CALIBRATION OF MRS RESULTS USING HYDRODYNAMIC CHARACTERISTICS FROM PUMPING TESTS

<u>Baltassat J.M.</u>[1], Legchenko A[1,2], Vouillamoz J.M.[3], Sabatier S.[4], Chigot D.[4], Schmidt J.C.[5]

[1]BRGM, Development Planning and Naturals Risks Division, 3, avenue C. Guillemin, BP 6009, 45060 Orléans, Cedex 2, France.
[2]Institut de Recherche pour le Développement (IRD), 32 avenue Henri Varagnat, 93143 Bondy Cedex, Paris, France.
[3]Formerly with the Institut de Recherche pour le Développement (IRD), 32, Av. Henri Varagnat, 93143 Bondy Cedex, Paris, France and Action contre la Faim, ACF, 9 rue Dareau, 75014 Paris, France
[4]ANTEA, Agence Orleans, 3, avenue C. Guillemin, BP 6119, 45061 Orléans, Cedex 2, France.
[5]Conseil General, Espace et Développement rural, Place Châtelet, 28000 Chartres, France.

INTRODUCTION

A methodological study using NUMIS^{plus} magnetic resonance sounding (MRS) equipment was performed in France from 2000 to 2002. The main aims were to:

- compare MRS results with hydrodynamic parameters resulting from pumping tests;
- establish an empirical relationship between MRS and pumping test results;
- establish a methodology for MRS characterisation over potential groundwater exploration drilling sites for drinking water supply.

Eleven water well sites with aquifers essentially composed of chalk and sandstone were investigated in the Eure-et-Loir Department. An additional site in alluvium of the Durance River (Vaucluse) and two sites in Bajocian limestone (Vienne) completed the data set. At the beginning of 2002, the Eure-et-Loir County Council requested that ANTEA and BRGM perform MRS characterisation over eight new potential drilling sites for drinking water supply. On the basis of these MRS results, two sites were selected at the beginning of 2003. A borehole was drilled and tested at the first site, the results of which show a good correlation with the MRS results. Drilling is currently underway at the second site.

In this paper, we present the methodology, the details of its practical application and experimental verification.

INVERSION OF MRS DATA

Inversion of MRS data provides the following parameters: aquifer depth and thickness, water content and relaxation time constant. Like many other surface geophysical methods, the MRS inverse problem is ill-posed. Because of the equivalence problem, inversion may lead to several models, which in turn means that different models may fit equally well a given MRS experimental data set. In MRS, two layers of thickness e_1, e_2, with a respective water content W_1, W_2, and located at the same depth, are said to be equivalent when $W_1 e_1 = W_2 e_2$ (Legchenko et al., 2003).

Models obtained from different interpretation procedures that fit equally well experimental data constitute a space of equivalent solutions. Analysis of the solution space is a means for evaluating the uncertainty of MRS results. In an attempt to evaluate this uncertainty and so as to compare MRS results with hydrodynamic data, three different interpretation procedures were applied to the data from 14 MRS stations located near water supply wells. Three sets of models were thus obtained (figure 1):

One is the result of the automatic inversion process provided by the Samovar software using the Tikhonov regularisation method (Legchenko & Shushakov, 1998). Using appropriate regularisation parameters, models composed of a large number of layers, show quasi-continuous variation of MRS characteristics along the depth axis (figure 1d).

Two others are obtained by calibrating aquifer depth and thickness with the lithological description from boreholes drilled by two different operators (figure 1b, 1c). The models are composed of a finite number of layers that show constant MRS characteristics within themselves and marked contrasts from one layer to the next.

The equivalence of the different models is assessed by keeping the residual mean square (RMS) between the data and theoretical signals within a range of 3% for each sounding.

COMPARISON OF MRS RESULTS AND HYDRODYNAMIC PARAMETERS

Following examples of empirical relationships developed through nuclear magnetic resonance logging for estimating formation permeability (Kenyon et al., 1997), the water content and relaxation time constant T_1 were used for MRS estimation of hydraulic conductivity (Legchenko et al., 2003), which was then compared to that derived from pumping tests.

For this exercise, the most convenient expression for MRS transmissivity (T_{MRS}) was found to be $T_{MRS} = C\sum_i e_i W_i T_1^2$; with W_i, e_i, T_1 being respectively the water content, thickness, longitudinal time constant of a layer *i*, and *C* an empirical constant.

The MRS estimator $\sum_i e_i W_i T_1^2$ was computed considering different equivalent models. The results are plotted against borehole transmissivity (figure 2a), which reveals that all the equivalent models, including that given by the automatic inversion, fit similarly well the transmissivities measured in the boreholes. Obviously, as T_{MRS} is computed using the product $e_i W_i$, the results are less affected by the equivalence problem when the model is changed.

Based on an evaluation of the dispersion of these various T_{MRS} data, an attempt was made to estimate the uncertainty on MRS transmissivity, as evaluated by the Samovar software with the empirical constant C being equal to $7x10^{-11}$ (default value). It was found that with NUMIS data with a signal-to-noise ratio greater than five, uncertainty on MRS transmissivity estimation extends from half to twice the calculated value (figure 2b). For example, an MRS estimated transmissivity T_{MRS} of $2x10^{-3}$ m²/s may vary from $1x10^{-3}$ up to $4x10^{-3}$ m²/s.

EXAMPLE OF APPLICATION

Soundings with a 75-m-long square antenna were carried out over eight new potential drilling sites for drinking water supply. The site locations had been selected on the basis of classical hydrogeological analysis, and MRS was applied for aquifer caracterisation before drilling.

In the Châtillon-en-Dunois area (figure 3), four soundings were performed. CHATIL2, CHATIL3, and CHATIL4 reveal better MRS transmissivity (T_{MRS}=*2.2 to 2.7x10*$^{-3}$ *m²/s*) than CHATIL1 (T_{MRS}= *8.x10*$^{-4}$). From existing wells, it is known that CHATIL2 and CHATIL4 have highly contrasting yields: 40 m^3/h and almost dry, respectively. The aquifers in this area are typically composed of fractured and/or karstified chalk, which easily explains this difference: CHATIL4 does not intersect the producing fracture zone, whereas CHATIL2 does. As a conclusion of the study, the CHATIL3 site was recommended for drilling.

In January of 2003, a new exploration borehole, F1, was drilled 100 m north of the CHATIL3 MRS station. It encountered a fractured chalk aquifer at a depth of 20 m and pumping tests revealed a transmissivity of 1.0 to 2.1 10^{-3} m²/s, which is in full agreement with MRS predictions (figure 2b).

CONCLUSIONS

Based on 14 groundwater wells mainly located in Eure-et-Loir , an empirical relationship was established between MRS results and pumping test transmissivity. An attempt was made to estimate the uncertainty on MRS evaluation of transmissivity (T_{MRS}). It was found that in favourable conditions, MRS estimation of the transmissivity using the Samovar software falls within an uncertainty margin extending from half to twice its value. For example, an MRS estimated transmissivity T_{MRS} of $2x10^{-3}$ m²/s may vary from $1x10^{-3}$ up to $4x10^{-3}$.

The methodology derived from this study was successfully applied to eight new potential drilling sites for drinking water supply in Eure-et-Loir.

This work was carried out in the framework of a BRGM research programme in collaboration with ANTEA ("Agence Centre") and the Eure-et-Loir County Council.

REFERENCES

Kenyon, W.E. (1997) - Petrophysical Principles of Applications of NMR Logging: The Log Analyst, March-April, p.21-43.

Legchenko, A.V. and Shushakov, O.A. (1998) - Inversion of surface NMR data, *Geophysics*, Vol. 63, no.1, pp. 75-84.

Legchenko A., Baltassat J-M., Bobachev A., Martin C., Robin H., Vouillamoz J-M. (2003) - The magnetic resonance soundings applied to characterization of aquifers, *Journal of Ground Water, in press*.

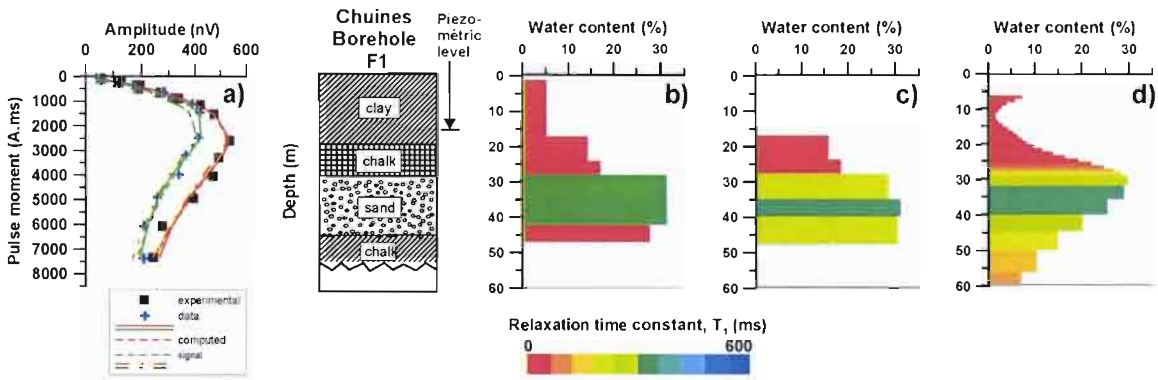

Figure 1: Example of three different models resulting from different MRS interpretations at the Chuisnes borehole site; a) experimental and computed sounding curves; b), c), d) models.

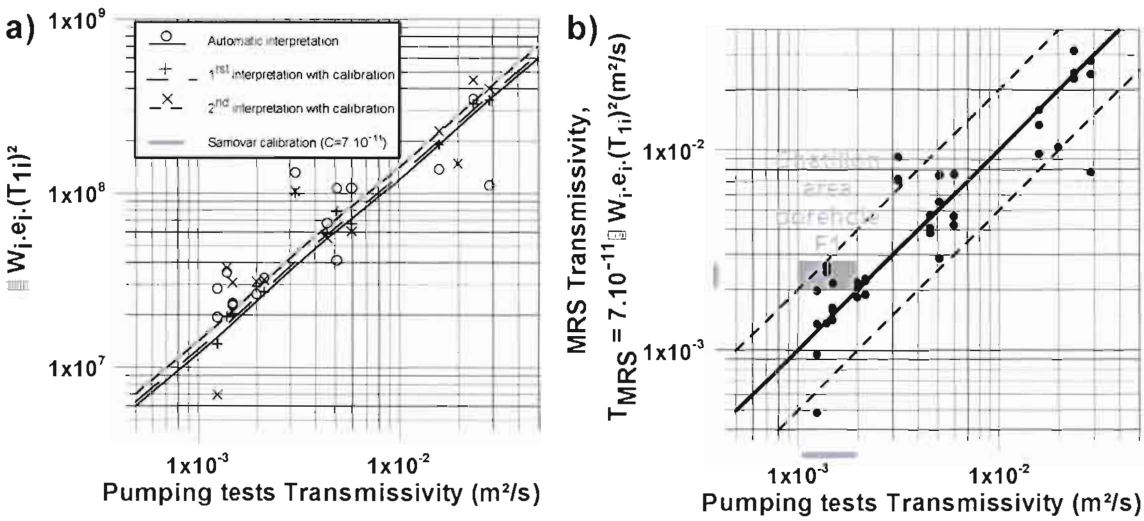

Figure 2: a) Comparison between MRS results of different interpretations and borehole transmissivity; b) Uncertainty margin (dashed lines) on MRS evaluation with Samovar software (bold line) and results obtained from F1 borehole in the Châtillon-en-Dunois area.

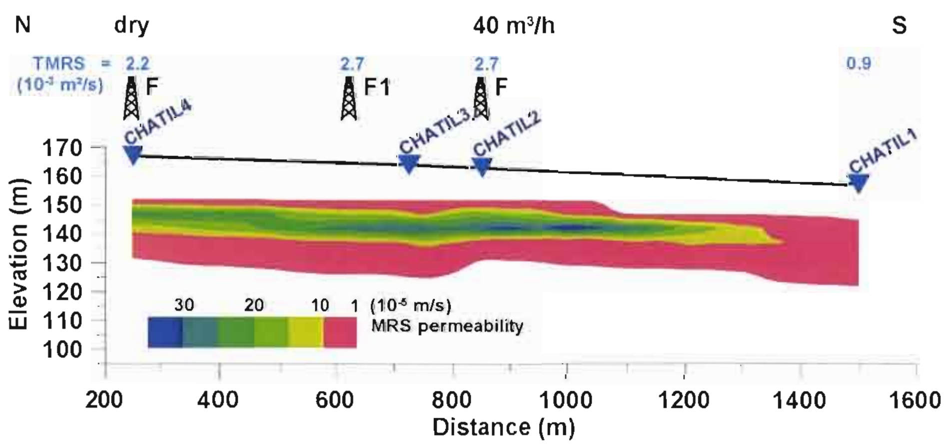

Figure 3: Vertical cross section showing MRS permeability through the Châtillon-en-Dunois area.

MRS

2ND INTERNATIONAL WORKSHOP
on the Magnetic Resonance Sounding method applied to non-invasive groundwater investigations

19 - 21 November 2003 - Orléans - France

PROCEEDINGS

Organizer

brgm — Geoscience for a sustainable Earth

Co-organizer

TU berlin

Support

IRIS Instruments

EAGE — European Association of Geoscientists & Engineers