Evolution of the Marine Intrusion Using Geophysical Methods after 25 Years in the Motril-Salobreña Aquifer (Southern Spain)

Carlos Duque[1], *María Luisa Calvache*[1], *Antonio Pulido-Bosch*[3], *Antonio González Ramón*[2], *Juan Carlos Rubio*[2], *José Antonio Navarro*[2], *Manuel López-Chicano*[1] and *Wenceslao Martín-Rosales*[1]

[1]Universidad de Granada. Departamento de Geodinámica. Granada. Spain
[2]Instituto Geológico y Minero de España. Oficina de Proyectos de Granada. Spain
[3]Universidad de Almería. Departamento de Hidrogeología y Química Analítica. Almería. Spain

ABSTRACT

Two Geophysical surveys have been compared to determine possible changes in marine intrusion in the Motril-Salobreña aquifer in Southern Spain. The first one was carried out with Vertical Electric Soundings (VES) before 1981. The second one was finished in 2006 and it was made using Time Domain Electromagnetic (TDEM) soundings. The zone selected for this study was a coastal aquifer with a lot of human alterations to the surface water and ground water. The changes happened in the area are not affecting, at least for the moment, to the saltwater encroachment. The analysis of the water table trend shows a similar situation between 25 years ago and now.

INTRODUCTION

Southern-Spain is one of the places of Europe with a higher potential risk of desertification due to the special climate properties and the human activity developed in this area. The absence of water is the main cause of the increasing hazards day by day, so the pumpings and hydraulic actions (as dams and transfers) are frequent. This kind of problems result in a decrease of the quality and quantity of the water resources, and the coastal areas are especially sensible because it is necessary to add the marine intrusion as another risk for the groundwater quality.

The groundwater in the Motril-Salobreña coastal aquifer (in the South of Spain) is suffering a lot of changes during the last twenty-five years related with some human actions. They are affecting directly or indirectly to the groundwater dynamics, and due to the contact with the Mediterranean Sea in the south boundary of the aquifer, could change the location of the saline wedge. It is remarkable the construction of a dam in one of the main recharge inputs, the river Guadalfeo; also the agriculture activity is suffering important changes from traditional cropping (such as sugar cane) with high infiltration rates of the irrigation water to greenhouses with increasing occupied surface. The population of the main cities in the area is growing continuously and in summer time, it reaches important maximums due to the tourism. Also, it is planned housing development with golf courses associated. The storage of the aquifer is about 250 Mm^3 (Castillo, 1975; Duque et al., 2007) with annual resources of 35 Mm^3, so for the moment, no water supply problem has been resulted. Anyway it is essential to know if all these changes are impacting the groundwater of the Motril-Salobreña aquifer, especially those related with the seawater intrusion before the effects start to affect the population.

GEOLOGICAL SETTING

The Motril-Salobreña aquifer, with a surface of 42 km^2, is composed of detrital material (gravels, sands and clays) resulting from the erosion of the nearby mountains like Sierra Nevada. Along the aquifer boundaries, metamorphic-rocks outcrop with different hydrogeologic properties (Fig. 1), mostly impermeable schist and permeable carbonates, the geological structure of these materials is very complex. The south boundary is marked by the Mediterranean Sea.

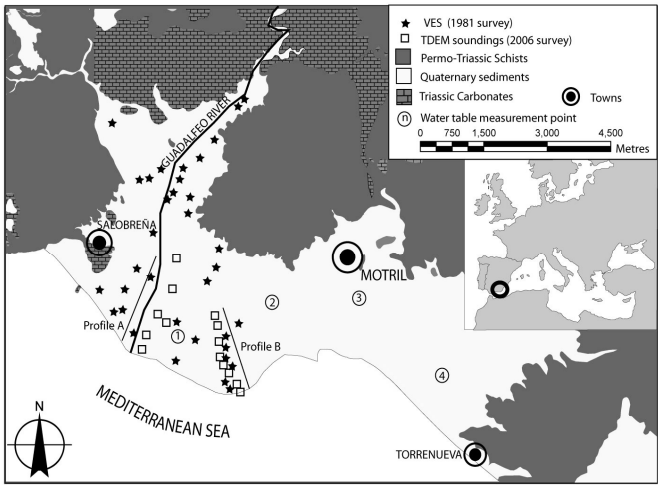

Figure 1. Location, geological map and situation of the geophysical and water table measurements

METHODOLOGY AND RESULTS

The best way for detecting the marine intrusion in this aquifer is the geophysical methods due to the great depth and the absence of deep boreholes. Nowadays we are able to compare the results obtained with electrical methods in 1981 (Geirnaert et al., 1981) with those acquired in a very recent electromagnetic survey in 2006 (Duque et al., 2008). The aim will be to establish if there are any changes.

The surveys developed until 1981 by different projects used Vertical Electric Soundings with different lengths in the Western zone of the aquifer (Fig. 1). It is, probably, the most interesting zone of the aquifer due to the presence of the Guadalfeo River and the size heterogeneity of the aquifer sediments because of the affection to the resistivity measurements. Thirty-four VES were organized in two profiles perpendicular to the coast and another two parallel to the coast. The results explained by Geirnaert et al. (1981) indicated an incipient marine intrusion in the VES nearest to the sea (Fig. 2). In 2006, Duque et al. designed a TDEM survey with 28 measurement points distributed in 4 profiles. Only 2 of the profiles were situated in the west zone (Fig. 1), so they were selected to compare the results with those of 1981 perpendicular to the coast. The comparison, after 25 years, shows almost the same marine intrusion. It is necessary to take into account some differences in the interpretation of the data, but both authors identify as saltwater saturated materials the lowest resistivities detected. In the profile A, the 1981 results did not reach big depths in the points nearest to the coast, so they interpreted a small decrease in the resistivities as marine intrusion (Fig. 2). In the 2006 survey, it was possible to reach 200 meters in depth, so lower values were detected that can be really related with seawater.

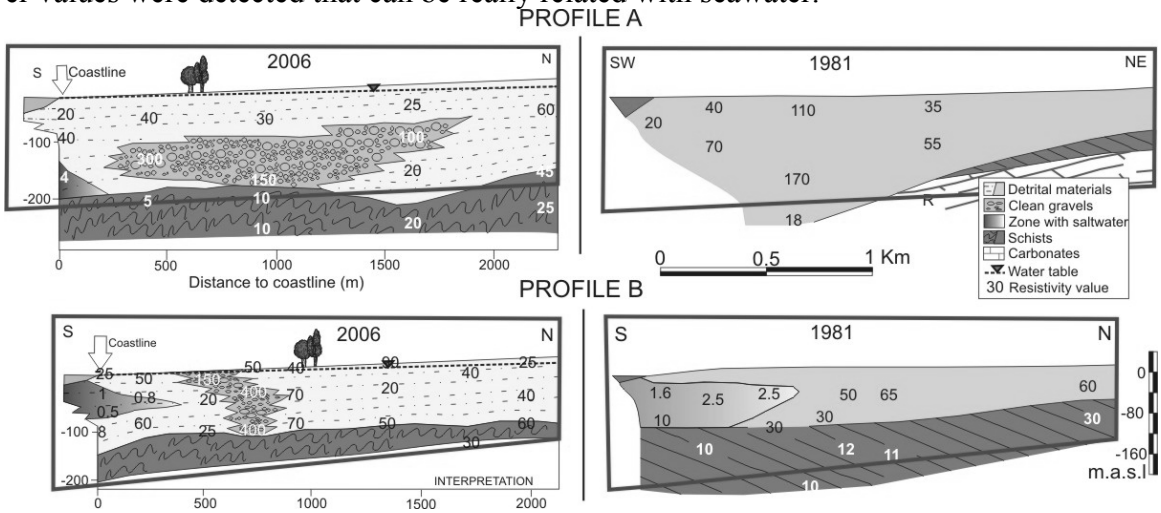

Figure 2. Geological interpretations of the VES in 1981 (right) and the TDEM soundings in 2006(left). The section in the frame remarks the coincident zones.

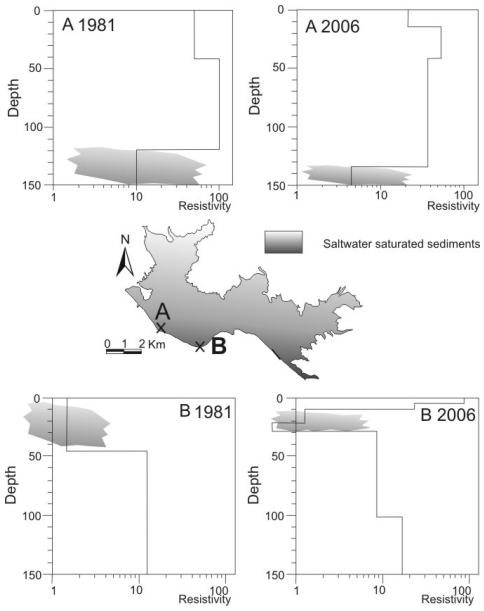

Figure 3. Resistivity versus depth curves in the points with coincident location of VES and TDEM soundings measurements points

The profile B is located along the former Guadalfeo mouth as demonstrated the delta morphology of the coastline. The whole interpretation of 1981 shows marine intrusion with an unusual shape, it is not a wedge. The detailed analysis of the depth-resistivity diagram (Fig. 3) allows a better interpretation. The area under the minimum resistivity zone can be related with detrital sediments saturated with freshwater. It is an anomalous situation due to the presence of an inversion of the ordinary situation or hydrological reversals (Goldman et al., 2003). A gravimetry survey (Duque et al., 2008) allows us to determine where the basement of the aquifer is located and so, it is possible to know that the change in resistivities is not related with the presence of the basement. During the 2006 survey it was possible to detect a very similar situation with more details, probably related with the improvements of the geophysical techniques (Fig. 3). The location of the low resistivity zone and the small change after 25 years sustains the possibility of a clay layer with high salinity content where the fresh groundwater can not penetrate to wash the contaminated sediments (Custodio, 2004). The origin of the salinity is maybe related with old marine intrusion events or with the depositional environment during the sedimentation process (it is remarkable the recent aquifer formation in the last centuries). The detail comparison of the VES and TDEM soundings in the profile A (figure 3) shows a very similar situation. Taking into account the differences in the techniques and in the location of the measurement points, we can assume a stable marine intrusion situation in the western area of the Motril-Salobreña aquifer. The marine intrusion is directly related with the water table; therefore the water table evolution will be related with the geophysical results obtained. The 25-year water table record in four points is analyzed (Fig. 4). The studied period coincides with the time length of measurements of the electrical and electromagnetic methods. The differences between the current and the 25-years ago water table are reduced, and the main changes during this time happened in the dry period of 1990-1995. In the last 2 years an incipient decrease of the water table was happening but it looks like that it is not affecting to the marine intrusion, at least for the moment. The cause of the drop is not clear for the time being because we are in a dry period, but maybe some of the human actions in the last few years are starting to affect.

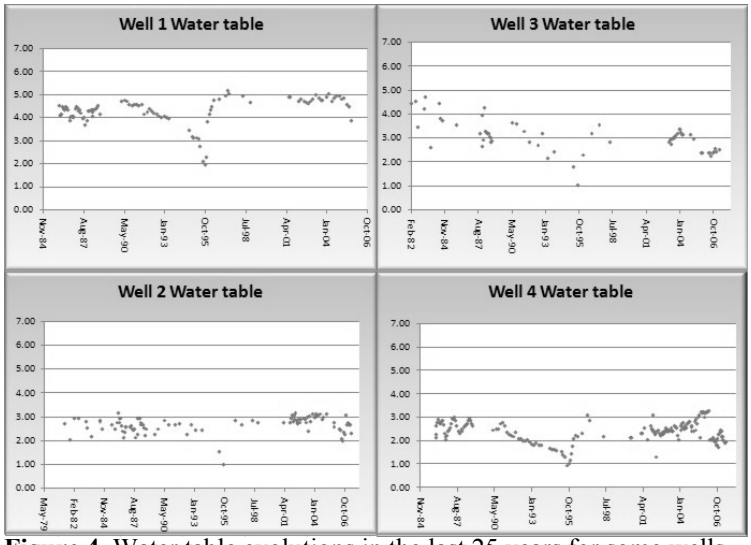

Figure 4. Water table evolutions in the last 25 years for some wells

CONCLUSIONS

The marine intrusion in the Motril-Salobreña aquifer is stable from 1981 or, at least the situation 25 years ago and now is very similar as it has been presented with the use of geophysical

techniques. The water table analysis shows small changes between 1981 and now. The low resistivities measured in the former mouth of the Guadalfeo River were detected 25 years ago and now in a near topographic surface location. The origin could be related with some low permeability materials that can not be washed by the fresh groundwater flow. The marine intrusion is not growing in a dangerous way, but it is starting a dry period with an associated drop in the water table. It is complicated to differentiate human activity and climate effects, however if the recovering capability of the aquifer during the wet periods is affected by the changes in the zone, it could be the starting point for the saltwater encroachment. An adequate monitoring activity will be possible to quantify and to advise for a sustainable resources management of one of the best preserved aquifers in the south of Spain.

REFERENCES

Castillo E., 1975. Hidrogeología de la Vega de Motril y sus bordes. Master Thesis. 184 p.

Custodio E., 2004. Myths about seawater intrusion in coastal aquifers. Proceedings of 18th SWIM, Cartagena. 599-608.

Duque, C.,Calvache, M.L., Pedrera, A., Martín-Rosales, W., López-Chicano, M., 2008. Combined time domain electromagnetic soundings and gravimetry to determine marine intrusion in a detrital coastal aquifer (Southern Spain). Journal of Hydrology, 349,536-547.

Duque C., Calvache M.L., Pedrera A., López-Chicano M., 2007. Cálculo de las reservas de un acuífero detrítico costero mediante gravimetría. Proceedings of TIAC, Almería.

Geirnaert W., Pulido-Bosch A., Castillo E. and Fernández-Rubio R., 1981. Estudio de la geometría del acuífero detrítico de la vega de Motril-Salobreña mediante SEV. In: Proceedings of 1st simposio del Agua en Andalucía, 291-302.

Goldman, M., Kafri, U., Yechieli, Y., 2003. Application of the TDEM method for studying groundwater salinity in different coastal aquifers in Israel. Proccedings of TIAC pp. 45-56.

ACKNOWLEDGMENTS

This study was made possible by funding approved for projects CGL2007-63450/HID financed by the MEC of Spain and the Spanish program of FPI.

Contact Information: Carlos Duque, Departamento de Geodinámica, Universidad de Granada. 18071, Granada, Spain. Phone 0034958243351; Email: cduque@ugr.es