# Aquifer-river interaction in the Río Velez aquifer (Málaga, Spain) based on hydrochemical ($SO_4^{2-}$, $NO_3^-$) and stable isotope ($\delta^2H$, $\delta^{18}O$) data

***Estudio de la interacción río-acuífero en el caso del Río Vélez (Málaga, España) a partir de datos hidroquímicos ($SO_4^{2-}$, $NO_3^-$) y de isótopos estables ($\delta^2H$ y $\delta^{18}O$)***

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**ABSTRACT**

*The Velez River alluvial aquifer is a suitable example for characterizing the interaction between stream water (SW) and groundwater (GW), based on the spatial and temporal variation of solutes derived from agricultural inputs ($SO_4^{2-}$ and $NO_3^-$) and stable isotope ($\delta^2H$ and $\delta^{18}O$) data. Particularly, we provide in this study a significant amount of new isotope data, both in GW and especially in SW, from water samples taken in wet and dry periods along the river and its banks. The results allow us to identify a reach of the river that shows more clearly the interaction between the two types of water. The effects of other hydrological processes, such as recycling of pumped water for irrigation, the relative concentration of GW in dry periods, as well as the local influence in the aquifer of water coming from a nearby reservoir, can also be suggested from our samplings.*

**Key-words:** *Alluvial aquifer, stable isotopes, gaining stream, irrigation recycling, Velez River (Malaga).*

**RESUMEN**

*El acuífero aluvial del río Vélez reúne buenas características para caracterizar la interacción entre aguas de río (SW) y aguas subterráneas (GW), a partir de la variación espacial y temporal de solutos derivados de actividades agrícolas ($SO_4^{2-}$ y $NO_3^-$) y de isótopos estables ($\delta^2H$ y $\delta^{18}O$). En particular, este estudio aporta nuevos datos isotópicos, tanto de GW como, sobre todo, de SW, a partir de muestras de agua tomadas en periodos húmedos y secos a lo largo del río y de sus márgenes. Los resultados nos permiten identificar un tramo del río que muestra claramente la interacción entre los dos tipos de aguas. También sugieren los efectos de otros procesos hidrológicos, como el reciclaje de agua bombeada para el riego, la concentración relativa de GW en los periodos secos, así como la influencia local en el acuífero de agua de un embalse próximo.*

**Palabras clave:** *Acuífero aluvial, isótopos estables, río ganador, reciclaje de riegos, río Vélez (Málaga).*

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## Introduction

The in-depth knowledge of the interaction between surface water (SW) and groundwater (GW) remains one important information gap in most of the hydrological management plans. This is due to the number of uncertainties that constrain the understanding of such relationship. One of the main challenges arises when there are protected ecosystems associated, as well as the necessity to achieve good quantitative status of water bodies.

The Río Velez alluvial-deltaic coastal aquifer (Fig. 1) has been classified in the last hydrological plan issued by the Andalusia Mediterranean Basin Water Board as a groundwater body (reference: 060-027) supporting protected aquatic ecosystems. It has the advantage of having a significant background of previous hydrogeological studies that have led to various monitoring networks (García Aróstegui, 1998). These studies have pointed out, among other aspects, the piezometric conditions that can favor the losing character of the river in some reaches, as well as its gaining behavior in others.

The main crops in the study area (subtropical fruits) need irrigation. The water for this comes mainly from the aquifer, although some restricted sectors use water from La Viñuela reservoir, in the headwater of the Velez River. The agricultural activities affect the quality of the GW due to the fertilization practices and the return flow processes, which increase its salinity.

Although the previous hydrochemical information of this aquifer is relatively abundant, the published data on the isotope contents of the two stable isotopes of the water molecule are very scarce: only eleven GW samples –indicating and Atlantic meteoric origin- and one from the reservoir showing clear evaporation evidences in early autumn of 2007 (Lentini *et al.*, 2009).

These circumstances make the Velez River aquifer a suitable case for the main

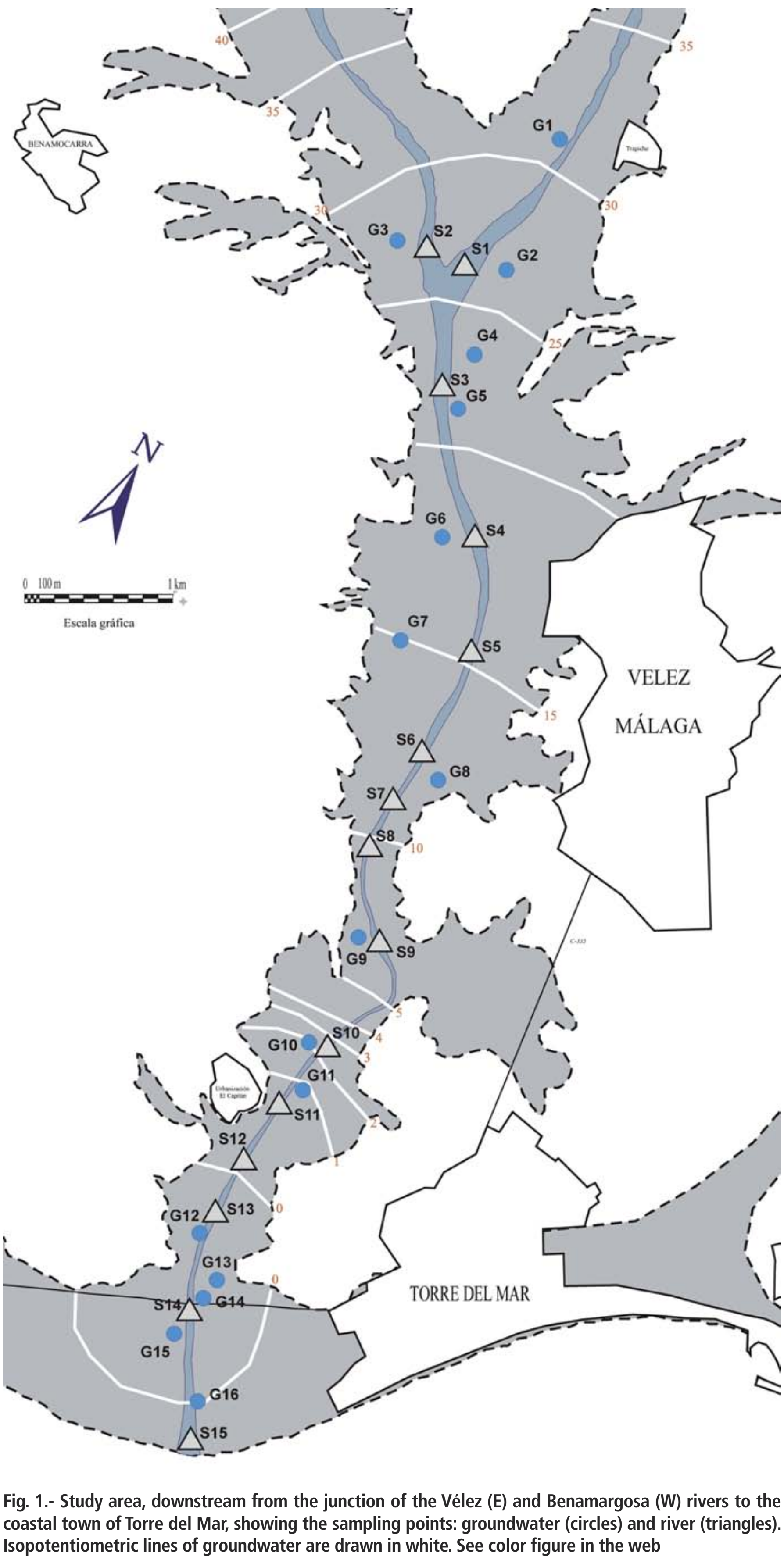


**Fig. 1.- Study area, downstream from the junction of the Vélez (E) and Benamargosa (W) rivers to the coastal town of Torre del Mar, showing the sampling points: groundwater (circles) and river (triangles). Isopotentiometric lines of groundwater are drawn in white. See color figure in the web**

*Fig. 1.- Área de estudio, aguas abajo de la confluencia de los ríos Vélez (E) y Benamargosa (O) hasta la localidad costera de Torre del Mar; se indican los puntos de muestreo: aguas subterráneas (círculos) y aguas de río (triángulos). Las líneas isopiezas del acuífero están dibujadas en blanco. Ver figura en color en la web.*

objective of this study: characterizing the interaction between SW and GW, based on the spatial variation of solutes derived from agricultural inputs (sulfate and nitrate) and stable isotope ( $\delta^2$H and $\delta^{18}$O) data of both the GW and the SW from three sampling campaigns in different hydrological conditions.

## Methodology

Three sampling campaigns were carried out in March, June and November 2013. March and November samplings can be considered as representative of wet and dry periods, respectively, because the rain during September and October that year was abnormally low. The monitoring network (Fig. 1) consisted of 31 points, 15 of which are SW and 16 are GW. During the field sampling the unstable parameters (EC, T, pH and DO) were measured on the field. In parallel, water samples from stream water and GW -from pumping wells and a few of monitoring boreholes- were collected and then measured following standard protocols in the laboratories of the Malaga University. Major and minor components, stable isotopes of water, sulfate and dissolved inorganic carbon were determined. In the present study we will consider only the following variables: $SO_4^{2-}$, $NO_3^-$, $\delta^2$H and $\delta^{18}$O.

The studied portion of the aquifer starts in the sector of the confluence of the rivers Velez (E) and Benamargosa (W), as can be seen in figure 1. Then the sampling points go sequentially downstream along the banks of the river until its mouth.

During the dry period of November both the Benamargosa River and most of the Velez River were dry, so we were only able to collect SW samples from point S6 downwards.

## Results and discussion

Figure 2 shows the spatial evolution of the studied variables in the November sampling. From the headwater sector until a distance of approximately 5 km from the coast, there is a progressive increase of the contents of the two considered ions in GW. This seems to reflect the influence of recycled water as far as we get into the area where the agricultural activity is more intense. The recycling process also involves evaporation, and this is the reason for the overall enrichment in the isotope contents along this

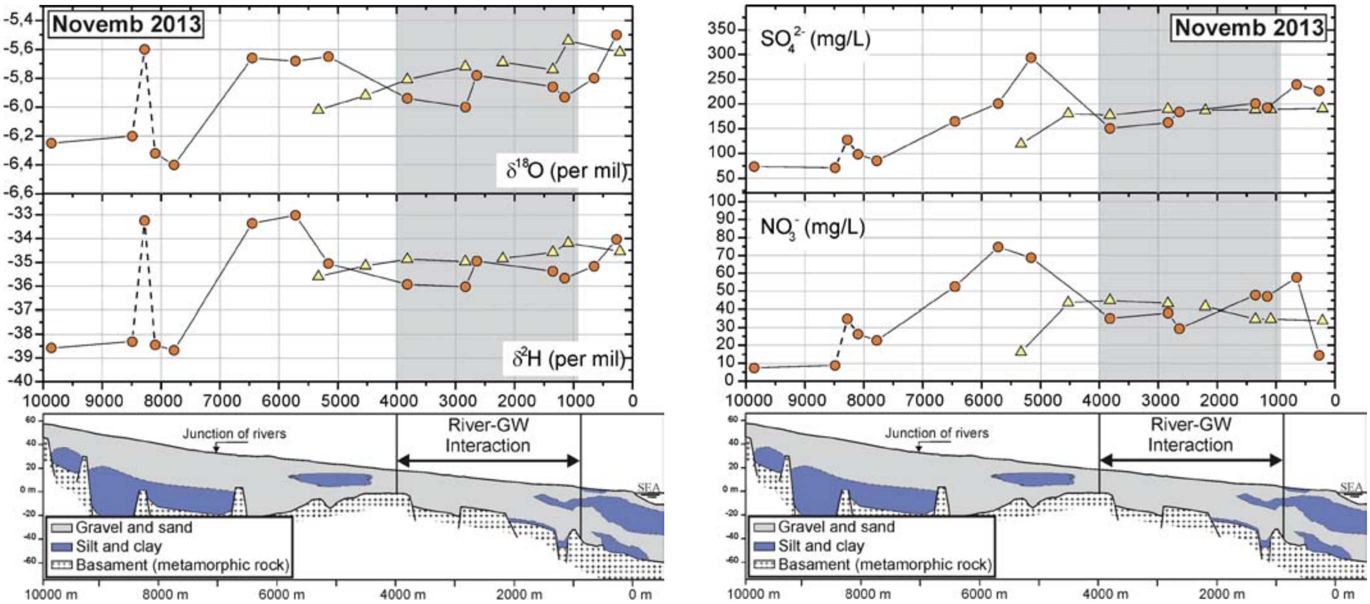


**Fig. 2.- Longitudinal cross sectional sketch of the aquifer along the Velez river showing the spatial evolution of the studied variables during one of the samplings (dry period). See color figure in the web**

***Fig. 2.- Corte longitudinal del acuífero a lo largo del río Vélez con indicación de la evolución espacial de las variables estudiadas durante uno de los muestreos (periodo seco). Ver figura en color en la web.***

reach. In this part of the graph there is a GW sample that shows a sudden increase of its isotope content, and this is interpreted as a local effect of irrigating the adjacent crop with reservoir water.

At about 5 km from the coastline, SW is less concentrated than the GW in this sector. It must be pointed out that during this dry period SW is in fact water of subterranean origin cropping out in the river bed. This GW discharge likely involves deeper flows in the aquifer, and then shows less influence of irrigation return flows. From 4 km to 1 km from the coastline there is great similarity in the contents of all the studied variables (marked in grey in Fig. 2). The interaction between SW and GW in this sector becomes more significant. The GW discharge to the river bed is facilitated by the reduction in the thickness of the alluvium (see cross section in Fig. 2). Finally, the net decrease in the $NO_3^-$ content of the GW sample near the coast is likely to be induced by denitrification processes (Vadillo *et al.*, 2007).

During the March sampling, three groups can be distinguished according to their relative isotope contents (Fig. 3). The group that shows more depleted values defines the sector of the junction between the Benamargosa and Velez rivers. It is worth to note the difference in the contents of each SW, being more depleted in the Velez as a consequence of the higher altitude of its headwater basin. A second group unifies groundwater (G10, G11, G12 and G13) and river water samples from the central sector of the aquifer. Here is where the aquifer experiences the mentioned narrowing, and this evidences the GW/SW interaction. Finally, the more enriched GW group indicates the influence of the Benamargosa River (S2) that conditions the isotopic composition of the GW in most of the right bank of the Velez River alluvium (G3, G6, and G7). This isotopic composition is also found in two samples near the mouth of the river (G14 and G16).

November sampling (Fig. 3) has the highest number of points, particularly in the second group. It shows the isotope enrichment by the recycling of pumping and infiltration of the evaporated water into the aquifer, as can be noticed by the alignment of samples along the evaporation line (slope 4-5). The similarity between SW and GW indicates that GW is supplying the flow along the river.

A $SO_4^{2-}$- $\delta^{18}O$ plot for the March sampling (Fig. 4) illustrates about the difference of $SO_4^{2-}$ concentration between SW and GW samples: the average concentration in GW is 165 mg/L opposite to 115 mg/L of SW. It also shows the isotopic enrichment of water due to the recycling of pumped GW.

Samples from the upper part of the

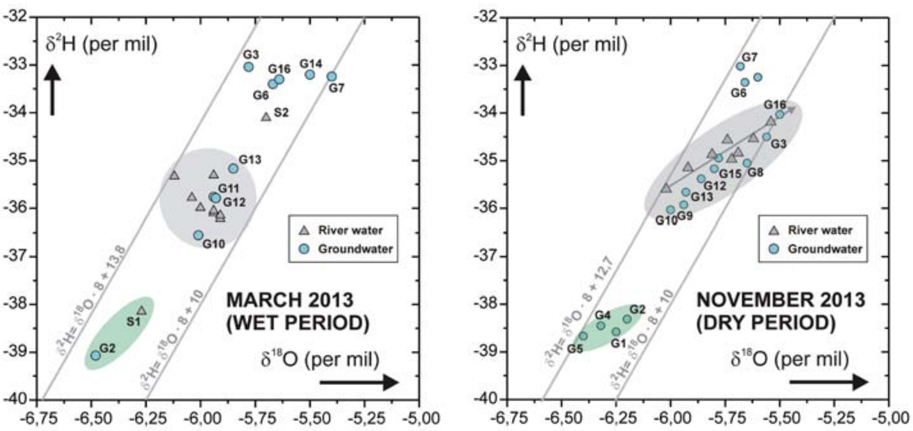


**Fig. 3.- Plots of the isotope contents of the samples in different hydrological conditions. Parallel lines indicate meteoric conditions. See color figure in the web**

***Fig. 3.- Gráficos de los contenidos isotópicos de las muestras en dos situaciones hidrológicas diferentes. Las líneas paralelas indican condiciones meteóricas. Ver figura en color en la web.***

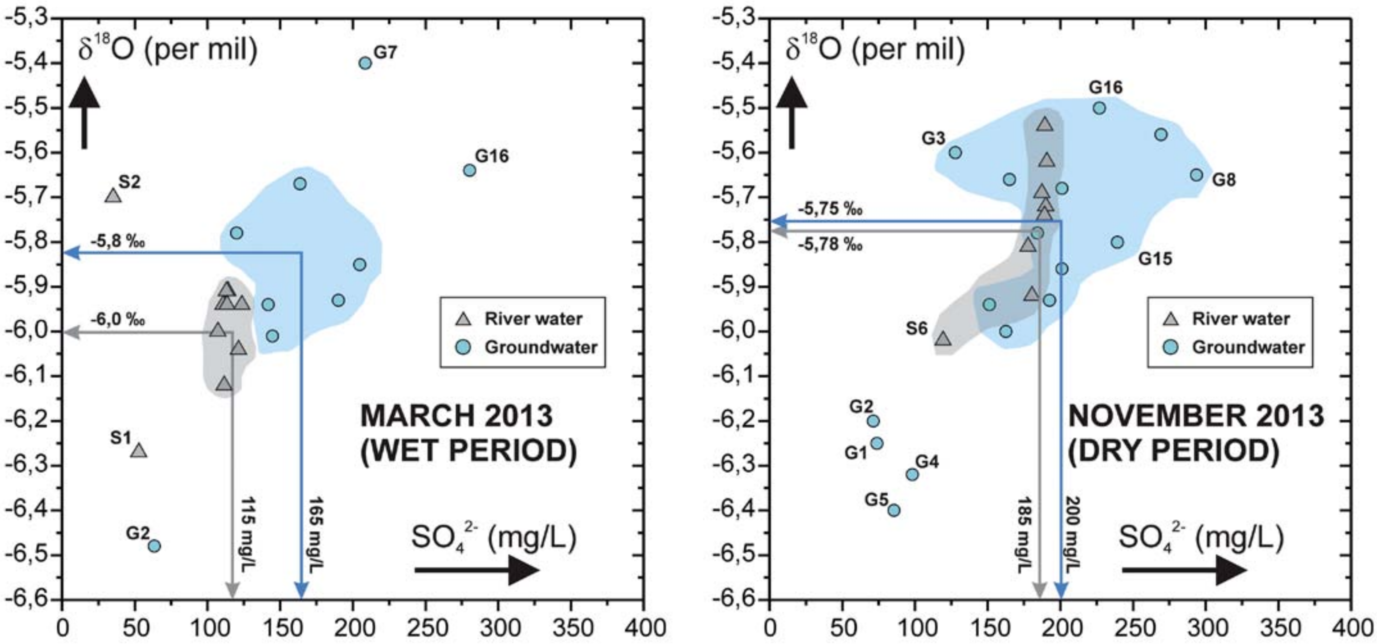


**Fig. 4.- Plot of δ18O versus sulphate contents of the samples in one of the samplings campaigns. See color figure in the web**

***Fig. 4.- Gráfico de los contenidos de δ18O respecto de los sulfatos en uno de los muestreos. Ver figura en color en la web.***

study area (S1, S2 and G2) have the lowest $SO_4^{2-}$ contents, as the agricultural pollution is less intense in this sector.

The same plot for November sampling shows an increase of $SO_4^{2-}$ concentration for GW samples (165 mg/L to 200 mg/L) and for SW samples (115 mg/L to 185 mg/L). This reflects the dryer condition of the sampling period. The isotopic signature of the SW now approaches the value of the GW in March (about -5,8 ‰). This again confirms the spatial interaction between the two types of water.

## Conclusions

This study provides a significant amount of new data on the isotope ($\delta^2H$ and $\delta^{18}O$) contents of the Velez River groundwater body (Malaga province), and especially of the stream water, in samples taken in three different campaigns following the main flow directions. The data set includes contents in two dissolved species ($SO_4^{2-}$, $NO_3^-$) linked with the impact of the agricultural practices –the main wealth of the study area- on the water resources.

There is a general process of groundwater concentration along the flow, which becomes more intense in the dry periods. The increase in solutes comes mainly from the recycling of pumped water used for irrigation and then re-infiltrated. This imposes a diffuse isotopic imprint to the groundwater due to the evaporative fractionation. Besides, there is another local effect of isotopic enrichment due to crop irrigation with water from the La Viñuela reservoir.

Hydrochemical and isotopic composition of the aquifer in the upper part of the study area is conditioned by the infiltration of the Velez river water. The river composition in the central sector of the aquifer is influenced by its gaining character. It is in this sector where the interaction between both types of waters is more intense, as can be deduced from the major ionic and isotopic similarities between them.

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