

Behaviour of contaminant plumes at the interface between the Pampeano and Puelche aquifers in the province of Buenos Aires, Argentina

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Abstract The objective of this work was to employ a numerical simulator to investigate the behaviour of contaminant plumes at the interface between the Pampeano and Puelche aquifers in the northeast of the Province of Buenos Aires. The influence of the clay layer on the concentration profiles of chloride and chromium VI was analysed. For this purpose we developed a characteristics finite element procedure to simulate contaminant transport in saturated anisotropic porous media under steady flow conditions. For the chromium simulations, adsorption effects were included in the model using a linear isotherm.

INTRODUCTION

The study of the Puelche aquifer is of great interest due to its extent, its water quality, and the large water volumes extracted. Even though it is a semiconfined aquifer, there are important vertical flows between this aquifer and the overlying Pampeano aquifer. These vertical flows allow the chemical pollutants present at the top of the Pampeano aquifer (i.e. at the water table), to migrate towards the Puelche aquifer. Numerical models are useful tools to understand and predict transport and chemical reaction processes in groundwater. However, these models are, in general, difficult to apply due to the meagre knowledge of the geological characteristics of the subsurface. Numerical simulations of contaminant migration have been studied by a large number of authors. Most of the plumes analysed have originated at either point or distributed shallow sources and migrated towards deeper aquifers (e.g. Van der Zee & Riewsdijk, 1987; Zhang *et al.*, 1993; Burnett & Frind, 1987; Frind & Hokkanen, 1987; Frind & Germain, 1986; Dawson *et al.*, 1996).

The aim of this work is to simulate contaminant transport in the Puelche and Pampeano aquifers at a site where the Pampeano aquifer has been contaminated by industrial activities. A non-reactive solute, chloride, and a reactive solute, chromium VI, are considered. The chloride concentration directly affects the general water quality. The presence of chromium VI, even at low concentrations, may cause several diseases in the population, ranging from hepatic disorders to cancer in the digestive system.

HYDROGEOLOGICAL CHARACTERISTICS

The study of the shallow Puelche and Pampeano aquifers is of importance because of their vulnerability to contamination.

In the study area, the Puelche aquifer is located at a depth of about 30 m, is up to 20 m thick, and is composed of fine to medium sand. Pumping tests show a transmissivity of $500 \text{ m}^2 \text{ day}^{-1}$ and a storage coefficient of 10^{-3} (Sala *et al.*, 1983). The Pampeano aquifer includes the water table and its water chemistry is directly related to processes originating on the land surface (infiltration, contamination). The unit is composed of silty sediments, in part clayey and sandy with calcareous materials. The unit has local anisotropy causing different productive levels. Its thickness is about 30 m, and the regional transmissivity is $100 \text{ m}^2 \text{ day}^{-1}$. The Pampeano aquifer is underlain by a clay layer, which ranges from 0 to 5 m in thickness. This layer is considered to be the separation between the Pampeano and Puelche aquifers. In spite of the presence of this layer of low permeability, the Puelche and Pampeano aquifers are hydraulically connected and thus constitute a “multilayer aquifer”.

Water sampled from monitoring wells indicates significant contamination, with maximum measured concentrations of 1375 mg l^{-1} for chloride (Cl^-) and 0.98 mg l^{-1} for chromium (Cr(VI)).

TRANSPORT SIMULATION METHOD

In this work we implemented a characteristics finite element method to solve the transport equation in a porous medium. This procedure allows for the proper treatment of the convective term and eliminates spurious numerical oscillations. The method of characteristics has been used extensively in several field studies (Dawson *et al.*, 1994).

The governing differential equation of advective-dispersive transport in a porous medium is:

$$\phi \frac{\partial C(x,t)}{\partial t} + \nabla \cdot (D \nabla C(x,t)) - q_w \cdot \nabla C(x,t) = f(x,t) \quad x \in \Omega \quad (1)$$

where $C(x,t)$ is the concentration, ϕ denotes the porosity, Ω the porous domain, $D = D(q_w)$ is the hydrodynamic dispersion tensor and $f(x,t)$ the contaminant source.

The transport of a reactive solute through soil depends on the reaction between the soil solution and the solid phase. Adsorption is the reaction process whereby solutes adhere to the surface of soil particles (Travis & Etnier, 1981). The functional relationship between the dissolved and adsorbed concentrations is called the adsorption isotherm. This isotherm is generally incorporated into the transport model through the retardation factor.

For the chromium VI case, taking into account adsorption effects, the mass balance equation becomes

$$R \frac{\partial C(x,t)}{\partial t} + \nabla \cdot (D \nabla C(x,t)) - q_w \cdot \nabla C(x,t) = f(x,t) \quad x \in \Omega \quad (2)$$

where:

$$R = \phi + \rho k_d \quad (3)$$

is the retardation factor (dimensionless), ρ denotes the bulk density of the soil and k_d is an empirical distribution coefficient from the linear adsorption isotherm.

GENERIC SYSTEM

We used a simplified geological system to represent the Pampeano-Puelche aquifers. Two simulation scenarios were analysed, with and without a separating clay layer. Details of the contamination history of the study area such as depth, position, and origin of the contaminant sources were unknown, unfortunately.

Consequently we considered a continuous point source of contamination in the Pampeano aquifer at a depth of 22 m and simulated the time evolution of the contaminant plume. The flow domain is two-dimensional and the groundwater discharge is to the right boundary in all the experiments. There is also a descendant vertical leakage between the aquifers. The domain size is 100 m in length and 20 m in thickness; this allows observation of the behaviour of the contaminant plumes at the top of the Puelche aquifer. The mesh size is $h_x = 2$ m in the horizontal direction and $h_z = 0.5$ m in the vertical direction. The total simulation time is 2 years with a time step of 1 day.

In the absence of suitable data for the Pampeano and Puelche aquifers, the dispersivities were taken from data reported by Frind & Hokkanen (1987) for formations of similar characteristics; longitudinal dispersivities ranged from about 5 to 20 m. Transverse vertical dispersivities were estimated as a fraction of the longitudinal dispersivities.

The factors affecting the heavy metal adsorption are difficult to isolate from experiments conducted on natural soils. The empirical distribution coefficient for the linear adsorption isotherm for chromium VI was taken to be $k_d = 0.0457 \text{ cm}^3 \text{ g}^{-1}$ (Selim *et al.*, 1989). This value was used in the absence of suitable data for the formations being analysed.

RESULTS

Results are presented (Figs 1–4) in the form of concentration contours (mg l^{-1}) that show the evolution of the chloride and chromium plumes. The plumes penetrate the Puelche aquifer, following the flow system and are deflected down-rightward.

Figure 1 shows the effect of the presence of the clay layer; concentration values of chloride at the top of Puelche aquifer do not reach 600 mg l^{-1} . Also, it is observed in Fig. 1 that when the clay layer is present, the top of the Puelche is contaminated in a horizontal direction, to a distance of about 60 m from the source.

On the other hand, in the absence of the clay layer, as shown in Fig. 2, the chloride concentration contours of 600 mg l^{-1} reach the top of the aquifer at a horizontal distance of 30 m and the plume reaches the right boundary of the domain.

In the case of contamination by chromium VI (Figs 3, 4) the figures show that the plume has a similar behaviour with respect to the presence or absence of the clay layer,

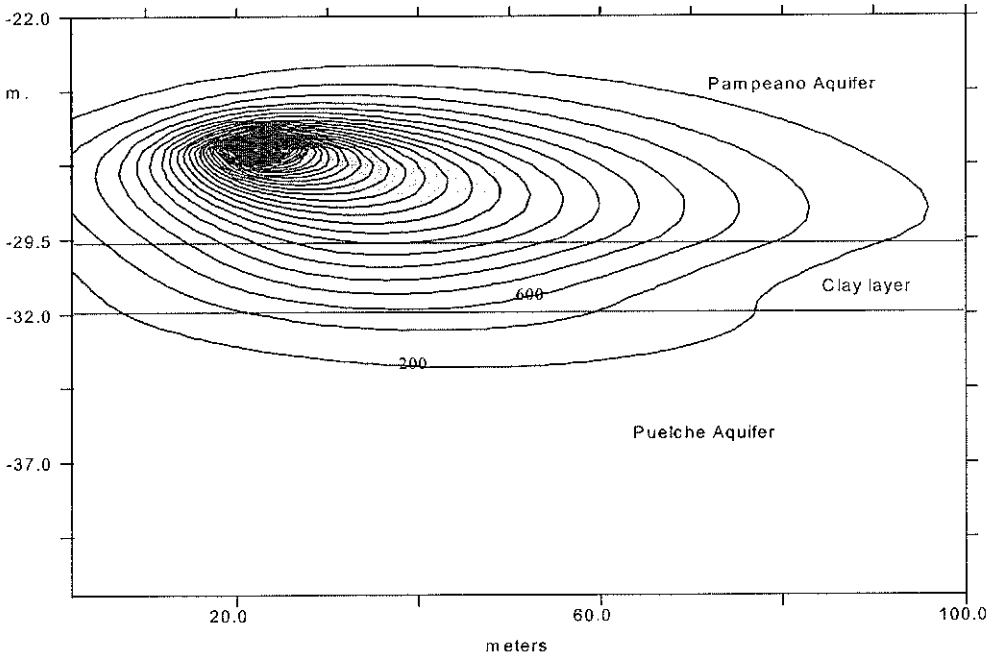


Fig. 1 Chloride plume evolution to 600 days when the clay layer is present. The contours are in mg l^{-1} .

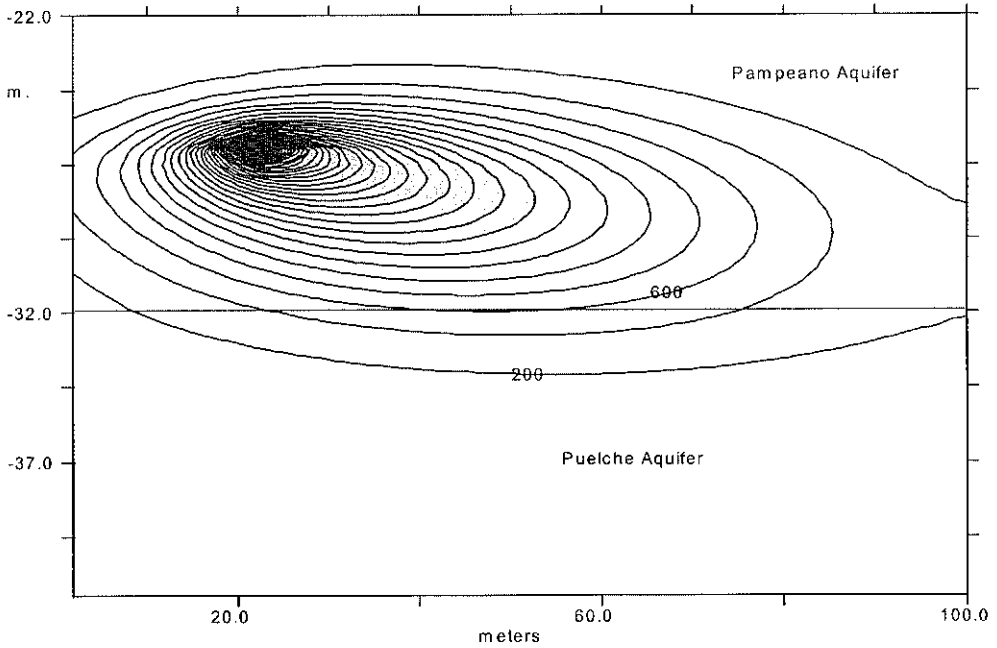


Fig. 2 Chloride plume evolution to 600 days in absence of the clay layer. The contours are in mg l^{-1} .

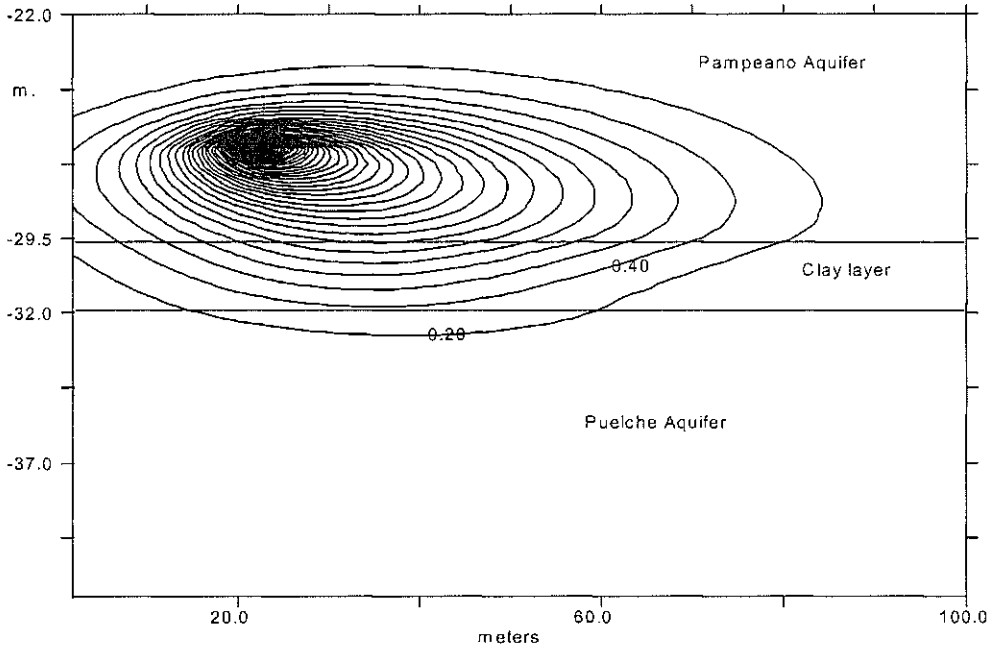


Fig. 3 Chromium VI plume evolution to 700 days when the clay layer is present. The contours are in mg l^{-1} .

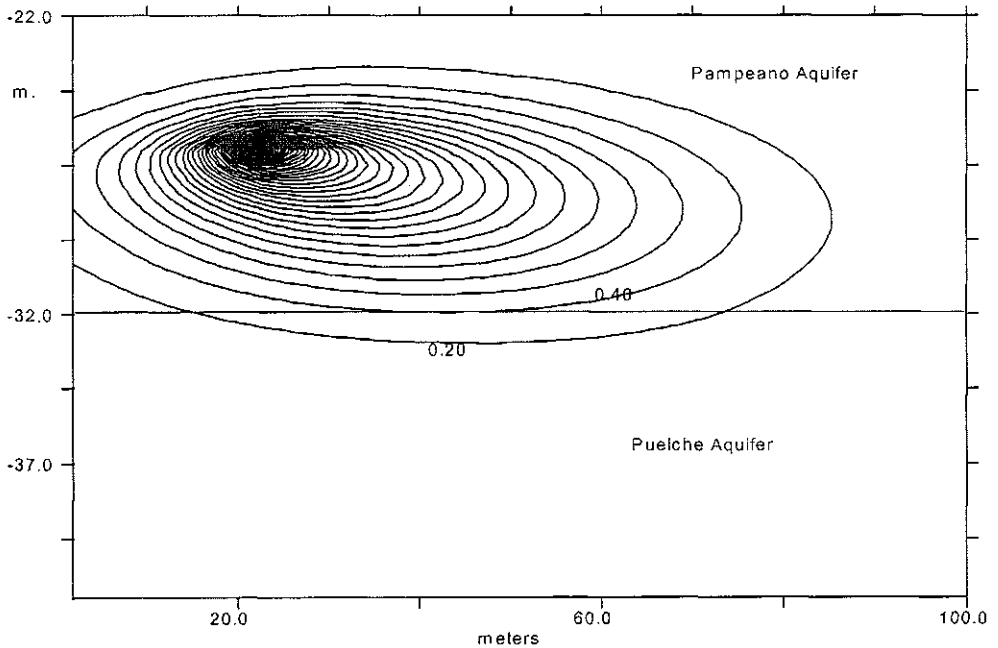


Fig. 4 Chromium VI plume evolution to 700 days in absence of clay layer. The contours are in mg l^{-1} .

and the adsorption effects can not prevent the contamination front from reaching the Puelche aquifer.

In the absence of the clay layer (Fig. 4), over a 700 day period, the chromium plume covers a horizontal distance of 60 m at the top of the Puelche, with concentration contours of 0.40 mg l^{-1} . On the contrary, when the clay layer is present the 0.40 mg l^{-1} concentration contours do not quite reach the top of the Puelche aquifer.

CONCLUSIONS

The objective of this study was to obtain a better understanding of dissolved contaminant migration in multilayer aquifers by means of numerical simulation. The evolution of contaminant plumes was simulated to determine if a contaminant source affecting the Pampeano aquifer can also affect the underlying Puelche aquifer, independently of the existence of the separating clay layer.

Data from monitoring wells show that the Puelche aquifer has been contaminated. Simulation results presented in this paper demonstrate that this contamination may be the consequence of contaminant migration from a source site in the overlying Pampeano aquifer. The plume reaches the Puelche aquifer in the two cases analysed, but the form of the contamination front is different and the presence of the clay layer delays the arrival of the contamination front to the Puelches aquifer.

REFERENCES

- Burnett, R. D. & Frind, E. O. (1987) Simulation of contaminant transport in three dimensions 2. Dimensionality effects. *Wat. Resour. Res.* **23**(4), 695–705.
- Dawson, C. N., Van Duijn, C. J. & Grundy, R. E. (1996) Large time asymptotics in contaminant transport in porous media. *Soc. Industr. Appl. Math. J. Appl. Math.* **56**(4), 956–993.
- Dawson, C. N., Van Duijn, C. J. & Wheeler, M. F. (1994) Characteristic-Galerkin methods for contaminant transport with nonequilibrium adsorption kinetics. *Soc. Industr. Appl. Math. J. Numer. Anal.* **31**(4), 982–999.
- Frind, E. O. & Germain, D. (1986) Simulation of contaminant plumes with large dispersive contrast: evaluation of alternating direction Galerkin models. *Wat. Resour. Res.* **22**(13), 1857–1873.
- Frind, E. O. & Hokkanen, G. E. (1987) Simulation of the Borden Plume using the alternating direction Galerkin technique. *Wat. Resour. Res.* **23**(5), 918–930.
- Sala, J. M., Gonzalez, N. & Kruse, E. (1983) Generalización hidrológica de la Provincia de Buenos Aires. In: *Coloquio Internacional sobre Hidrología de Grandes Llanuras* (Olavarria, Argentina), Proc. 2, 975–1008.
- Selim, H. M., Amacher, M. C. & Iskandar, I. K. (1989) Modeling the transport of chromium (VI) in soil columns. *Soil Sci. Soc. Am. J.* **53**, 996–1004.
- Travis, C. C. & Etnier, E. L. (1981) A survey of sorption relationships for reactive solutes in soil. *J. Environ. Qual.* **10**(1), 8–17.
- Van der Zec, S. & Riewsdijk, W. H. (1987) Transport of reactive solute in spatially variable soil systems. *Wat. Resour. Res.* **23**(11), 2059–2069.
- Zhang, R., Huang, K. & Van Genuchten, M. T. (1993) An efficient eulerian-lagrangian method for solving solute transport problems in steady and transient flow fields. *Wat. Resour. Res.* **29**(12), 4131–4138.