

APPLICATION OF DIFFERENT COMPUTER MODELS TO THE STUDY OF SOLUTE TRANSPORT IN A VERTICAL PROFILE OF MADRID AQUIFER

M.R. LLAMAS and P.E. MARTINEZ ALFARO

Departamento de Geología de la Universidad Autónoma y Departamento de Geomorfología de la Universidad Complutense. Madrid (Spain).

ABSTRACT

The Madrid aquifer is in a large tectonic basin filled with continental tertiary deposits with a thickness up to almost 4 Km. The area is over 4000 Km². Annual precipitation and temperature are 500 mm and 15°C, respectively. Some vertical profiles may be considered representative of the hydrogeologic system. The preliminary results of applying a finite-differences flow model, a mixing-cell model and a method of characteristics model to a vertical profile are shown.

INTRODUCTION

The Madrid sedimentary basin is a large and thick tectonic basin, filled with continental Tertiary deposits. The area of the aquifer system is a little more than 4000 Km². Population living in the area, mostly in Madrid City, is over 4 million people.

Over the past several years various authors have worked with finite difference digital models to simulate the flow system in Madrid aquifer (ref. 4).

Numerical models for groundwater quality are less developed than numerical flow models. These models only began to be developed in the early seventies. In this paper two quality models are applied. One developed by the U.S.G.S., which employs the method of characteristics (ref. 3). The other one - a mixing-cell model - has not been much applied yet to groundwater studies (ref. 4). In this model, a mass transfer system is represented by dividing the medium into a network of interconnected cells. Each cell is a "mixing-cell", in the sense that no concentration gradient may exist in an individual cell. The flow

system, should be obtained independently. The movement of dissolved matter through the cells and along discrete time steps is modeled by a set of recursive equations based on the equation of continuity. The computer program used in this paper is a slightly modified version of the one written by Campana (ref. 2). The model can calculate the concentration of a conservative or non-conservative tracer in each cell at any time step. Also the mean age of the water in each cell can be obtained. The program can use different types of mixing patterns inside the cell and of flow and exchange of water between individual cells. In this way it seems that longitudinal and lateral dispersion phenomena can be taken into account, and also the role of stagnant zones.

In the 1979 study (ref. 4) the whole aquifer was discretized into 30 large cells distributed in two superposed layers. The results, calibrated with C-14, were encouraging, but they showed the convenience of taking into account in a more sophisticated way the significant variations which exist in the vertical dimension. This was done in 1980 by applying a flow model and a mixing cell model to a vertical profile (ref. 2). Another application to a second vertical profile using C-14 data for calibration has been done. A summary of it was presented during the last International Geological Congress (ref. 7).

In this paper are shown the preliminary results of the application of both models (flow and mixing cell) and also another solute transfer model (method of characteristics) to a third vertical profile.

GENERAL HYDROGEOLOGICAL CHARACTERISTICS

A scheme of the hydrogeological vertical profile can be seen in fig. 1. The boundaries of the basin are assumed impervious. The aquifer is constituted mainly by quasi-horizontal lenses of arkosic sand surrounded by clay and silt.

On a local scale hydraulic conductivity changes sharply in a random fashion, but on a regional scale statistical studies have shown a pattern in these changes according to the geology. Nevertheless, for modeling, a homogeneous, anisotropic, hydraulic conductivity is assumed. Horizontal conductivity is assumed 0.25 m/day; vertical conductivity is assumed 100 times smaller. Porosity is estimated equal to 0.2.

Average annual precipitation and temperature are 500 mm/year and 15°C, respectively. Recharge, is about 60 mm/year.

The detrital Tertiary deposits underlie five watersheds corresponding to tributaries or subtributaries to the Tajo river. All these five rivers are "gaining" rivers.

The water-table contours of the aquifer system are approximately parallel to the rivers. This fact means that the groundwater velocity vectors are in planes approximately perpendicular to the river valleys. Therefore, the system can be studied by means of several vertical profiles.

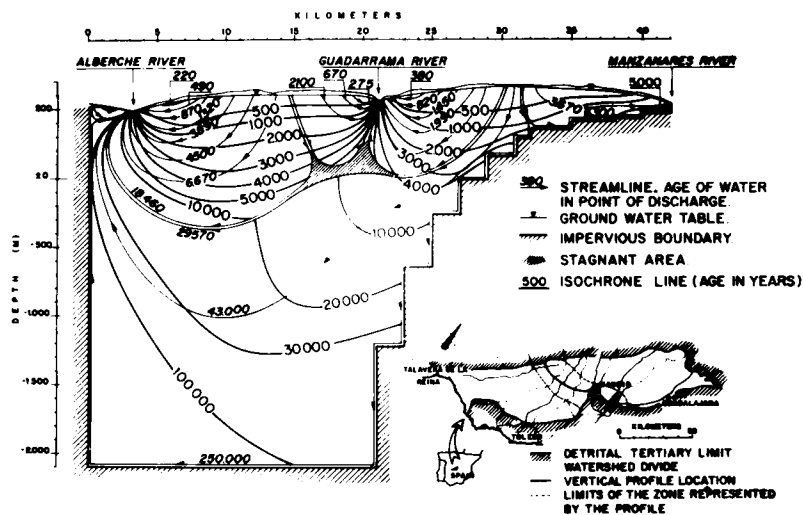


Fig. 1. Vertical profile showing streamlines and isochron lines.

THE FLOW MODEL

To simulate the groundwater flow the well-known Prickett-Lonquist model has been used. The basic assumptions are: (1) steady-state flow, (2) upper constant-head boundary defined by the water table, and (3) all other boundaries impervious. The calibration of the model was achieved mainly by comparing the computed recharge and discharge with the corresponding values calculated in previous studies by other methods. The isochrone lines were obtained by simple application of Darcy's law to the flow net. Piston flow was assumed.

The grid of the model used to obtain the flow net and isochrones of fig. 1 is rectangular with 42 columns and 28 rows. Δx is constant and equal to 1 Km. Δz is equal to 20 m. until the 10th row; from this row to the bottom of the aquifer Δz increases by a factor of 1.5.

The flow net shows the existence of a quasi-stagnant zone between the Alberche and Guadarrama valleys and of an intermediate flow. The

isochrone lines show that water age in some points of the discharge zones of the center of the valleys, especially under the Alberche valley can be more than one hundred thousand years old.

THE MIXING-CELL MODEL

The cell network adopted can be seen in fig. 2. The lateral borders on the cells coincide with the streamlines of the flow net obtained with the flow model (fig. 1). Therefore there is no net flow, across these lateral borders. The quasi-stagnant zone between Alberche and Guadarrama valleys has been considered as a "dead-cell", with no net flow from - or to - the adjoining cells but only "exchange" with those cells (dispersive mass flow).

In fig. 2 can also be seen the mean ages of water in each cell. It can be seen that the values obtained are similar to those of piston flow assumption (fig. 1).

In the fig. 3a the computed breakthrough curves in some cells are presented. They correspond to an initial state of zero concentration and to a constant boundary recharge concentration equal to 100.

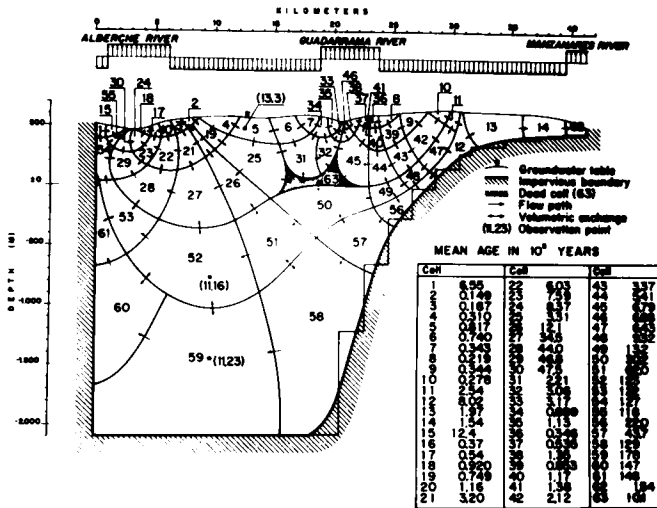


Fig. 2.- Vertical profile showing mixing-cell net and table of mean water age in each cell.

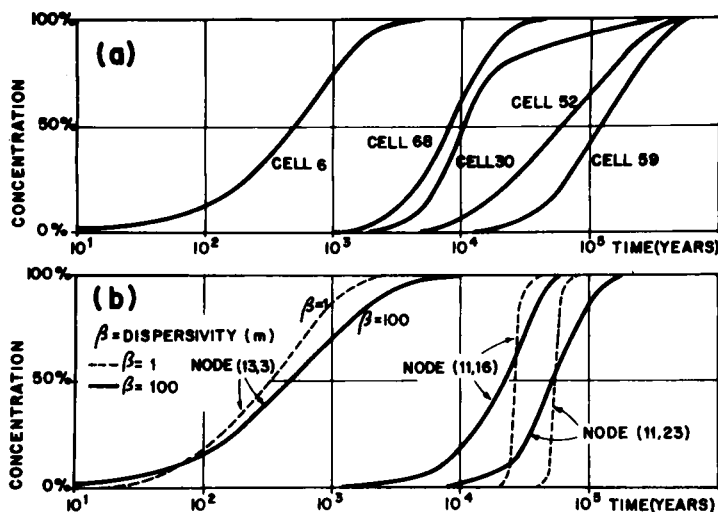


Fig. 3.- Breakthrough curves computed by numerical models. Situation of cells and nodes can be seen in fig. 2. (a) Mixing-cell model. (b) Method of characteristics model.

THE METHOD OF CHARACTERISTICS MODEL

For the sake of comparison a preliminary application of the method of characteristics model of the U.S.G.S. (ref. 3) has been done. This is one of the very few groundwater models which is easily available to any user (ref. 1).

The U.S.G.S. program has been applied to the same vertical profile of figure 1 and with the same parameters for permeability and porosity and the same initial and boundary conditions. The grid used is also rectangular with 40 columns and 32 rows. In this case Δz is constant and equal to 100 m; Δx is constant and equal to 1000 m. Longitudinal dispersivity is assumed equal to 100 m. and to 1 m. Transversal dispersivity is assumed equal to the longitudinal dispersivity times 0.3. The only two available experimental values of dispersivity are about 1 m (ref. 6).

Some representative breakthrough curves obtained with this U.S.G.S. program can be seen in fig. 3b. The similarity of these curves and those obtained by the mixing cell model (fig. 3a) is apparent. The computer time necessary to solve the U.S.G.S. model is much longer than that needed to solve the mixing-cell model.

CONCLUSIONS

Much more research is still needed, mainly about some basic assumptions, e.g. the role of molecular diffusion and the possible influence of temperature and salinity variations. Nevertheless, it seems that in this case the relatively simple mixing-cell model needs much less computer time and gives similar results to those obtained by the more sophisticated model of the method of characteristics.

REFERENCES

- 1 J. Bachmat, J. Bredehoeft, B. Andrews, D. Holz, and S. Sebastian, (1980). Groundwater management: the use of numerical models. American Geophysical Union. Water Resources Monographs, nº 5, 127 pp.
- 2 M.E. Campana, (1975). Finite-state models of transport phenomena in hydrologic systems. Ph. D. dissertation, University of Arizona, Tucson, Arizona, 252 pp.
- 3 L.F. Konikow and J.D. Bredehoeft, (1976). Computer Model of two-dimensional solute transport and dispersion in groundwater. Techniques of Water Resources Investigations of the U.S.G.S. Book 7, Chapter C2, 90 pp.
- 4 M.R. Llamas and E.S. Simpson, (1979). Estudio del transporte de solutos en las aguas subterráneas del sistema acuífero de Madrid mediante un modelo digital de celdas de mezcla. Tomo Homenaje Prof. Solé, Barcelona, España (preprint 20 pp.). Acta Geológica Hispánica. Vol. 14.
- 5 M.R. Llamas y P.E. Martínez Alfaro, (1980). Análisis preliminar mediante modelos digitales de la edad de las aguas subterráneas del acuífero terciario de Madrid. Comunicaciones. Primera Reunión Nacional sobre Geología Ambiental. Madrid-Mayo 1980. Asociación de Geólogos Españoles. 20 págs.
- 6 P. Rubio y F. López Vera, (1979). Algunos valores de dispersión en los materiales detríticos de la cuenca de Madrid. II. Simposio Nacional de Hidrogeología. Pamplona. vol. 5. pp. 57-74.
- 7 E.S. Simpson and M.R. Llamas, (1980). A mixing cell model of Madrid aquifer. Abstracts of the XXVI International Geological Congress. París. vol. III. p. 1156.