SETTING HYDRAULIC CHARACTERISTICS OF A KARST COASTAL AQUIFER USING GEOSTATISTICAL TOOLS

Michele MAGGIORE (a), **Luigi TULIPANO** (b) **Giuseppe RASPA** (c), **Domenico SANTORO** (d) and **Oronzo SANTORO** (e)

(a) Università di Bari, Via Orabona , 4 - 70125 Bari (ITALY)
e-mail: m.maggiore@geo.uniba.it
(b) University of Rome “La Sapienza”, Via Eudossiana, 18 - 00185 Roma (ITALY)
e-mail: l.tulipano@uniroma1.it
(c) University of Rome “La Sapienza”, Via Eudossiana, 18 - 00185 Roma (ITALY)
e-mail: raspa@columbus.it
(d) Technical University of Bari , Viale del Turismo, 8 - 74100 Taranto (ITALY)
e-mail: d.santoro@poliba.it
(e) Servizi Ecologia Ambiente (SEA) srl - Via Scarli, 1 – 72015 Fasano (ITALY)
e-mail: o.santoro@rp.tno.it

INTRODUCTION

The aim of this paper is to remark, with respect to seawater intrusion processes, the different hydrodynamic behaviours showed by groundwater, flowing into an aquifer characterized by not negligible local scale transmissivity variations. This investigation would also like to contribute in improving the basic understanding of the dynamic of lateral intrusion mechanism in anisotropic karst coastal areas.

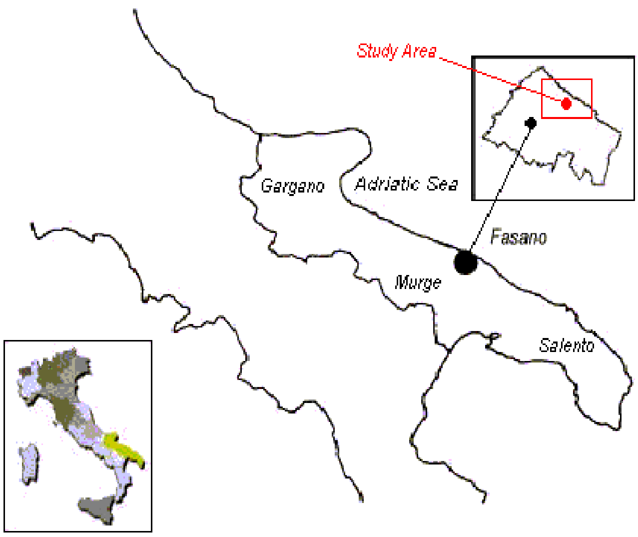

Figure 1 *Location of the study area and main hydrostructures of Puglia Region (Southern Italy)*

In a typical study-area of Murgia coastal aquifer (Figure 1), three wells have been selected and equipped with multi-parametric probes able to record, by measuring electric conductivity (mS/cm), salinity water content variations of the upper zone of groundwater (5 m b.s.l.). The monitored period, extending in time for 80 hours, allows to simultaneously collect three electric conductivity time series constituted by 80 experimental data, having we programmed the probe controller with an hourly scanning lag.

The study-wells (Figure 2) has been chosen according to the general hydrostructural features of the area (already described in previous papers [Maggiore et al., 1999, 2001]) and on the bases of further considerations about the specific value of the saline intrusion potential, which can be assumed as main indicator of hydrogeological districts regulated by local hydrodynamic mechanisms [Tulipano&Fidelibus, 1988, 1989, 1999].

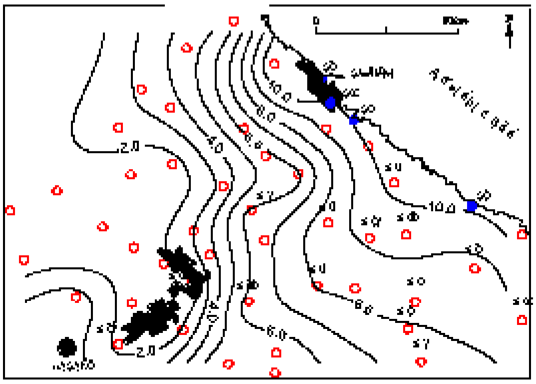

Figure 2 *Salinity map of the study area and selected monitoring wells*

GEOLOGICAL AND HYDROGEOLOGICAL FEATURES OF THE STUDY-AREA

Geological features of the study area belong to the general geological framework of Puglia Region, which can be essentially resumed as constituted by a huge thickness (more than 3000 meters [Ricchetti et al., 1988]) of Mesozoic limestones, locally named Calcari delle Murge. Besides, on the top of this geological unit, it is possible to observe, in particular next to the coast, continental and marine deposits referred to plio-quaternary age.

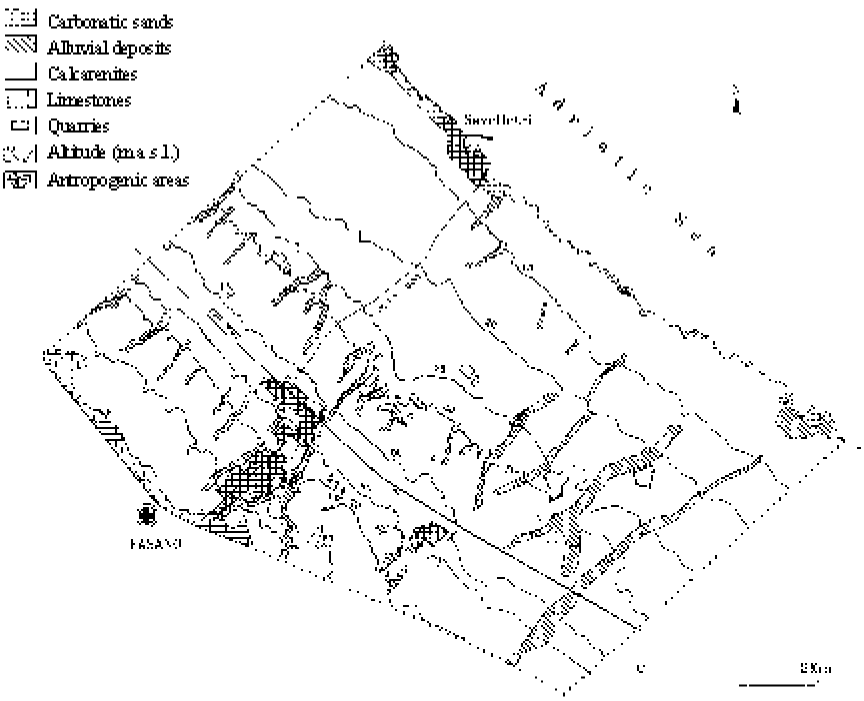

Figure 3 *Schematic geologic map of Fasano territory (Brindisi district)*

Age of the limestones is referred to as cretaceous [Maggiore et al.,1978; Luperto Sinni & Borgomano,1989]. They outcrop in the western part (higher zone) of the study area and are covered of thin thick of quaternary calcarenites, in the lower part (Figure 2). Moreover, one can observe that such unit outcrops with continuity from the Adriatic Sea until to an altitude of 80 m above sea level. Alluvial and colluvial deposits are located at the bottom of karst channels, locally named “lame”. These channels are placed along a fractures system, which is perpendicularly developed with respect to the coastline.

Litostratigraphic data coming from several wells (previously drilled in the area) allow the thickness reconstruction of the overlaying calcarenites, which are placed on the limestone substratum. Moreover, by performing hydrogeochemical logs along the well water columns, it has been possible to estimate geostatistically, the 3D domain of water quality parameters (pH, Temperature, DO, EC, RedOx), in order to define the main hydrostructural features of the area [Maggiore et al., 2001]. Such analysis has confirmed that a group of springs, aligned along a fault running parallel to the coast line, can be assumed as main discharge mechanism of groundwater [Maggiore et al., 1999].

Experimental data collected

The collected data set was simultaneously recorded in the three study wells. Figure 4 shows the electric conductivity time series and their natural variations with respect to each measuring point.

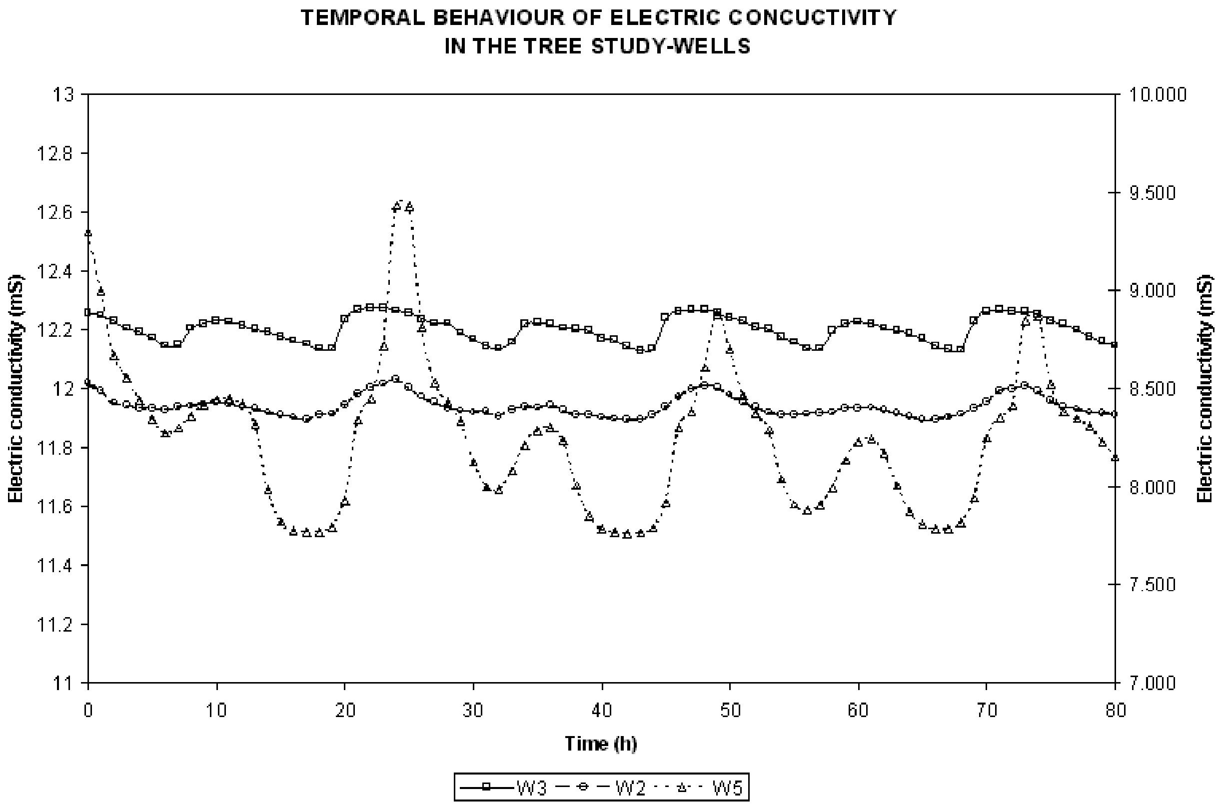

Figure 4 *Electric conductivity time series recorded in the three monitoring wells*

In particular, it is possible to observe the presence of periodical variations, characterizing the temporal structure of the recorder data. This periodical behaviour is due to the propagation in groundwater of the tidal waves [Magri & Troisi, 1969]. Moreover, the presence of different phase delays, recorded in the three time series, underlines the existence of local dynamics of lateral seawater intrusion processes, depending (at this scale of analysis) on the hydraulic characteristics of the breakthrough media.

Geostatistical time modelling of electric conductivity in groundwater

Let Zk (t) the hourly recorded electric conductivity in well k, we will use the following notation to express the time variogram model:

$$\gamma_k(\tau) = \sum_u \gamma_k^u(\tau) = \sum_u C_k^u \cdot g_u(\tau)$$

In the previous, the sum index u identifies the time variability structure and C_k^u and $g_u(\tau)$ represent, for each structure *u*, the sill and the unitary sill variogram respectively.

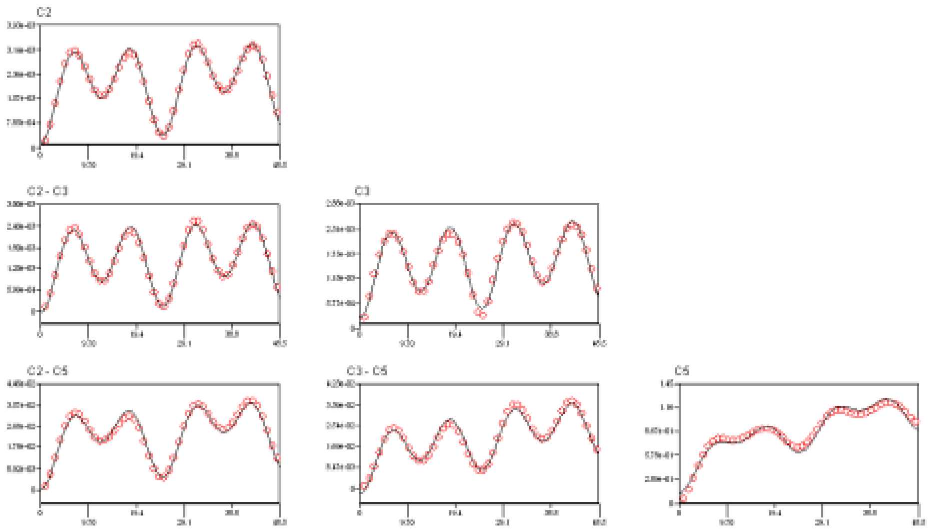

Figure 5 *Experimental semivariograms (red points)and geostatistical model (black line) of the electric water conductivity time series*

Variographic analysis of time series showed that electric conductivity variability could be modelled by using a nested variogram with four different structures: one nugget, two periodic with 12-hours and 24-hours periods and one spherical. In agreement with the expression (1) variability of Zk(t) can therefore be modelled as following [Raspa & Gomez, 2001]:

$$\gamma_k(\tau) = \gamma_k^0(\tau) + \gamma_k^1(\tau) + \gamma_k^2(\tau) + \gamma_k^3(\tau) = C_k^0 \cdot [1 - \rho_{nug}(\tau)] + C_k^1 \cdot [1 - \cos\omega_1\tau] + C_k^2[1 - \cos\omega_2\tau] + C_k^3 Sph(30)$$

in which (i=0,3) are the sills of the basic structures, $\rho_{nug}(\tau)$ the nugget covariance, ω1 and ω2 the frequencies of the two periodic structures (2π/12 and 2π/24, respectively and Sph(30) the 30 hours range spherical structure: 1.5*τ/30-0.5* τ3/303.

Periodic component computation

It is well known that when an experimental variogram shows a nested variability, such variable can be separated into its components. In particular, in this case the two periodic components $Z^1_k(t)$ and $Z^2_k(t)$ can be expressed as following:

$$Z_k^1(t) = \sqrt{A_k^1 + B_k^1}\cos(\omega_1 t - \varphi_k^1)$$

$$Z_k^2(t) = \sqrt{A_k^2 + B_k^2}\cos(\omega_2 t - \varphi_k^2)$$

Coefficients A, B have been classically computed from time series and thus intensities and phases have been derived. As can be observed, intensity and phase, varying with location, let us to affirm that, on turn, model parameters are function of hydraulic characteristic of the aquifer. Particularly, this occurrence seems to be more evident if we look at the estimated twelve hours periodic component then the twenty four hours one (Figure 6).

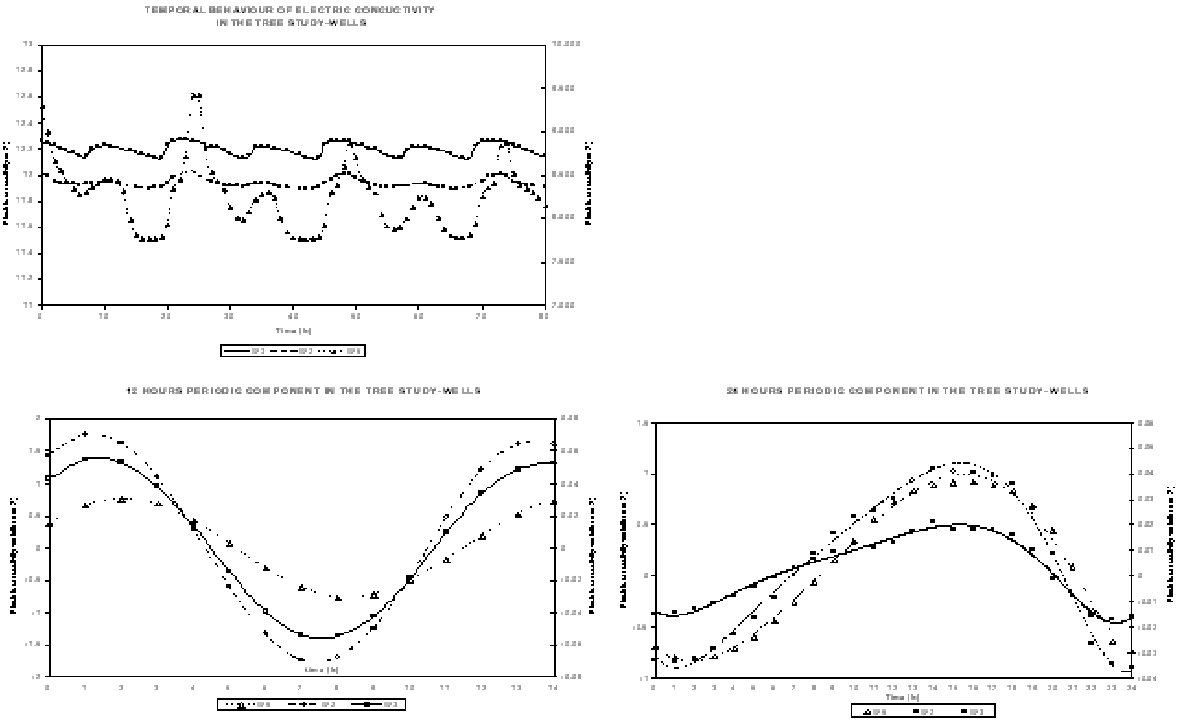

***Figure 6** Experimental data of electric conductivity (on the left) and periodic components of the experimental time series (below)*

CONCLUSIONS

The variability study of natural phenomena with regionalized behaviour, performed in this paper with geostatistical tools, can successfully lead us towards a phenomenological interpretation of variability as well.

Moreover, this working approach would contribute to put in evidence, either in qualitative or quantitative way, the links between parameters of variability model and physical characteristics of the under discussion phenomena.

In particular, data analysis has confirmed that tidal wave propagates in groundwater inducing periodical variations (not in phase) on groundwater electric conductivity (measured on the top of groundwater). This evidence has been clearly recorded in the equipped monitoring wells.

We can finally state that phase delays are influenced either by distance of measuring point from tidal wave source or local hydraulic characteristics of the investigated aquifer.

Thus, performing a not invasive survey method (by means of phase delay measures) in private or public wells, it will be possible to reconstruct the distribution of the hydrostructural aquifer heterogeneity at the scale analysis of the problem. Furthermore, it allows emphasizing the most exposed structures with respect to lateral seawater intrusion mechanism, not only by the hydrogeological but also by geochemical point of view. We can affirm already now that this aspect will be the topic of an oncoming paper.

ACKNOWLEDGEMENTS

The authors are pleased to thank Municipality of Fasano and SEA srl for the kind and professional assistance in surveying activities and wells monitoring.

REFERENCES

Luperto Sinni,E., Borgomano, J., "Le Crétacé supérieur des Murges sud-orientales (Italie Méridionale): stratigraphie et évolution des paléoenvironnements,» Riv.It.Paleont.Strat. ,95(2), 95-136, 1989.

Maggiore, M., Ricchetti, G. and Walsh, N., "Studi geologici e tecnici sulle pietre ornamentali della Puglia – Il Filetto rosso ionico di Fasano", Geologia Applicata e Idrogeologia,13, 335-345,1978.

Maggiore, M., Sabatelli, L., Santoro, O., Tanzarella, V. and Vurro, M., "Primi risultati della sperimentazione di un sistema di monitoraggio in acquifero carsico costiero", Quaderni di Geologia Applicata (Pitagora eds) - Bologna, 3.245-3.254, 1999.

Maggiore, M., Sabatelli, L., Santoro, O., Santoro, D. and Vurro, M., "Monitoring seawater intrusion in a karst coastal aquifer (Southern Italy)", First International Conference on Saltwater Intrusion and Coastal Aquifer – Monitoring, Modelling and Management, Essaouira, Morocco, April 23-25, 2001

Magri,G. and Troisi,S., "Sulla influenza delle fluttuazioni di specchi d'acqua sui livelli delle falde costiere. Applicazioni allo studio della circolazione idrica sotterranea nella penisola salentina", Geologia applicata ed Idrogeologia (eds), Volume IV, Bari, 1969.

Raspa,G. and Gomez,L.H., "Geostatistical Modelling of Precipitation Regimes in Colombia", WJ Kleingeld and DG Krige (eds), Geostat2000 Cape Town, Volume 2, 605-614, 2001.

Ricchetti,G., Ciaranfi, N., Luperto Sinni, E., Mongelli, F. and Pieri, P., "Geodinamica ed evoluzione sedimentaria e tettonica dell'avampaese apulo," Memorie della Società Geologica Italiana, 41, 57-82, 1988.

Tulipano, L. and Fidelibus, M.D., "Temperature of groundwaters in coastal aquifers: some aspects concerning salt-water intrusion," 10th SWIM Ghent (Belgium) 1988, Natuurwet. Tijdschr., 70, pp.308-316, 1989.

Tulipano L., "Temperature logs interpretation for the identification of preferential flow pathways in the coastal carbonatic and karstic aquifer of the Salento Peninsula (Southern Italy)" 21th Congress IAH on Karst Hydrogeology and Karst Environment Protection, 1988 - Guilin (China).

Tulipano L., Fidelibus M. D., "Evaluation of over-exploitation effects for the Salento coastal karstic aquifer through the interpretation of thermo-conductivity logs in observation wells. 2nd Symp. On "Protection of groundwater from pollution and seawater intrusion", 1999, Istituto Italo-Russo di Formazione e Ricerche Ecologiche, Bari.