New data on the assessment of the salinity of the shallow aquifer of the Ebro River delta

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ABSTRACT

A detailed study of the salinity of the shallow aquifer of the Ebro River Delta has been carried out by means of physical, chemical and isotopic analysis as well as hydraulic measurements and Electrical Conductivity (EC) vertical profiles. The results show the spatial changes on water quality and the existence of a strong stratification of the shallow aquifer likely related to the Ebro River.

INTRODUCTION

Background

The Ebro River delta is located in the western Mediterranean Sea. The river has a length of 930 km and the extension of the basin is about 85,534 km^2. Morphologically, the Ebro Delta is a mass of land progradating seaward, with a typical arrow shape of wave dominated deltas, starting from the town of Amposta, 25 km inland. The submerged part of the delta covers an area of 1,880 km^2 which, added to the 320 km^2 of the emerged delta, results in total surface of 2200 km^2. The sediments of the delta are recent, pro-deltaic sedimentary material dated some 10,000 years old, deposited in response to a rise in sea level of 100 m (Maldonado, 1972). The upper aquifer extends almost all of the deltaic plain, presenting a very consistent thickness of about 10 m, limited by a continuous layer of approximately 30 m thick of silt and clays at the base. Below the clay layer a package of 20-30 thick of high hydraulic conductivity sandy gravel river discharge sediments forms the so-called second aquifer. These materials form the deep aquifer, poorly known, unexploited and highly saline due to the low hydraulic gradient (Custodio *et al*., 1997). Water table in the upper aquifer is very shallow, just a few decimeters below the surface. The aquifer predominant material is fine-grained sand (0.15 - 0.25 mm) (Custodio *et al*., 1997) with a highly variable contents of organic matter (Torrents and Alonso, 1991).

Almost all of the deltaic plain is used as agriculture land, especially rice crops. There is a dense network of channels starting with the main right hand side channel (starting in the Ebro River in the Xerta dam 50 km inland) used to flood the fields during rice culture (mid-April to September) and during November and December. Otherwise, the delta does not receive irrigation and fields are drained through drainage network carrying water to the flanks, where it is evacuated towards the sea by pumping through Archimedes spirals.

The Ebro River at its mouth behaves as an estuary, allowing the ingress of seawater, which in contact with river water, forms a layered water body with a well-defined halocline (Movellán, 2003). The extent of sea water into the Ebro River reaches 40 km inland, close to Tortosa city, which is established as the theoretical limit of marine influence (Aragon, 1943).

The study area lies between the island of Buda and the town of Sant Jaume d’Enveja, in the right hand side (southern) half-delta (Figure 1).

Objectives

The Ebro Delta is the unique area within the Ebro Basin with the coexistence of inland surface waters, groundwater, transitional waters and coastal waters, which forms a system with complex interrelationships. The natural equilibrium can be easily unbalanced as a result of a minimum disturbances. The objective of this work is to identify the different mechanisms that control the distribution of salinity in the Ebro Delta, in order to establish proper guidelines to preserve the current delta dynamics.

METHODS

Eleven piezometers have been constructed through the entire thickness of the upper aquifer (depth integrated). Since lithology is uniform and no significant heterogeneities are recognized, piezometers are considered to be representative of the aquifer in the vertical (Appelo and Postma, 2007).

Three control points were located in the shore of the Ebro River, which, together with the piezometers, create three study lines perpendicular to the river. All control points and piezometers have been leveled. The level control has been done by hand-dipping and continuous measurement devices.

Periodically, electrical conductivity (EC) vertical profiles were carried out in all the piezometers and in six locations of the river. The profiles were performed using a continuous measuring device, which records simultaneously pressure, temperature and EC. The device recorded an average of 14 values per meter.

Water samples have been collected on the basis of the observed EC vertical profiles. Different types of water have been sampled in each piezometer, without mixing, using a pump type WHALE WP4012. The elements analyzed were the major anions and cations, as well as Br.

Isotopic sampling and characterization (^{18}O, D, and in future work, tritium) were carried out in piezometers, river, channels and sea water.

RESULTS

The position of the water table varies away from the river and fluctuates throughout the year (Figure 2). Almost all levels are always above the river surface (fairly constant) and a hydraulic gradient from the river towards the center of the delta is observed. The highest level is located close to the main irrigation channel.

The EC vertical profiles display remarkable contrast in depth. All control points suddenly increase by 70 mS/cm, with the exception of the Ebro River, which shows a step of 40 mS/cm. The EC step is located between -2 and -6 masl, depending on the area. The shallow water has a EC range from 3 to 33 mS/cm and the deep water from 20 to >80 mS/cm (Figure 3). In some places the interface can oscillate up to 2 m along the year. The EC values and position of the interface in the Ebro River did not change during the observations period.

Two groups of samples can be observed based on its chemical composition (Figure 4), corresponding to the upper water samples (-1.5 masl., above the fresh-salt water interface) and lower water samples (-6 masl, below the interface). Conspicuous differences are found for Cl^- (15,000 mg/l) and Na^+, K^+ and Mg^{2+} (200 mg/l). Top samples display a trend departing from the irrigation water towards sea water, which could be interpreted as a mixing process. It is worth noting, that contents in Na^+, Mg^{2+} and Cl^- can be even higher than actual seawater though.

However, $SO4^{-2}$ is found to decrease for most of the bottom samples, with respect to seawater. The corresponding increase in HCO^{3-} qualitatively indicates a reduction of the former and an increase of the latter as a consequence of the oxidation of organic matter (Appelo and Postma, 2007, among others).

The values of stable isotopes of water of the samples in the upper aquifer (D and ^{18}O), expand between the seawater and irrigation water composition, irrespective of their salt content. They align perfectly below the local meteoric line (R = 0.99) and in agreement with the chemical composition, suggest that mixing is a dominant process.

DISCUSSION AND ONGOING WORK

Water table measurements do not reflect a clear hydraulic gradient between the river and the upper aquifer and it seems that piezometry of the aquifer depend largely on the flooding of the fields. EC vertical profiles show the coexistence, in the first meters of the upper aquifer, of two water types, highly stratified and separated by a sharp interface.

The annual flood-drain cycle seems to prevent the mixing of the two waters. While shallow and less saline water is periodically renewed with the flood-drainage cycles, deep water is stagnant and under sulfate reducing redox conditions, Brine (up to 147 mS/cm) is found systematically in other parts of the delta aquifer (Custodio *et al*, 1997). The existence of brine seems to be due to a different delta dynamics taking place before the rice crop started. At that time, the natural dynamics allowed a significant seawater entrance, being confined in the surface and increasing concentration by evaporation.

Currently there is no hydraulic connection between the lower and upper delta aquifers. Although the presence of an upwards gradient, it is unlikely that significant water flow takes place, as a source of salt. In addition, the rNa^{+}/rCl^{-} relationship is very close to seawater (no cation exchange has taken place).

The chemical composition of the upper aquifer and the isotope values indicate that mixing of irrigation water with seawater is the dominat process occurring.

Further work will expand over the monitoring campaigns, with emphasis in analysis of tritium, continuous monitoring of salinity, and spatial and temporal monitoring of the position of the interface in several piezometers.

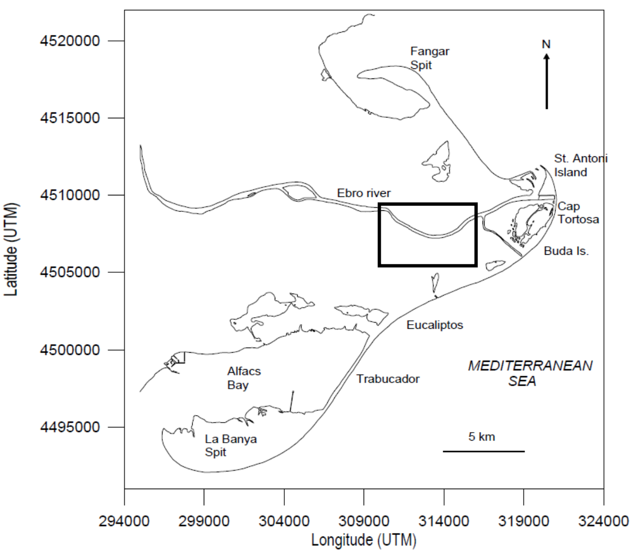

Figure 1. Layout of the Ebro Delta (Movellán, 2003) and study area.

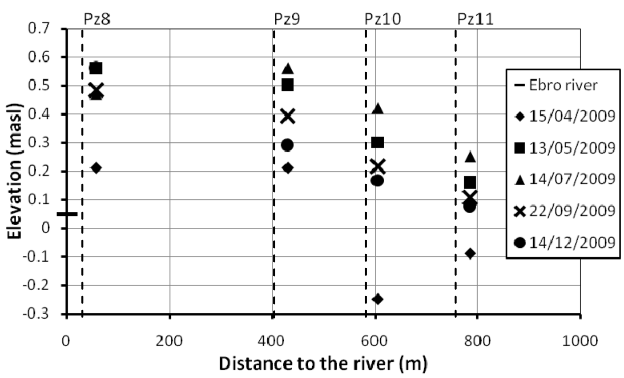

Figure 2. Evolution of the piezometric level versus distance to the Ebro River.

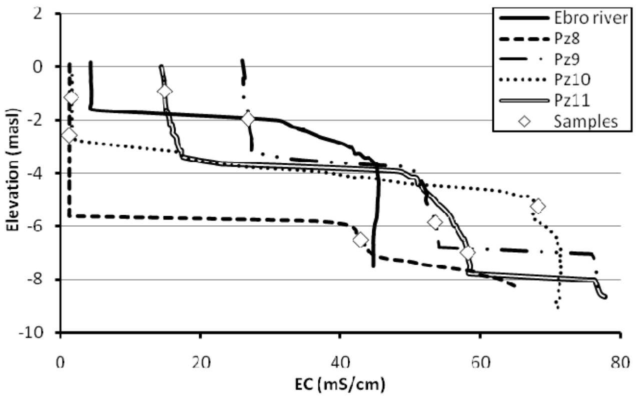

Figure 3. EC Vertical profiles for one line of piezometers (Dec-2009).

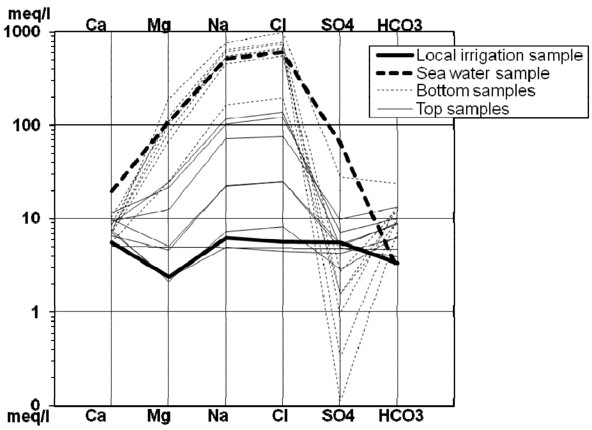

Figure 4. SCHOELLER-BERKALOFF chart where samples from the irrigation channel, sea water and the top and bottom of the piezometers are differentiated.

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