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RESOLUTION POWER OF WELL LOG GEOPHYSICS IN KARST AQUIFERS

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Empirical relationships are presented between geophysical log parameters and hydraulic parameters in the South Havana Basin karst aquifer. These relationships have not been reported in previous investigations. The most significant results follow. A direct correlation exists in some wells, and inverse correlation exists in other wells, between groundwater flow velocity and natural gamma radioactivity. This shows the presence of two different model collectors. The Dar Zarrouk parameters correlate poorly with aquifer transmissivity. This depends on the relationship that exists between the electrical conductivity and the hydraulic conductivity in the aquifer. If the product of the hydraulic conductivity and electrical conductivity is approximately constant, the relationship between traverse electrical resistivity and transmissivity of the aquifer is more significant. When it is expressed as the quotient between these parameters, and shows little variability, the correlation is more significant between longitudinal electrical conductivity and hydraulic transmissivity. These results contribute to elevating the resolution power of geophysical methods in hydrology investigations in karst aquifers, and they also contribute to the best management of groundwater resources.

INTRODUCTION

The knowledge of aquifer hydraulic parameters is essential in order to optimize exploitation programs and to define protection strategies for groundwater quality. Aquifer pumping test interpretation is the classic procedure used to estimate aquifer parameters, but these results provide value averages for large volumes of the porous medium. From pumping tests is not possible to study the aquifer structural variability, which is very necessary in order to efficiently solve many hydrology problems (Lima and Sri Niwas, 2000). Surface geophysical measurements and well log geophysics offer a higher resolution power in this sense. Rock tortuosity and porosity control the electric current flow as well as the groundwater flow and, by inference, the electrical conductivity and the hydraulic conductivity of the geologic medium. From this similarity, a great number of empiric relationships used to correlate geophysical parameters and hydraulic parameters have been developed (Kelly, 1977; Kosinski and Kelly, 1981). Sri Niwas and Singhal (1981, 1985) developed an analytic relationship between hydraulic conductivity and electrical resistivity from the well-known Darcy and Ohm's Laws in a homogeneous medium.

These results offer a physical-mathematical basis for the fundamental statistical relationships that have been obtained in granular media. Lima and Sri Niwas (2000), developed a procedure to estimate sand clay permeability from electrical measurements (well and surface). Purvance and Andricevic (2000), demonstrate theoretically and experimentally that the electrical conductivity and the hydraulic conductivity of the aquifers can be correlated. These authors demonstrate that positive simple linear correlation exists between the electrical and hydraulic conductivity when the volume of pores defines the electric flow, while the correlation will be negative when the electric flow is dominated by the surface of the pores.

Valcarce (1998) studied the statistical correlations between well log geophysics parameters and hydrodynamic parameters in the karst aquifer in the South Havana Basin. Keeping in mind the high heterogeneity and anisotropy of the karstic medium, the author applied pattern recognition techniques to the layers defined by the interpretation of well log geophysics, and distinguished 10 groups of relatively homogeneous composition. These groups are characterized by the mean values of electrical resistivity (Rt), traverse resistance (RT), longitudinal conductance (S), formation factor (F), and radioactivity natural gamma (Ig). For each one of these groups the groundwater flow velocity (Vf) was also calculated.

The statistical correlation study among the mean values of these parameters for the 10 groups, reflected, as a general tendency, that the increment of the natural gamma intensity is related to a decrease in aquifer permeability, and the longitudinal conductance varies proportionally with the aquifer transmissivity according to a positive linear logarithmic regression model.

In this paper the results described previously for the South Havana Basin are improved, and new relationships are obtained among geophysical and hydrodynamic parameters that better reflect the karst aquifer heterogeneities.

GEOLOGICAL CHARACTERISTICS OF THE SOUTH HAVANA BASIN

The region is located between coordinates 310.00 and 340.00 of North latitude and 310.00 and 420.00 of East longitude, in the southern part of Havana Province (Figure 1). The South Havana Basin is a coastal aquifer formed by rocks of Neogene Age, mainly of the Güines Formation, made up of a great variety of limestones, with a high degree of karstification. The hydrogeological

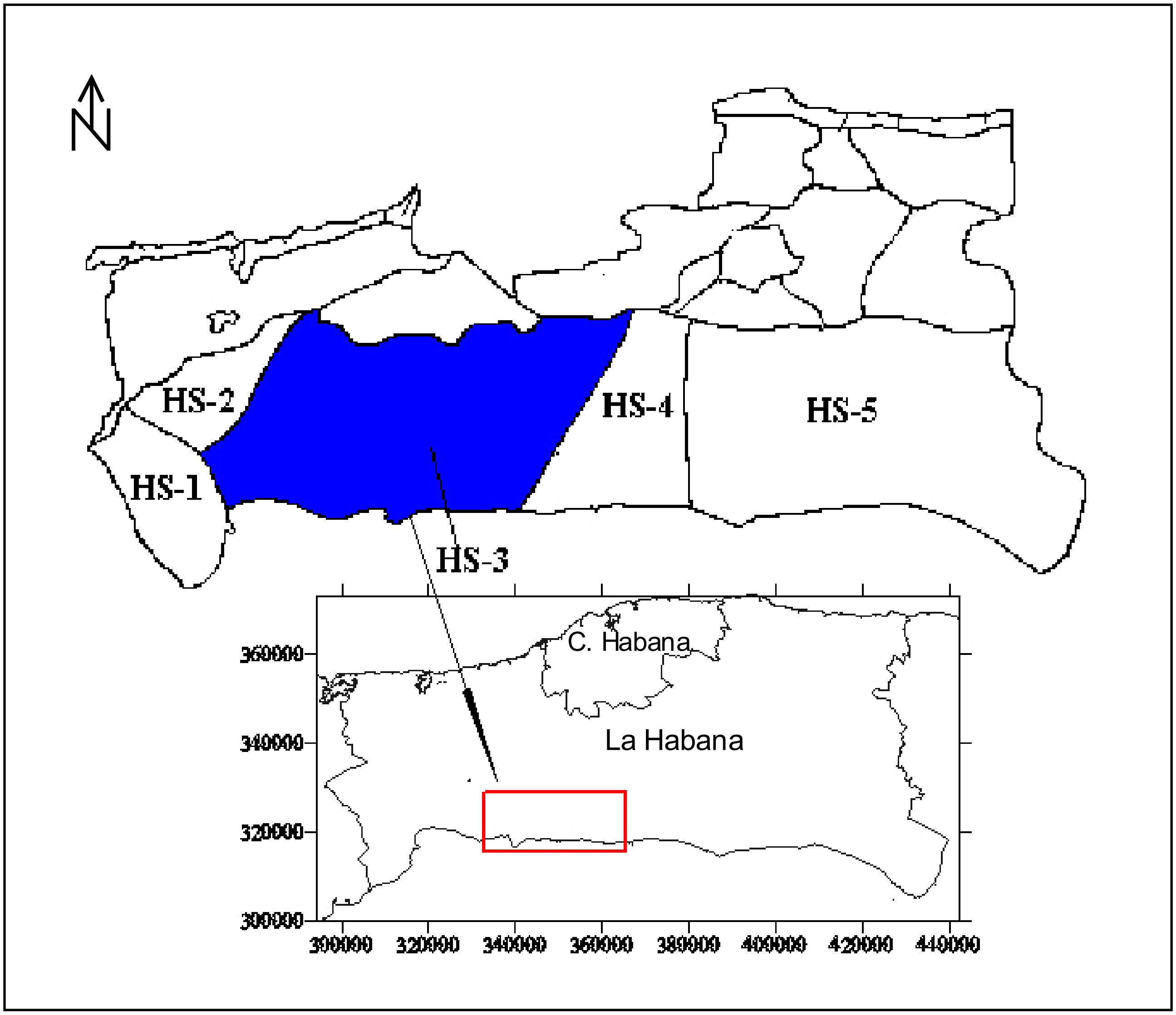

Figure 1. Location of the study area.

parameters of this aquifer were studied 50 years ago, when the first projects for water supply and industrial use were carried out. The properties of the aquifer have been calculated from pumping tests which show transmissivities between 1.15 x 10^{-1} and 5.78 x 10^{-1} m^2/sec, and in some cases even higher. The high values and variability are determined by karst development of the limestones.

STUDY DATA

Starting from the geophysical interpretation of the logs of natural gamma and the electrical resistivity in 14 wells, 215 litho-geophysics layers were defined. Each layer was characterized by its values of Ig, Rt, RT, S; as well as by its values of Vf, Kf (filtration coefficient) and T (transmissivity), from the salt dilution method. Also, each well was characterized by the pooled average of these parameters, taking as a weighting factor the thickness of the defined layers.

Relationship between Ig and Vf

For each well, the relationship between the gamma intensity (Ig) and the groundwater filtration velocity (Vf) was studied. In some wells a positive correlation exists, and in other wells a negative correlation exists between Ig and Vf. The results are shown in Table 1.

Table 1. Statistical Correlation Between Ig and Vf for Each Well

Well	N	R [Vf vs Ig]
TS-110	8	-0.60
TS-106	12	-0.21
TS-E1E2	11	0.28
TS-3	10	-0.55
TS-5	13	-0.53
TS-121	14	0.60 (*)
Cala 2 - Alquizar	11	0.72 (*)
I-II-9K	22	0.45 (*)
I-II-21K	17	-0.33
I-II-16K	14	0.25
TS-45	22	-0.30
40-MSN	25	-0.72 (*)
TS-38	18	0.05
TS-125	14	-0.53 (*)

(*) significant correlation for 95% of probability

The correlation was studied between the pooled average of Ig and Vf for the wells that show a direct and inverse regression between both parameters. The results are shown in Table 2.

Table 2. Correlation Between the Pooled Average of Ig and Vf

Relationship between Ig and Vf	N	Correlation Coefficient
Inverse	8	-0.7 (*)
Direct	5	0.82 (*)

(*) significant correlation for 95% of probability

Relationship between aquifer transmissivity and Dar Zarrouk parameters

For each well, the correlation was studied among the aquifer transmissivity (obtained by he salt dilution method in wells) and the Dar Zarrouk parameters (obtained from the electrical log interpretation). The results are presented in the Table 3.

In Table 3 the larger correlation coefficients have been underlined. It can be shown that the increment of the variation coefficient of the quotient Kf/Rt, causes it to diminish the correlation between T and RT. On the other hand, the increment of the variation coefficient of the product Kf*Rt, causes it to diminish the correlation between T and S. This coincides with results reported by Yadav (1995) in an intergranular aquifer.

This is also demonstrated in Table 4, which presents the correlation between V(Kf/Rt) (variation coefficient of Kf/Rt) and the correlation coefficient between T and RT; as well as between V(Kf*Rt) (variation coefficient of Kf*Rt) and the correlation coefficient between T and S. Figures 2 and 3 show these results.

Table 3. Statistical Correlation Between Aquifer Transmissivity and Dar Zarrouk Parameters for Each Well.

Well	N	log (T) vs log (RT)	log (T) vs log (S)
TS-110	8	0.73 (*)	0.06
TS-106	12	0.13	0.62 (*)
TS-E1E2	11	0.46	0.71 (*)
TS-3	10	0.88 (*)	0.77 (*)
TS-5	13	0.74 (*)	0.95 (*)
TS-121	14	0.62 (*)	0.11
Cala 2 - Alquizar	11	0.65	0.82 (*)
I-II-9K	22	0.61 (*)	0.37
I-II-21K	17	0.58 (*)	0.2
I-II-16K	14	0.62 (*)	0.81 (*)
TS-45	22	0.5 (*)	0.62 (*)
40-MSN	25	0.57 (*)	0.58 (*)
TS-38	18	0.57 (*)	0.6 (*)
TS-125	14	0.8 (*)	0.18

(*) significant correlation for 95% of probability

Table 4. Correlation Between the Variability of the Relationships Between Kf and Rt and the Correlation Coefficient of the Aquifer Transmissivity and the Dar Zarrouk Parameters

Relationship	N	Correlation Coefficient
V(Kf/Rt) vs r(T-RT)	14	-0.63 (*)
V(Kf*Rt) vs r(T-S)	14	-0.67 (*)
V(Kf/Rt) vs r(T-S)	14	0.0
V(Kf*Rt) vs r(T-RT)	14	0.37

(*) significant correlation for 95% of probability

CONCLUSIONS

Some wells were identified where there exists a direct correlation, and other wells where an inverse correlation exists, between groundwater flow velocity and natural gamma radioactivity. This shows the presence of two different model collectors.

The Dar Zarrouk parameters correlate poorly with aquifer transmissivity. A correlation depends on the existence of a relationship between the electrical conductivity and the hydraulic conductivity in the aquifer.

When in a specific area, the product of the hydraulic conductivity and electrical conductivity is approximately constant, the relationship between transverse electrical resistivity and aquifer transmissivity is more significant. When it is the quotient of these parameters, and it shows little variability, the correlation is more significant between the longitudinal electrical conductivity and the hydraulic transmissivity. This result has great importance from the practical point of view.

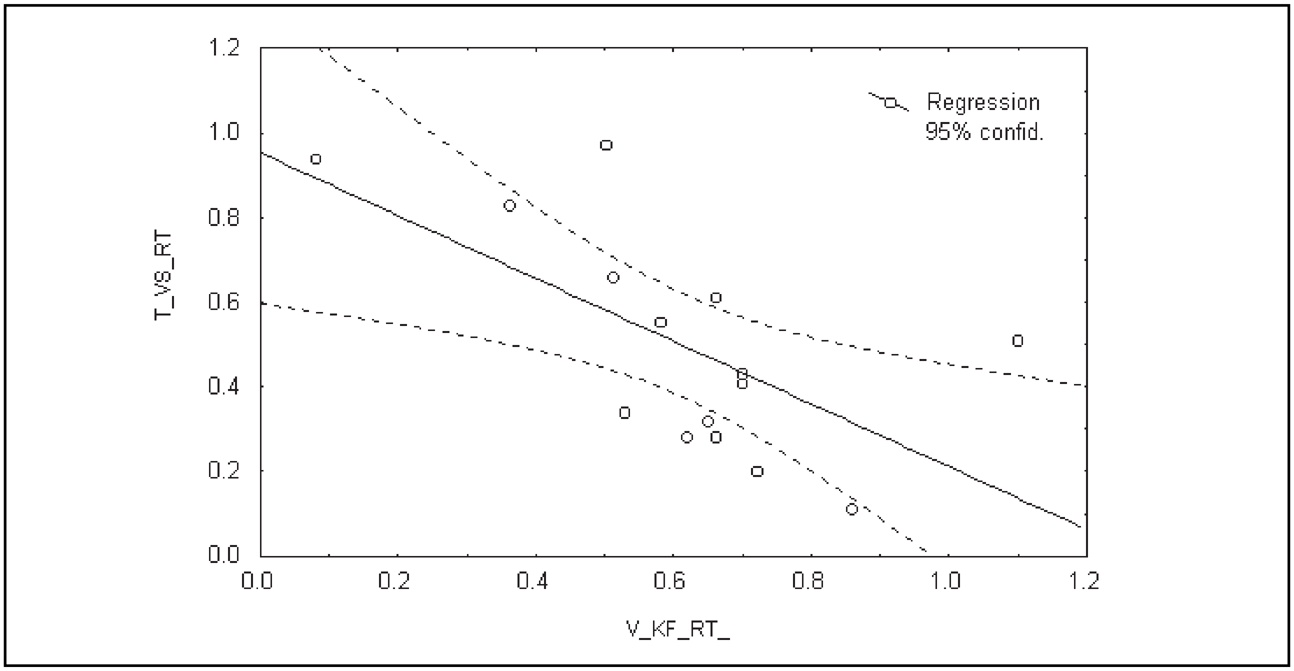

Figure 2. Correlation between V(Kf/Rt) and r(T vs RT).

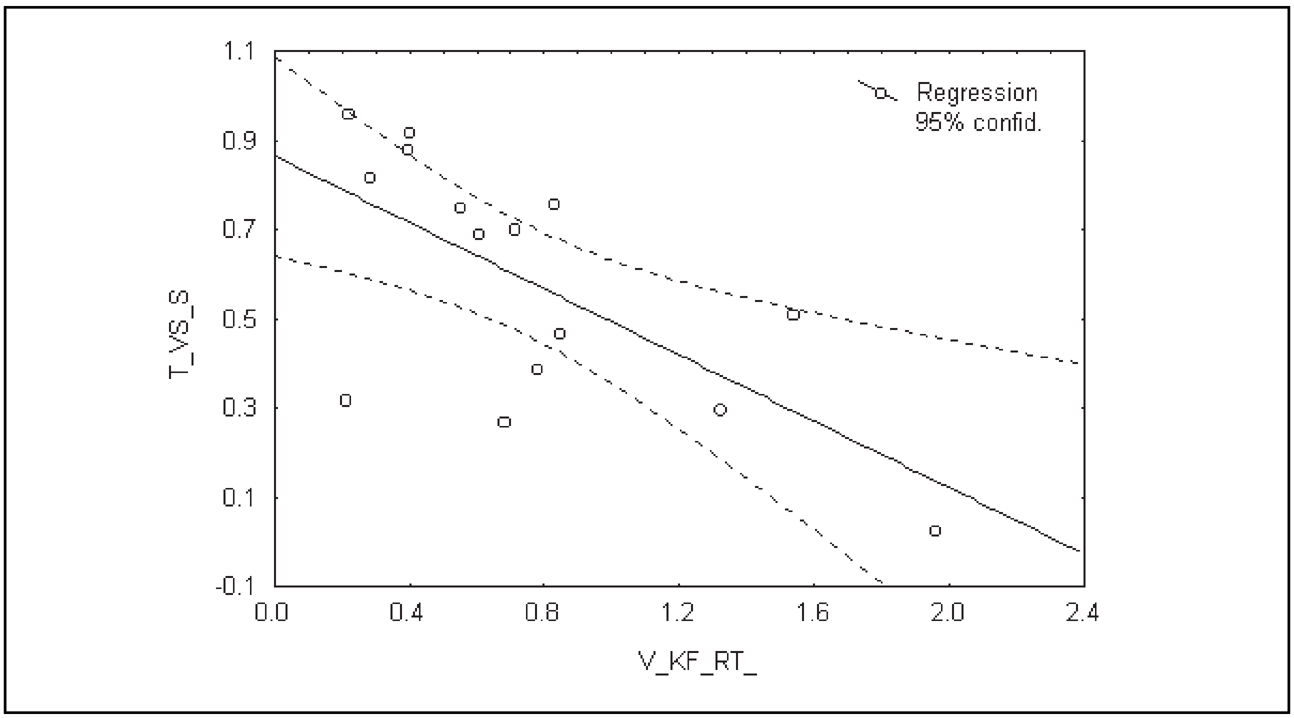

Figure 3. Correlation between V(Kf*Rt) and r(T vs S).

The study of the relationships among geophysical and hydraulic parameters contributes to elevating the resolution power of the geophysical methods, and to the solution of geologic tasks in a more efficient way from a technical and economic point of view.

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