Monitoring seawater intrusion by means of long-term series of EC and T logs (Salento coastal karstic aquifer, Southern Italy)

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INTRODUCTION

The objective of this work is to highlight the potentials of the Electrical Conductivity (EC) and Temperature (T) logs in seawater intrusion studies.

EC logs (though discontinuous) have been carried out during a 40 year period along wells (OWS) specifically drilled for the control of seawater intrusion in the karst coastal aquifer of Salento (Southern Italy). The OWSs belong to the Regional Monitoring Network (RMN), which was established in the nineties for the control of groundwater quantitative/qualitative status. The net is presently intended for the objectives of the FWD 2000/60/EC. All the wells of the network are accessible to multi-parametric probes and samplers. The geo-statistical elaboration of T logs gives the distribution of aquifer temperature.

EC LOGS IN OWS

The Salento peninsula, located at the SE edge of Italy, extends for about 3800 km^2. Miocene to Quaternary Transgressive covers overlay the largely outcropping Cretaceous limestone and dolomitic limestone basement. The coastal karst aquifer is mostly present at sea level. It is highly permeable due to fissures, fractures and karst; at regional scale it behaves as a porous aquifer. The hydraulic head varies from about 4 to less than 0.5 m AMSL (average hydraulic gradient of about 0.02 ‰). Precipitation is about 638 mm/yr, 132 mm/yr of which recharges the aquifer (yearly averages of last 50 years; Portoghese et al. 2013). Freshwater floats as a lens on saltwater of marine origin. Freshwater TDS varies between 0.2 and 0.6 g/L.

In the Salento Peninsula, groundwater demand has increased especially due to agriculture from the 1960, causing the progressive salinization of fresh groundwater: presently, ground waters with TDS>0.6 g/L are distributed in the entire coastal zone. The first research project concerning seawater intrusion in the Salento aquifer dates back to the sixties. There a net of observation wells reaching saltwater beneath freshwater was drilled and purposely equipped (Tadolini & Tulipano 1979). T-EC logs were regularly performed from 1970 up to 1986: afterward, monitoring went along with a few time gaps till 2011 under the responsibility of Puglia Regional Government.

Salento OWSs are suitable to represent the actual density stratification of groundwater: most OWSs are located in zones of horizontal flow and are screened along groundwater thickness, thus allowing the measure of the "environmental water head" (Lusczynski 1961; Post et al. 2007). In principle, timeline analysis of related EC logs allows outlining the evolution of groundwater salinization and (locally) quantifying the freshwater-saltwater equilibrium. TDS logs allow measuring freshwater thickness, position and thickness of transition zone, saltwater top and average TDS of fresh and transition thicknesses. Elevation of theorical sharp interface (TSI) and equivalent saltwater head (t_s) derive from density profiles (Tulipano and Fidelibus, 2002).

Till 1986 the EC-T logs were realized with different probes, prototypes of modern ones, purposely projected and designed at the time by the University research team. The EC-TDS-density conversion was followed through the measure of these parameters on a series of "standard" solutions obtained by mixing freshwater and saltwater sampled in each OWS. After 1986 the Regional Government used commercial probes. Thus, due to the large time span from the first to last monitoring survey (1970-2011), timeline analysis suffers of a few uncertainties due to variation in probes, calibrations and operators. However, if absolute values can be debatable, and notwithstanding the uncertainty in defining the real sea level elevation of reference for calculations (different from the zero topographic level), the trends over time of the TSI, the thickness of the complementary freshwater column (TFC), of the equivalent saltwater head (t_s) and the other measured and calculated parameters, provide a reliable picture of evolution of FW-SW equilibrium mostly related to the regime of exploitation and alternation of wet and dry years.

The trends of TSI and TFC (example for OWS LR, Figure 1) during the period 1974-2011, coupled with those of the annual heights of effective infiltration and irrigation (mm/yr), and with the index of groundwater stress (data from Portoghese et al. 2013), allow highlighting the behavior of groundwater under variable climate During 1987-1991, the GW stress index (moving average, Figure 1) increases up to 0.7 (severe stress) in 1990 in relation to the concurrence of the decrease of the effective infiltration down to a minimum of 38.2 mm/yr and the increase of irrigation up to 60.9 mm/yr (estimated through the soil moisture deficit method, with an average of about 34.1 mm/yr in the period 1950-2010, Portoghese et al. 2013). Another peak of GW stress (moderate stress) occurs between 2000 and 2004.

Unluckily, OWS monitoring has two wide time gaps just during the periods of high GW stress: data on TSI are thus missing. However, 1995 and 1996 EC logs show that, following the first high GW stress, TSI moved upward of about 13 m with respect to the first TSI evaluation (1974). The sharp interface, despite the following increase of recharge, shows only a modest downward shift. After the second period of GW stress, TSI maintains roughly the previous elevation. In the whole monitoring period, the average TDS of the entire water column from water table up to the reference level, fixed into salt waters, obviously increases with the upwarrise of the sharp interface.

T LOGS IN THE RMN

T logs were carried out on the observation wells of RMN (location in Figure 2) each quarter during 1994-1997 and every six months between 2007 and 2012. The temperature distribution is of interest, especially in karst aquifers with low anisotropy ratio of hydraulic conductivity (k_h/k_v), for outlining preferential pathways, recharge areas and spatial extent of brackish and salt waters at regional scale (Fidelibus et al. 2011).

An example of horizontal section of the aquifer temperature (at -5 m AMSL) is shown in Figure 2: it has been obtained through a geo-statistical approach (variographical analysis and Ordinary Kriging) for the winter 1995. In the specific climatic setting, the recharge areas are identified by the lowest temperatures of thermal field (14°C); temperatures higher than 18°C signal zones of the aquifer with brackish and salt waters. The effect of the low anisotropy ratio, linked to the presence of vertical discontinuities and/or high permeability zones because of karstification, is clear from the vertical section SS' (Figure 2).

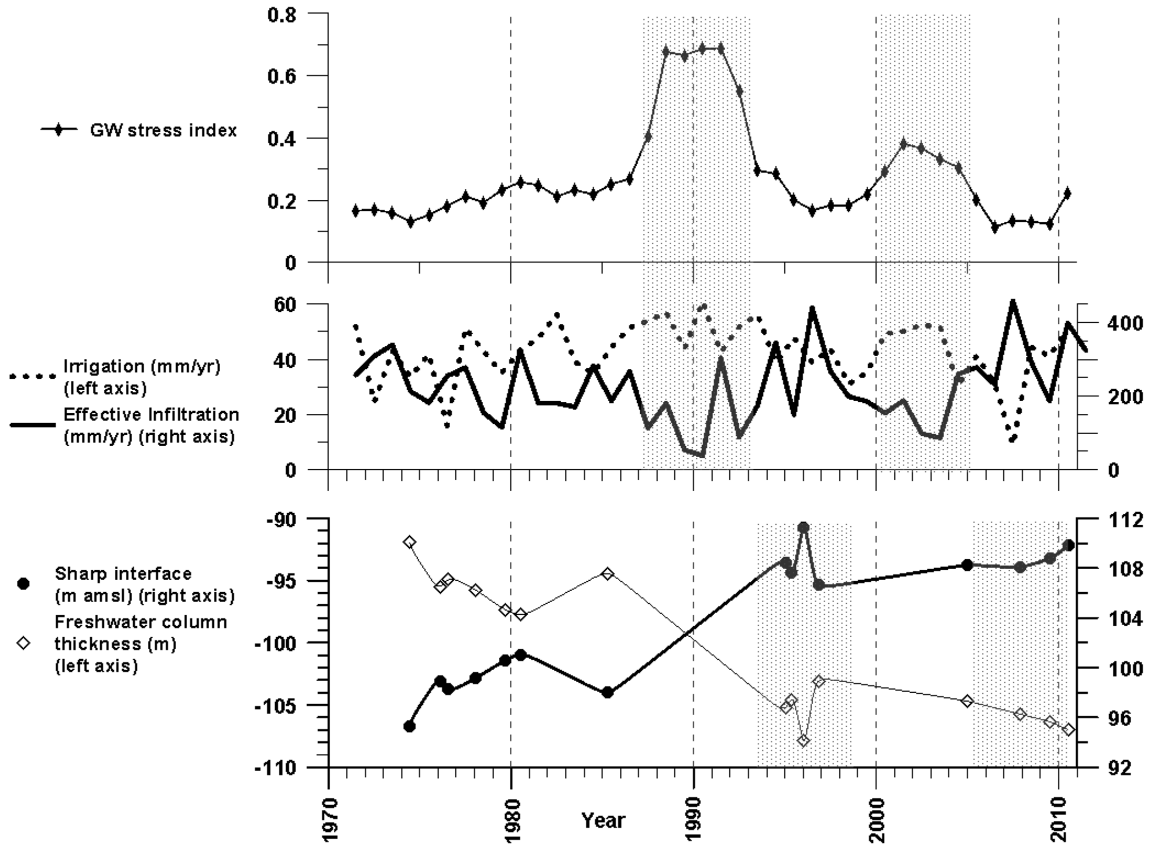

Figure 1. Groundwater Stress index (moving average), yearly irrigation and effective infiltration trends (data from Portoghese et al. 2013) compared to the tendencies of the sharp interface elevation and the freshwater column thickness during a 36 year period.

CONCLUSIONS

The timeline analysis of the trends of TSI and TFC, coupled with those referred to GW stress, irrigation and recharge, points out that, in semi-arid coastal areas with high exploitation of groundwater, the periods of low recharge (which go with drought periods and/or precipitation pattern changes) can have a decisive influence on the FW-SW equilibrium. In the selected case, even with monitoring gaps, a "critical transition" toward a new equilibrium can be observed: there are limited signs of recovery after the periods of GW stress. Human forcing and climate change do not promise any future improvement: on the light of climate change, Portoghese et al. (2013) forecast for the next 50 years even worse periods of GW stress, especially linked to the change of precipitation patterns.

A sensitivity analysis of the method of calculation of TSI shows that results are not so much affected by precise EC-TDS-density calibration or by a different reference point for calculation, how much from the "shape" of EC profiles, i.e. from the TDS distribution along the vertical of the saturated zone. This can be also demonstrated by other parameters, not shown here. Thus, a net of OWS can represent a good tool for describing the real "health" conditions of coastal groundwater. Obviously, in contexts other than that illustrated the TSI method should be tested and adjusted.

As to the temperature, it has to be emphasized that, apart from geo-statistical constraints, it represents an optimal natural proxy of the flow system, whose reconstruction is very critical in presence of variable density flow (Post et al. 2007).

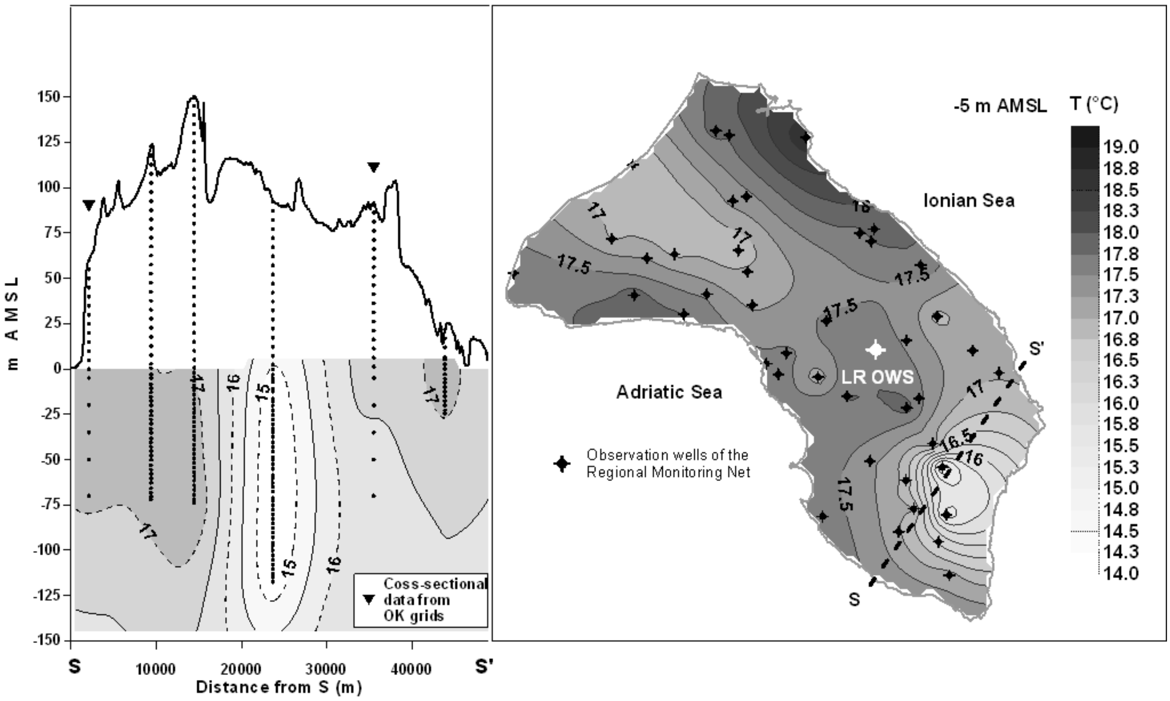

Figure 2 – Vertical section (S-S' trace) and horizontal section (-5 m AMSL) of aquifer temperature; location of Observation Wells of Regional Monitoring Net and of the LR OWS.

REFERENCES

Fidelibus M. D., Tulipano L, and P. D'Amelio. 2011. Convective thermal field reconstruction by ordinary kriging in karstic aquifers (Puglia, Italy): geostatistical analysis of anisotropy. In Advances in Research in Karst Media, Andreo B. et al.(Eds), Environmental Earth Series, vol. XX, 203-208, Berlin Heidelberg: Springer-Verlag, doi: 10.1007/978-3-642-12486-0_31.

Lusczynski, N.J. 1961. Head and flow of ground water of variable density. Journal of Geophysical Research 66, no. 12: 4247-4256.

Portoghese, I., Bruno E., Dumas P., Guyennon N., Hallegatte S., Hourcade J.C., Nassopoulos H., Pisacane G., Struglia M.V. and M. Vurro. 2013. Impacts of Climate Change on Freshwater Bodies: Quantitative Aspects. In Regional Assessment of Climate Change in the Mediterranean, Navarra A. and L. Tubiana (eds.), Advances in Global Change Research 50, Ch. 9, Springer, Dordrecht.

Post V., Kooi H. and C. Simmons. 2007. Using Hydraulic Head Measurements in Variable-Density Ground Water Flow Analyses. Ground Water 45, no. 6: 664–671.

Tadolini T. & L. Tulipano. 1979. The evolution of fresh water-salt water equilibrium in connection with drafts from the coastal carbonate and karst aquifer of the Salentine Peninsula (Southern Italy). 6th SWIM, Hannover (Germany).

Tulipano L. and M.D. Fidelibus. 2002. Mechanisms of groundwater salinization in a coastal karstic aquifer subject to over-exploitation. in Procs. 17th SWIM, Boekelman R.H. et al (Eds), 262-272, Delft (The Netherlands), 6-10 May 2002. ISBN 90-800089-8-2,

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