XXXVIII IAH Congress

Groundwater Quality Sustainability
Krakow, 12–17 September 2010

Extended Abstracts

Editors:
Andrzej Zuber
Jarosław Kania
Ewa Kmiecik

University of Silesia Press 2010

abstract id: **490**

topic: **1**
Groundwater quality sustainability

1.1
Evaluation and management of groundwater — sustainable exploitation

title: **Groundwater supply deterioration due to an upconing process**

author(s): **Ofelia C. Tujchneider**
Faculty of Engineering and Hydrological Sciences, Argentina,
ofeliatujchneider@yahoo.com.ar

Marcela A. Perez
Faculty of Engineering and Hydrological Sciences, Argentina,
maperez@fich1.unl.edu.ar

Marta C. Paris
Faculty of Engineering and Hydrological Sciences, Argentina,
parismarta@gmail.com

Mónica P. D'Elia
Faculty of Engineering and Hydrological Sciences, Argentina,
mdelia@fich1.unl.edu.ar

keywords: groundwater deterioration, upconing, Esperanza city, Argentina

ABSTRACT

Groundwater is of fundamental importance in Esperanza city, Santa Fe province, Argentine Republic, since there is no other water supply to satisfy regional demands. The exploited aquifer is lodged in a sandy sequence of fluvial origin with good quality water.

Loess and clayey silt deposits, having in depth aquitard behaviour, overlie these sands. These deposits lodge water of variable quality with fluoride and arsenic presence. Grey sands and green clays of marine origin underlie the fluvial sands. The aquifer has been intensively exploited since the beginning of the '70s. As a result of this abstraction and its exploitation scheme, in several pumping wells groundwater levels decreased and its quality had a progressive deterioration. In these wells, the increment of chloride and sulfate was due to an upconing. The areas affected by this salt water rising were identified taking into account: the conceptual model previously defined and the space-time evolution analysis of the hydrodynamic and hydrochemical conditions. The salt water volume that could have entered the fresh groundwater system was quantified by mathematical modelling. The studies that have been carried out allow obtaining the proper system knowledge in order to adequate the management model guaranteeing the protection of the water supply.

INTRODUCTION

Esperanza city is located 31°25' S and 60°56' W, at the west centre of Santa Fe province (Argentine Republic), with a population of 35,000 inhabitants. The study area (Figure 1) covers almost 300 km^2, belonging to the great "Pampeana" plain. The climate of the region is humid and moderated, the average annual temperature and precipitation are 18°C and 930 mm, respectively.

In this zone, the aquifer system constitutes the only available water resource which supports not only the local socio-economical requirements but also those of an extensive zone of influence. The neighbouring city of Rafaela (90,000 inhabitants) 40 km westward from Esperanza, also supplies its demands through this system. The region's main economic activities are agriculture, livestock, and industries of various kinds: textiles, metallurgical, tannery, food, furniture factories, among others.

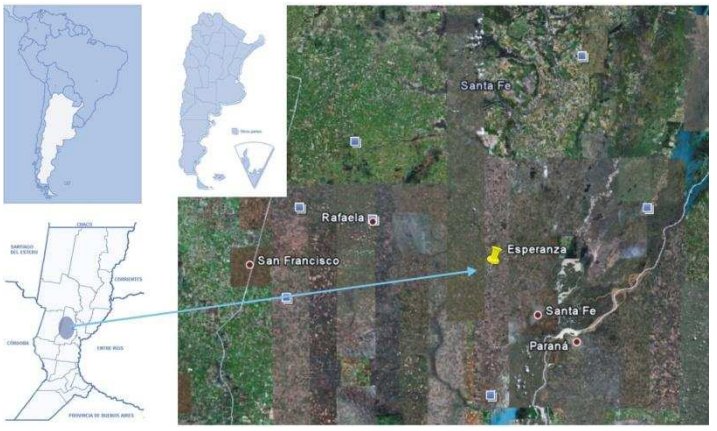


Figure 1. Location of the study area.

In the study area, from 15 m in depth, there is an aquifer layer whose hydraulically behaves as semiconfining to confining unit, without local recharge, lodging good quality fresh water.

This aquifer layer is being exploited since 1930. Underlying this layer, there are saturated marine sediments which lodge high salinity water but of continental origin.

The pumping wells were concentrated in two sectors: one of them located in the urban area (Esperanza town) and the other located 4 km westward, in the rural area. It has been estimated that the total yield extracted for water supply from this aquifer system in the study area is of about 11 millions of m^3/year.

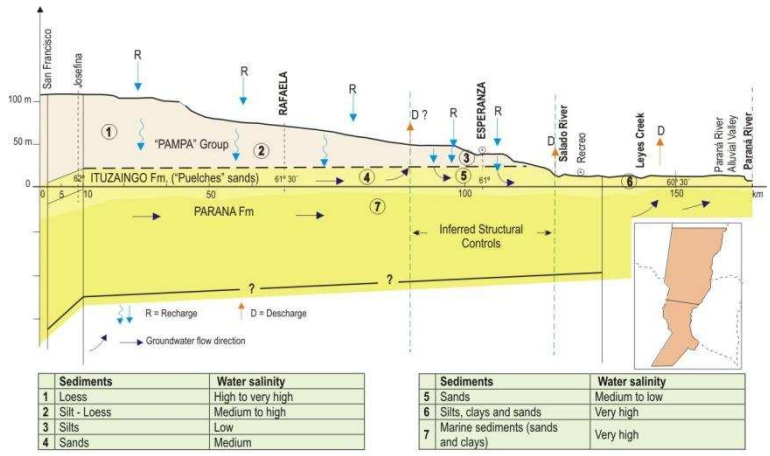
The conceptual model of the aquifer system and the spatial and temporal evolution of the hydrodynamic and hydrochemical conditions allowed identifying the areas affected by this upconing process. Hydrogeological mathematical modelling allowed estimating the volume of salt water that could have entered the system, deteriorating its quality.

GEOLOGY–HYDROGEOLOGY

The hydrogeological local column corresponds to Tujchneider et al. (1998), and define the geohydrologic system composed by:

1. An aquiclude basement composed by green clays (Paraná Formation, of marine origin, Upper Miocene). Above these clays, and always belonging to the same formation, are located heterogeneous grey sands. These marine sands are directly in contact with sands of fluvial origin. The general direction of the groundwater flow is from west to east and the discharge area is the alluvial valley of the Paraná River, located 40 km eastward from the study area.
2. A semiconfining o leaky aquifer, composed by fine to medium-sized grain sands, (Ituzaingó Formation — Upper Pliocene), with an average thickness of 24 meters. In much of the Chaco-Pampeana Plain, are also called "Puelches" sands. Ituzaingó Formation is of fluvial origin and its sediments lodge good quality fresh water. Isotopic investigations have led to corroborate that its recharge is allochthonous (D'Elía et al., 2004). The general groundwater flow direction is from west to east and the hydraulic gradient was estimated at 2×10^{-4}. The hydraulic parameters: transmissivity (T = 750 m^2/day), hydraulic conductivity (K = 30 m/day) and storage coefficient (S = 7E-04), were obtained by pumping tests.
3. Sedimentary deposits, mainly of aeolian origin, composed by silts, clays and loess, belonging to Pampa Formation (Holocene). There is a semiconfining layer or aquitard towards the bottom, discontinuous to the east. The water lodges in these sediments has variable contents of fluorine and arsenic.

This system has a multiunit hydraulic behaviour, with the possibility of downward flow through the aquitard layer and/or upward flow from the underlying sands of marine origin, according to the prevailing hydraulic heads relations (Figure 2).



	Sediments	Water salinity
1	Loess	High to very high
2	Silt - Loess	Medium to high
3	Silts	Low
4	Sands	Medium

	Sediments	Water salinity
5	Sands	Medium to low
6	Silts, clays and sands	Very high
7	Marine sediments (sands and clays)	Very high

Figure 2. Hydrogeologic Model (by: Tujchneider et al., 2004).

HYDROCHEMICAL AND HYDRODYNAMICAL BEHAVIOUR

The waters used for supplying the needs of the population — and lodging in the semiconfining layer — are sodium bicarbonates. However, the cationic branch presents a differential behaviour, spatially coincident with the water samples of such wells located in the urban area of Esperanza town. Besides, it is important to remark that in those wells where the highest pumping discharges were registered there was a change in the water type from sodium bicarbonate to sodium chloride type.

Since mid-90s, these changes were noticed in some pumping wells of the urban area. As an example, Figure 3 and Figure 4 show the temporary increase of sulfate and chloride contents in three pumping wells of this zone. As a particular case, pumping well E17 presents the highest chloride contents — almost five times greater than its initial concentration — whereas total alkalinity contents (TAC) decrease. This content variation comes together with the increment of the pumping discharges, due to the exploitation schedule changes. With regards to the groundwater flow, in 1994 the equipotential lines clearly showed the influence of both pumping fields (two cones of depression, at the rural and urban areas) (Figure 5). Two years later, 1996, these lines shown a considerable variation, proved in an average groundwater lowering of almost 2 meters and a defined divide in the 29 m equipotential line.

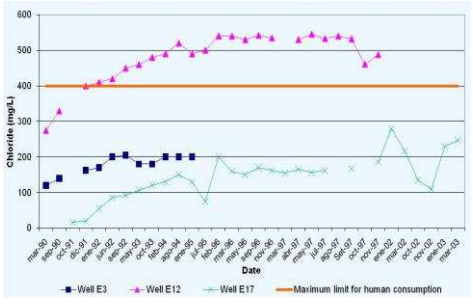


Figure 3. Chloride increment.

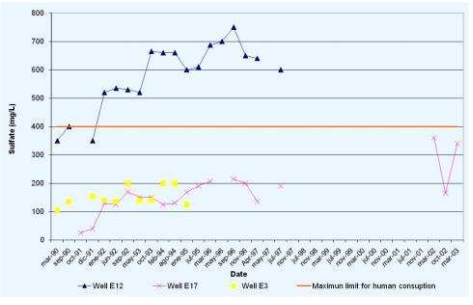


Figure 4. Sulfate increment.

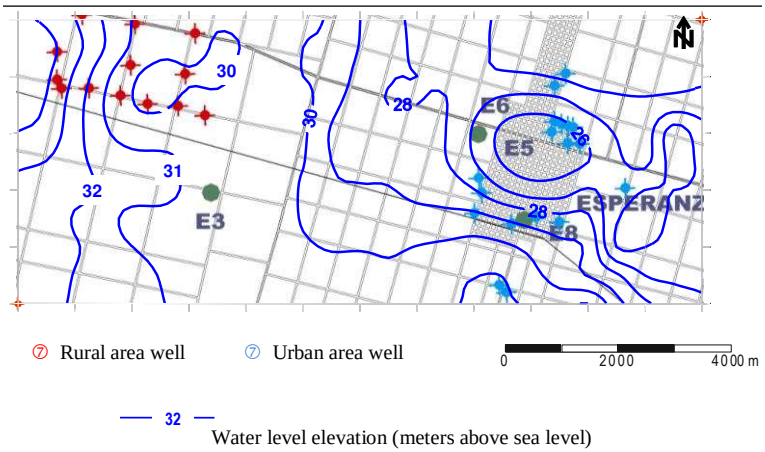


Figure 5. Potentiometric surface in 1994.

METHODS AND RESULTS

In order to identify the areas affected by the upconing process the following physicochemical contents were considered: total dissolved solids (TDS), bicarbonate (HCO_3^-), sulfate ($SO_4^=$), chloride (Cl^-), nitrate ($NO_3^=$), calcium (Ca^{++}), magnesium (Mg^{++}) and sodium (Na^+). These records correspond to different sources of information and water samples collected in the wells located in both urban and rural area from 1990 to 2003. The statistics of the ionic records were calculated. They summarised the characteristics of the water sample ionic contents and their great variability. The R-mode cluster analysis (using the r-Pearson correlation coefficient as a similarity measurement and the non-weighted average pairs as the linking rule) was applied. The main groups identified are shown in Figure 6.

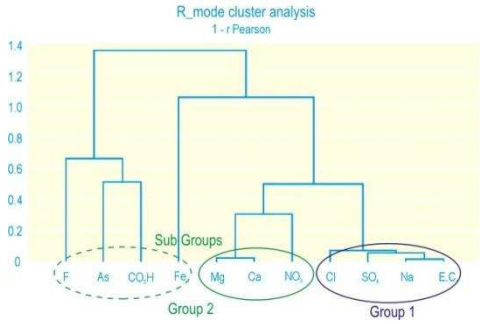


Figure 6. R-mode cluster analysis (1 – r Pearson).

The Q-mode cluster analysis (using the Euclidean distance coefficient as a measure of similarity and the non-weighted average pairs as the linking rule) allowed identifying several groups and subgroups. These clusters are related both to the chemical characteristics of the water samples from the urban and rural wells and to the changes in the exploitation schedule. There were identified two groups:

Group 1: water samples from wells located in the urban area with high salinity and chloride contents. The records belonging to this group correspond to those wells from the urban area that were removed from service between 1995 and 1997, and those who remained operating until 2002.

Group 2 — subgroup 2A: water samples from urban and rural wells with medium to high salinity and sulfate concentrations, belonging to the beginning of the period when saline increases began to be recorded.

Group 2 — subgroup 2B: water samples from wells in the rural area and those located in the urban area before the increasing of their salinity.

Group 3 — Subgroup 2B and Group 2 — Subgroup 2A according to the increase in salinity as well as concentrations of sulphates and chlorides.

The mathematical model implemented allowed estimating the incoming flow from the underlying marine formation to the exploited layer. Visual Mod Flow v2.7.1 code (Guiguer, Franz, 1997) was used to simulate the upconing process.

The simulated area, of 288 km^2, was discretized into rectangular elements of 500 m, and was refined in areas of greater interest such as the zone where the withdrawal was more intense. The vertical discretization consisted of three layers of variable thickness. They were considered isotropic and homogeneous, depending on the conceptual model defined in previous studies and available information. The downward recharge and the regional flow were considered as boundary conditions. The model calibration was done depending on the groundwater levels registered in monitoring wells located in the area for 1999. The model was validated as a prediction tool for the period 1999–2003. The simulation carried out during this period allowed to estimate the rate of salt water flow that might have entered by upward flow. This is of about 22 mm year^{-1} (Figure 7).

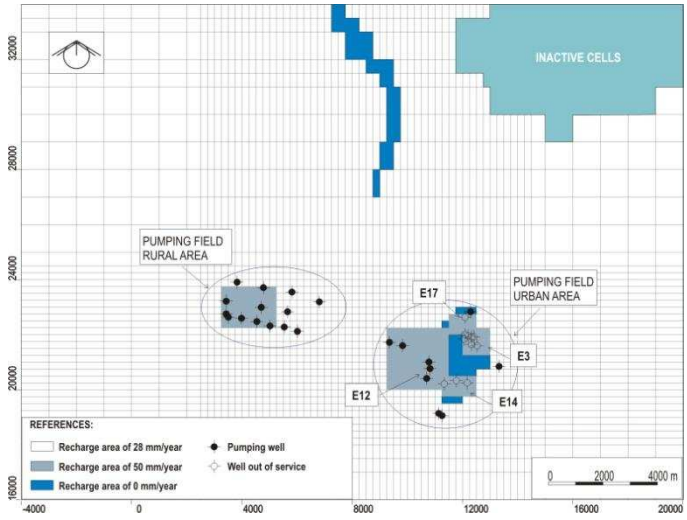


Figure 7. Discretization of the study area.

CONCLUSIONS

Groundwater systems in the Chaco-Pampeana plain behave very subtle. In this case, freshwater aquifer lodges in sands of fluvial origin is located above an aquifer layer comprising by marine sediments with salt groundwater. The hydrodynamic balance between the two types of waters is maintained whether the operation is done properly.

The changes manifested in the hydrodynamic and hydrochemical behavior between 1994 and 1996 indicate the effect of pumping, which is consistent with the increase of chloride and sulfates and lower TAC. This fact, together with the water balance carried out in the simulation made it possible to identify the upward intrusion of the overlain salt water by the breakdown of the hydrodynamic equilibrium. The involvement of the freshwater aquifer by salt water forced the company that provides water service and sanitation to abandon the wells affected by the upconing process. Because up to now there is no other source of water to meet regional demands, it is critical to maintain the balance of hydrodynamic and hydrochemical multilayer aquifer system so as to protect the freshwater source that supplies Esperanza and Rafaela cities and their surrounding areas. It is therefore strongly recommended to monitor the spatial and temporal evolution of the areas affected by this process.

ACKNOWLEDGEMENTS

To the Esperanza City Government, Aguas Santafesinas S.A., Faculty of Engineering and Water Sciences of the National University of El Litoral, National Agency of Scientific and Technological Promotion (ANPCYT) and National Council of Scientific and Technical Research (CONICET), for their support.

REFERENCES

D´Elía M., Tujchneider O., Paris M., Perez M., Aravena R., 2005: *Técnicas isotópicas en la caracterización de sistemas de flujo subterráneo (Isotope techniques to characterize groundwater flow systems).* Revista Latino-Americana de Hidrogeología. Volume 5: 31-38. ISSN: 1676-0099. ALHSUD.

Guiguer N., Franz T., 1997: *User´s Manual for Visual MODFLOW, V.2.7.1.* Waterloo Hydrogeologic. Canadá.

Tujchneider O., Paris M., Fili M., D'Elía M., Perez M., 1998: *Protección de aguas subterráneas. Caso de estudio: Ciudad de Esperanza, República Argentina. Primera fase: Diagnóstico del sistema (Groundwater Protection. Case study: Esperanza city, Argentina. Phase I: System diagnosis).* IV Congreso Latinoamericano de Hidrología Subterránea. Memorias. Vol. 2, pp. 805–820.

Tujchneider O., Perez M., Paris M., D'Elía M., 2004: *Singularidad constitutiva de sistemas geohidrológicas de llanuras y gestión de los recursos hídricos subterráneos (Constitutive singularities of plain geohydrological systems and management of groundwater resources).* Revista Latino-Americana de Hidrogeología. Volume 5, ISSN: 1676-0099. ALHSUD, pp. 117–121.

International Association of Hydrogeologists

AGH University of Science and Technology

2-vol. set + CD
ISSN 0208-6336
ISBN 978-83-226-1979-0