrast in the K-field without too much deteriorating the flow calibration but it ended in a failure. Unrealistic effective porosity values from 0.0002 to 0.008 had to be introduced locally (i.e. in the fractured/karstified zones). The lower effective porosity values that could be reasonably accepted are around 0.01 as measured by Biver & Dassargues (1993) when considering for this chalk medium that the only mobile water is located in fissures. Even if small cells/elements (2 m x 2 m) are used, their size is still too large for representing accurately the fractured and slightly karstified preferential channels. Our modelling approach becomes empirical involving coefficients without actual physical meaning. Many authors have studied the fact that the REV "equivalent" values of the parameters are never the same than those observed from lab- and field-tests, but a model is generally considered as "physically consistent" when its parameters remain in an interval of realistic values.

CONCLUSIONS

It has been shown (Bradburry & Muldoon, 1994; Guérin & Billaux, 1994) that numerical models based on continuum and REV concepts may provide satisfactory results for simulating bulk groundwater flow and head distribution in chalky aquifers. The same models may be seriously deficient when attempting to predict contaminant transport. Despite local refinements and the highest contrasts (as possible in the frame of the groundwater flow calibration) in K-values, unrealistic values of the effective porosity had still to be distinguished locally to calibrate the transport models. The only way to restore the physical meaning of the effective porosity in the models should imply a more detailed geometrical description of each fractured axis by using very small finite difference cells or finite elements. It can be considered, for example, with use of a double-continuum model. However, if an accurate discretization is more and more possible with the increasing power of the computers, the detailed and accurate description of the preferential channels in such an aquifer is still a dream !

REFERENCES

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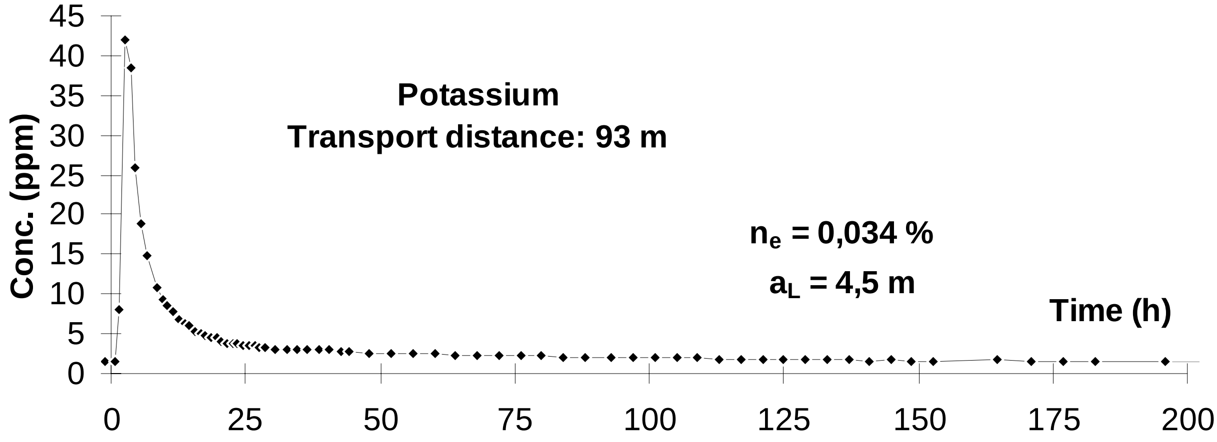
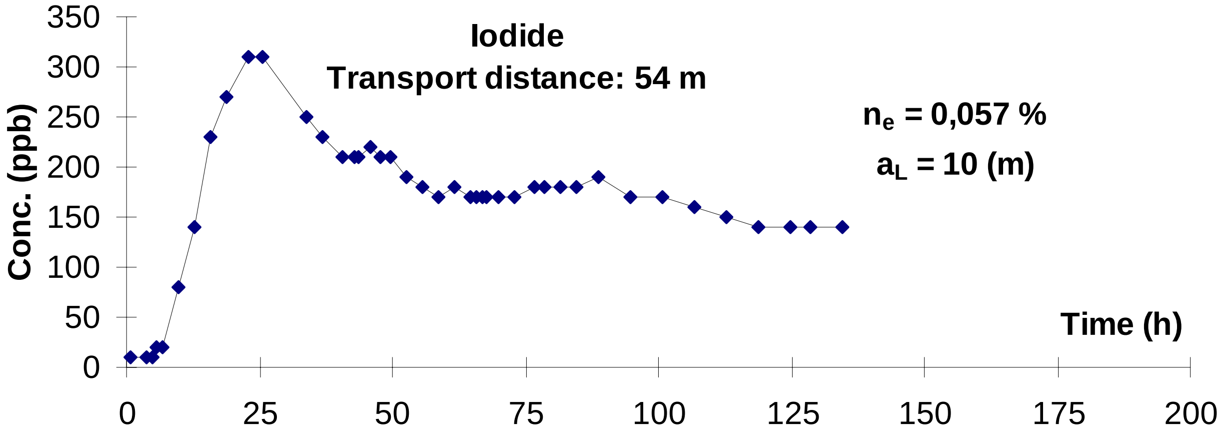
Fig. 1 Examples of breakthrough curves showing the three kinds of transport behaviour in the chalk aquifer: A) dominant advective transport, B) advective and dispersive transport, C) dominant dispersive transport.



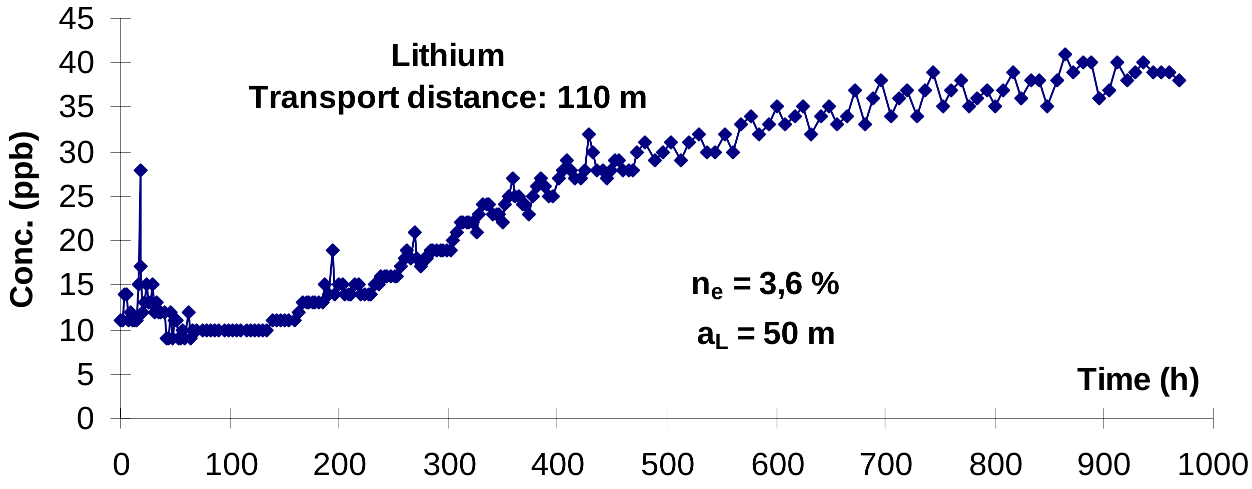
Potassium
Transport distance: 93 m
n_e = 0,034 %
a_L = 4,5 m
Conc. (ppm)
Time (h)
45
40
35
30
25
20
15
10
5
0
0
25
50
75
100
125
150
175
200

A



Iodide
Transport distance: 54 m
n_e = 0,057 %
a_L = 10 (m)
Conc. (ppb)
Time (h)
350
300
250
200
150
100
50
0
0
25
50
75
100
125
150
175
200

B



Lithium
Transport distance: 110 m
n_e = 3,6 %
a_L = 50 m
Conc. (ppb)
Time (h)
45
40
35
30
25
20
15
10
5
0
0
100
200
300
400
500
600
700
800
900
1000

C