Groundwater temperature and electrical conductivity as tools to characterize flow patterns in carbonate aquifers: The Sierra de las Nieves karst aquifer, southern Spain

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Abstract In carbonate massifs, flow patterns are conditioned by karstification processes which develop a conduit network and preserve low permeability microfractured blocks. The Sierra de las Nieves karst massif (southern Spain) is subjected to a given climatic and geological context, and thus it is possible to analyse the spatial and temporal variability of the water temperature and electrical conductivity at its main karst outlets, which display different responses to rainfall episodes. In this experimental field area, conduit flow and diffuse flow drainage patterns have been distinguished by combining groundwater temperature and electrical conductivity data. Both parameters show large variations in water coming from conduit flow systems and low variations in water drained by springs draining diffuse flow systems. However, groundwater temperature displays the smallest variations, which seems to indicate that this parameter is less sensitive as regards characterising the degree of karstification, which is a key question in characterising the aquifer functioning.

Keywords Karst · Groundwater temperature · Electrical conductivity · Conduit and diffuse flow systems · Spain

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Background

Flow patterns within carbonate aquifers are conditioned by karstification processes. These processes increase the bulk permeability of the massif, developing a conduit network of high hydraulic conductivity, with short water-residence time, and preserving microfractured blocks with long water-residence time. Thus, karstification provokes flow heterogeneity, increasing the permeability contrast between conduit flow and diffuse flow systems. Indirect indicators such as electrical conductivity, hydrochemistry and discharge have been used to characterise these systems. Temperature and electrical conductivity are useful in this respect, and the two parameters are compared in this work, as suggested by Martin and Dean (1999) and Birk et al. (2002).

Groundwater temperature is a physical parameter which is widely used in hydrogeological investigation. Its usefulness is evident, for instance, in the study of seawater intrusion in coastal aquifers (Tulipano and Fidelibus 1995), as well as in aquifer contamination studies (Malard and Chapuis 1995). In other cases, groundwater temperature has been used to determine forms of heat transport in karst aquifers (Bundschuh 1993; Liedl and Sauter 1998).

Other researchers (Andrieux 1978; Crowther and Pitty 1982; Roy and Benderitter 1986; Lastennet 1994; Martin and Dean 1999; Birk et al. 2004) have used water temperature jointly with other natural hydrodynamical and hydrochemical responses, as additional information to characterise the different flow types and the structural organisation of drainage patterns in karst aquifers. Thermal investigations have been done previously in karst areas in southern Spain (Cruz Sanjulián and García-Rossell 1975; Lopez-Chicano et al. 2001).

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The Sierra de las Nieves karst massif (southern Spain) is an interesting area for analysing the thermal behaviour of karst springs, several of which are subjected to the same climatic and geological contexts. The main karst outlets of this massif display various responses to rainfall episodes, enabling us to analyse the spatial and temporal variability of the water temperature. In addition, the hydrogeological behaviour of this area is well known from previous works (Liñán et al. 1999; Andreo et al. 2004; Liñán 2005). This report highlights the potential of groundwater temperature as a mean of furthering our knowledge of the behaviour of karst aquifers, and compares the results obtained from temperature data with other parameters such as electrical conductivity.

Characteristics of the experimental field area

The Sierra de las Nieves aquifer system (Fig. 1) is located in southern Spain, (Andalusia, Malaga province) in a zone of high environmental interest, and is classified as a biosphere reserve by UNESCO. From a climatic point of view, the monitoring network included nine stations with historical records of precipitation, between 1964 and 1999, and the temperature records of five stations, most of which covered the period 1982–1999 (Liñán 2005); however, only some of these stations are considered in the present work (Fig. 1)—these are sufficiently representative of the variations of these parameters in the study area. The annual mean temperature values are (Table 1): 18.5°C at T-1 (380 m altitude), 10.8°C at T-2 (1,290 m altitude), 16.3°C at T-3 (695 m) and 15.7°C at T-4 (769 m). Concerning precipitation, the annual mean values are the following (Table 1): 600 mm in P-1 (380 m), 1,163 mm in P-2 (1,290 m) and 1,056 mm in P-3 (695 m). Thus, the study area is subjected to average yearly temperatures lower than 15°C, and precipitation of about 1,000 mm (Liñán 2005).

The air temperature and precipitation are mainly correlated with altitude, and correspond to a –0.8°C/100 m and 65 mm/100 m gradient, respectively. Other factors such as the orientation of the relief and the vicinity both to the Mediterranean Sea and the Atlantic Ocean are of less importance in regards to the scale of the study area (Liñán 2005). During an average hydrological year, precipitation and temperature display the opposite trend (Fig. 2): the rainfall is higher in winter and lower in summer, whilst the temperature is higher in summer and lower in winter when it may snow on the higher part of the mountain.

The aquifer rock is mainly formed by Triassic dolomites and limestones (Fig. 1), with a thickness of 1,200 m. The general structure is an overturned syncline, which is affected by normal N130°E faults that compart-

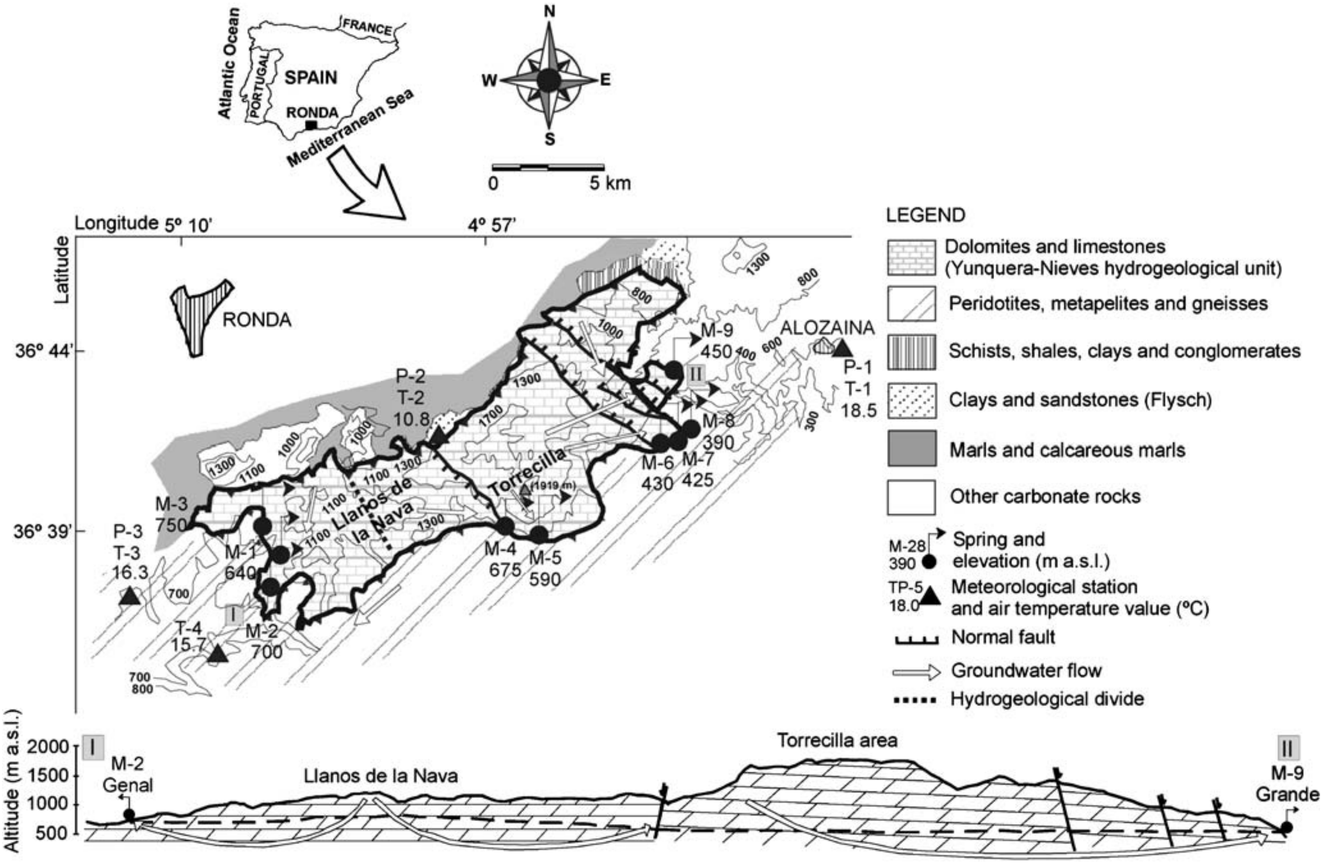

Fig. 1 Location of the experimental field site and a hydrogeological sketch including hydrogeological map and cross-section

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Table 1 Annual mean values of precipitation and air temperature in the meteorological stations of the studied area

	Stations P-1 and T-1 (380 masl)	Stations P-2 and T-2 (1,290 masl)	Stations P-3 and T-3 (695 masl)	T-4 (769 masl)
Precipitation				
P (mm/year)	600	1,163	1,056	–
NY	51	39	56	–
Air temperature				
T (°C)	18.5	10.8	16.3	15.7
NY	19	12	9	14

NY number of years. For temperature (*T*) and precipitation (*P*), the reference and the altitude are indicated for each meteorological station

ment the folded structure, originating a horst-graben pattern (see cross section in Fig. 1).

Lithology and geological structure determine the characteristic relief of the area, with numerous exokarstic and endokarstic forms (sinkholes, karren, swallow holes, shafts, caves). Two well differentiated areas are separated by a major N130°E fault (Fig. 1): to the West, the Llanos de la Nava half-polje (graben), and, to the East, the Torrecilla peak area (horst).

Data on the water table (altitude of the springs), together with isotope, hydrochemistry and tracer test results (Liñán et al. 1999; Andreo et al. 2004; Liñán 2005) permit the identification of a hydrogeological divide in the Llanos de la Nava sector and mark the estimated groundwater flow path (Fig. 1). Thus, an approximation to the catchment area of the springs can be inferred.

Recharge of the Sierra de las Nieves is achieved by infiltration of rain and snowmelt waters, and discharge

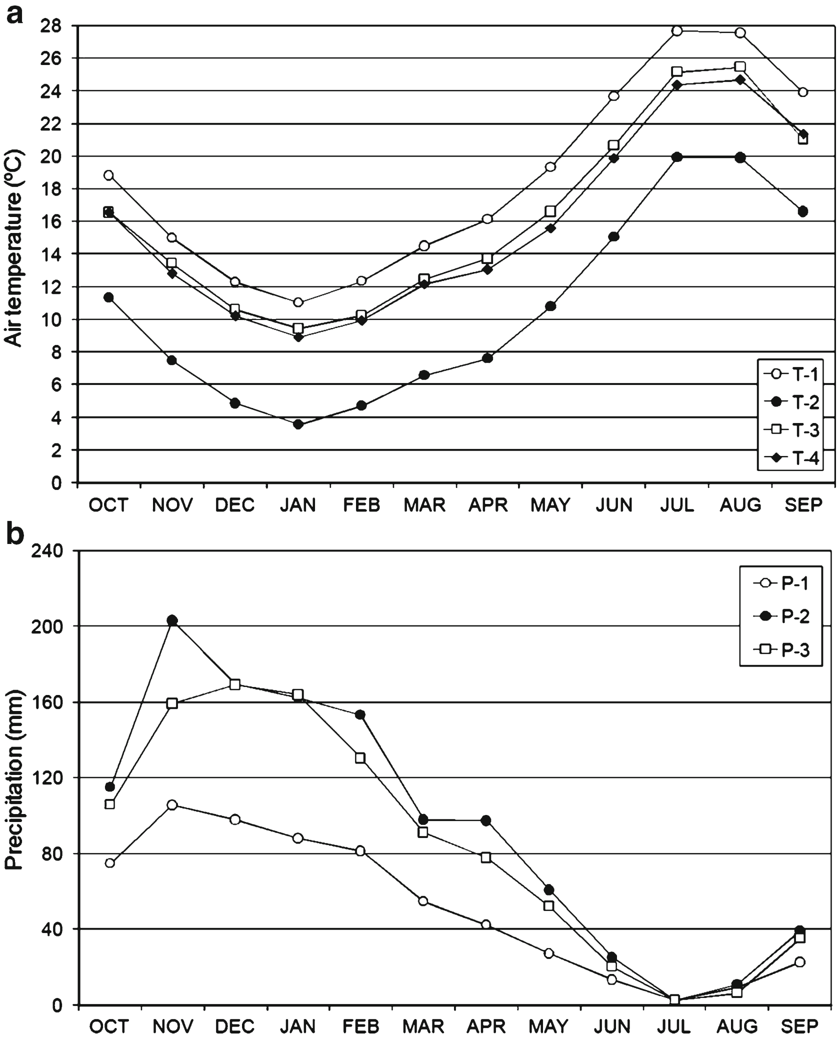

Fig. 2 Monthly temperature (**a**) and precipitation (**b**) variations at the meteorological stations of the studied area during an average year. See location in Fig. 1

Table 2 Average values and coefficient of variation of temperature, electrical conductivity and discharge of groundwater

Names of springs	Algoma	Genal	Granados	Verde	C. Moro	Piloncillo	C. Fuente	Cisnera	Grande
Reference numbers	M-1	M-2	M-3	M-4	M-5	M-6	M-7	M-8	M-9
Altitude (masl)	640	700	750	675	590	430	425	390	450
Water temperature									
T (°C)	15.5	13.4	14.4	12.9	15.1	18.6	19.9	22.5	13.8
V (%)	0.7	1.8	2.0	1.9	3.3	0.9	3.5	0.7	3.9
NT	27	50	10	47	33	18	14	39	48
Electrical conductivity									
EC (μS/cm)	357	350	309	337	301	407	448	533	370
V (%)	1	5	2	3	8	5	3	3	19
NC	27	257	10	223	34	18	14	40	410
Discharge									
Q (L/s)	110	400	20	700	70	16	10	60	625
V (%)	131	184	88	158	160	55	–	129	86
NQ	30	534	10	1,188	35	8	1	36	336

NT total number of temperature measurements; *NC* total number of electrical conductivity measurements; *NQ* total number of discharge measurements (all cases apply to the period 1995–1999); *V* coefficient of variation

occurs at three main outlets situated to the south (Fig. 1): Río Grande (M-9, average discharge $Q=625$ L/s), Río Verde (M-4, $Q=700$ L/s), and Río Genal (M-2, $Q=400$ L/s). These springs account for most of the discharge from the Sierra de las Nieves massif. Other springs are Algoma (M-1, $Q=110$ L/s), Cuevas del Moro (M-5, $Q=70$ L/s) and Cisnera (M-8, $Q=60$ L/s), representing a minor part of the discharge draining the study area.

Hydrographs of Grande (Fig. 3a), Verde (Fig. 4a) and Genal (Fig. 5a) display rapid and important discharge increases (several L/s to several m^3/s) as a response to rainfall episodes, with an input/output delay (transit time) shorter than 1 day. The Río Verde hydrograph displays convexities during the recession (Fig. 4a, see arrow within), which have been interpreted as hydraulic saturation phenomena (saturation of karst conduits) and gradient inversion within the saturated zone of the aquifer (Liñán 2005). At the Algoma (M-1) and Cisnera (M-8) springs, discharge increases induced by rainfall are less marked (Figs. 6a and 7a), and hydrochemical variations are more buffered than at the three main outlets, even for longer record periods (Liñán 2005).

All the springs drain water with a low mineralisation (301–533 μS/cm) and a very similar chemical composition: calcium or calcium-magnesium bicarbonate. During recharge episodes, dilution processes are displayed by a decrease in electrical conductivity (Figs. 3, 4, 5, 6, 7), due to the mixing of poorly mineralised rainwater with groundwater. The rate of dilution varies, according to the spring considered, the highest being at Grande and Cuevas del Moro, intermediate at Genal and Verde, and minimum at Cisnera and Algoma.

Methodology

From 1995 until 1999, groundwater temperature was monitored at nine springs, with a fortnightly average frequency. Simultaneously, electrical conductivity and discharge were measured, and samples taken for stable isotope (δ^{18}O and δ^{2}H) and major ion measurements, following international recommendations, although these latter data are not considered in the present work. To determine discharge, instantaneous measurements were realised with a propeller flowmeter, except at springs equipped with gauging stations, where continuous discharge measurement was available. Sampling frequency depended on the importance of spring discharge and on the variations in its responses such as flow rate, temperature, electrical conductivity, and even hydrochemistry and isotopes considered in previous studies (Liñán et al. 1999; Andreo et al. 2004) and for a longer period (Liñán 2005). Thus, in the M-9, M-4 and M-2 springs, daily electrical conductivity measurements are available. To avoid the influence of the air temperature, measurements of the physico–chemical parameters were performed at the point of emergence by means of a WTW conductivimeter equipped with a temperature probe (sensitivity: 1 μS/cm and <0.1°C). The sensitivity of the temperature probe was relatively low and, for this reason, the electrical conductivity was recorded to compare the temperature measurements. Values both of temperature and electrical conductivity were noted when they were stable in the display of the probe, which normally occurred after a few seconds.

It is well known that electrical conductivity (EC) depends on the temperature, and for this reason the measurements taken must be reported as corresponding to a standard temperature. According to Hayashi (2003), an arbitrary constant is commonly used for temperature compensation, assuming that the electrical conductivity-temperature relation is linear; however, the present one was slightly nonlinear—nevertheless, the linear equation approximates reasonably well, in a temperature range of 0–30°C. The EC values measured in the present study are automatically reported by the conductivimeter as corresponding to a standard temperature of 20°C. The temperature values ranged from 12 to 23°C, and so the linear compensation of the WTW conductivimeter used can be applied.

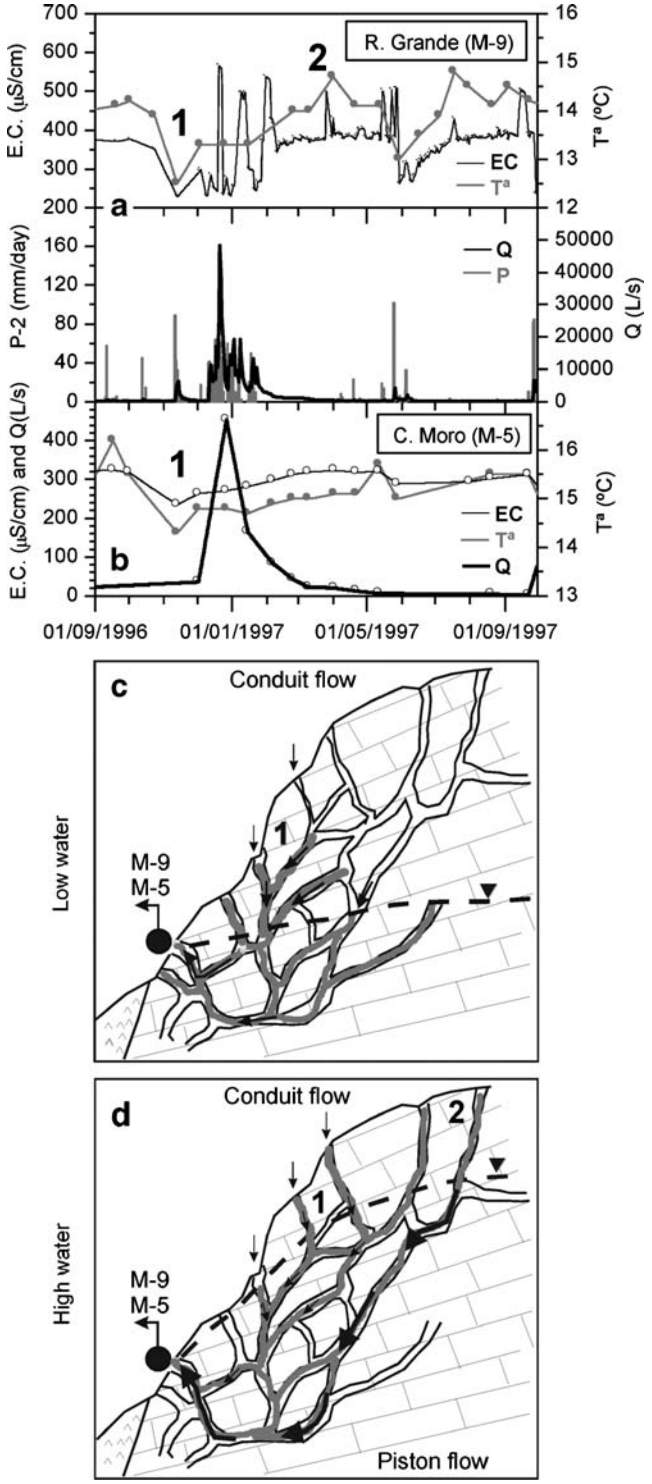

Fig. 3 **a** Temporal evolution of electrical conductivity and groundwater temperature in the upper subplot (*top half*), and discharge and precipitation in the middle subplot recorded at the Río Grande (*M-9*) spring (*bottom half*); **b** electrical conductivity and groundwater temperature versus discharge at the Cuevas del Moro (*M-5*) spring. **c** Simplified sketch of the aquifer functioning during low water conditions and **d** high water conditions, for the Río Grande (*M-9*) and Cuevas del Moro (*M-5*) springs

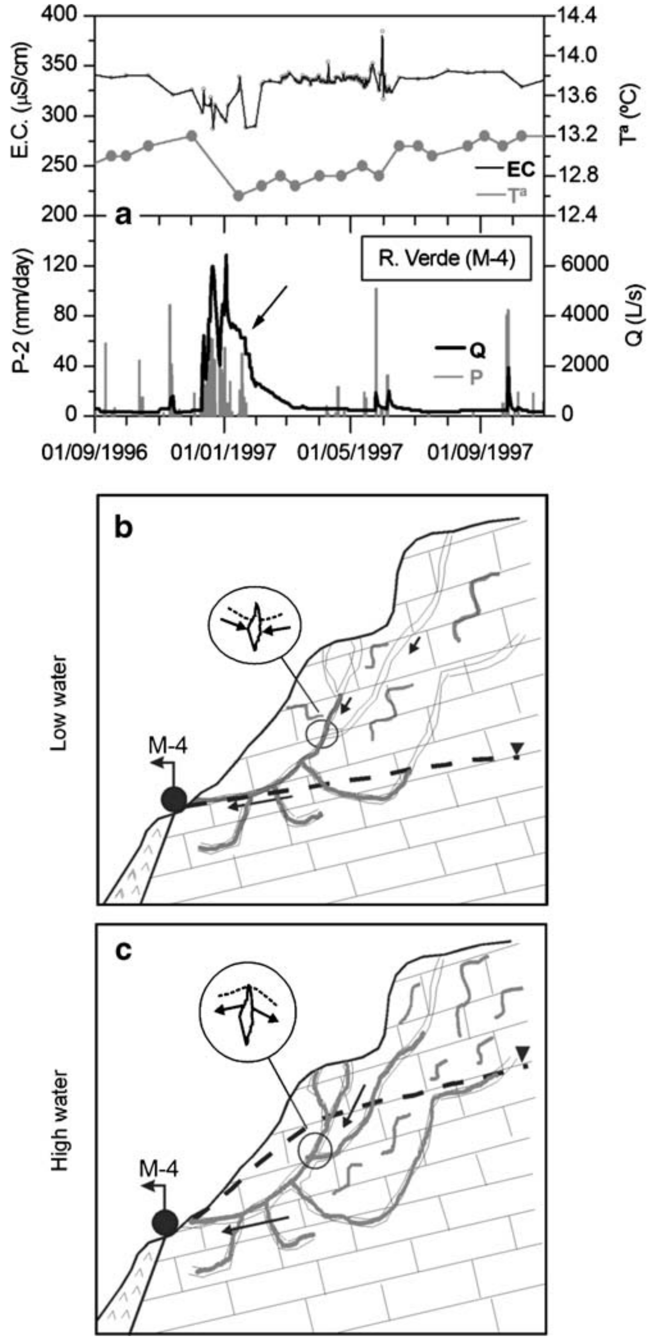

Fig. 4 **a** Electrical conductivity and groundwater temperature in the upper subplot (*top half*) and discharge and precipitation in the lower subplot recorded at the Río Verde (*M-4*) spring (*bottom half*). **b** Simplified sketch of the aquifer functioning during low water and **c** high water conditions

Results

Geographic distribution of groundwater temperature

Spring discharge average temperature (Table 2) ranged from 12.9°C at the Río Verde spring (M-4) to 22.5°C at Cisnera (M-8) over the sampled period. The highest water temperatures were measured in a group of springs called Piloncillo (M-6), Cañada Fuente (M-7) and Cisnera (M-8), all located at the NE border of the system (Río Horcajos

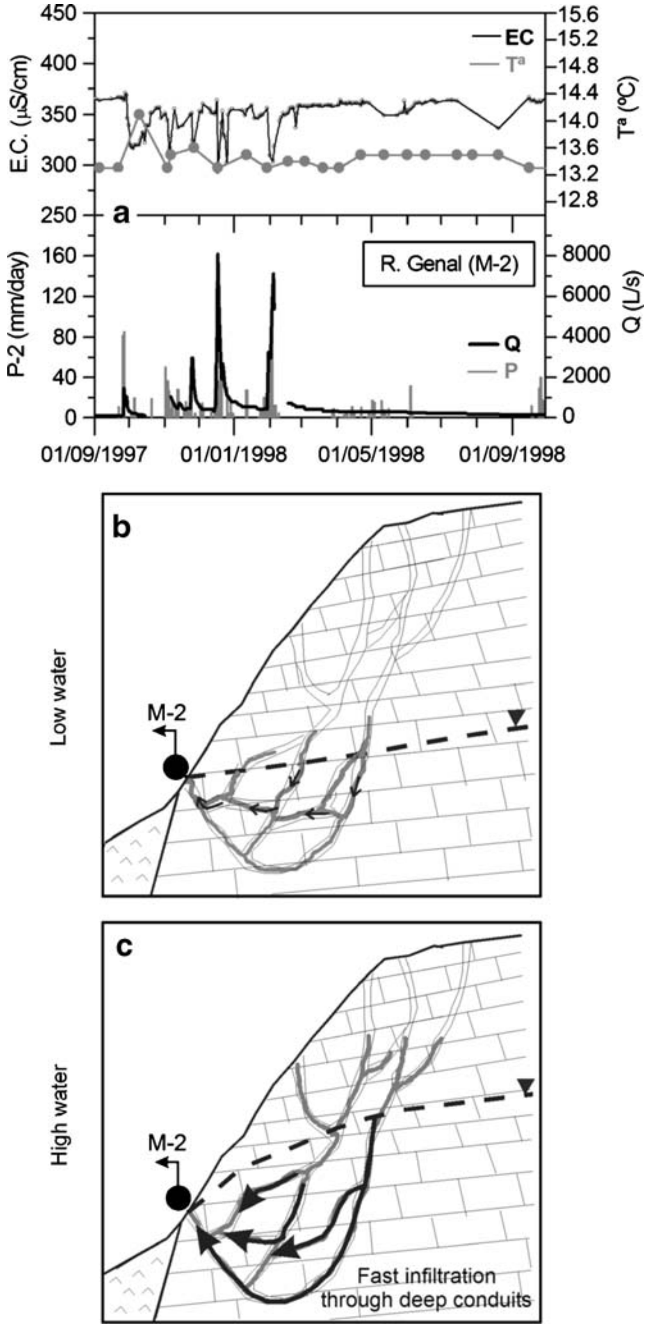

Fig. 5 **a** Electrical conductivity and groundwater temperature in the upper subplot (*top half*) and discharge and precipitation in lower subplot recorded at the Río Genal (*M-2*) spring (*bottom half*). **b** Simplified sketch of the aquifer functioning during low water and **c** high water conditions

area). One of these springs is clearly hypothermal (M-8), meaning its temperature is a few degrees above the mean value of the environment. Thus, the average temperature of this spring water is 4°C higher than the highest value of the air temperature recorded at the catchment area.

A negative linear correlation exists between the altitude and the water temperature of the spring (Fig. 8a), corresponding to a –1.8°C/100 m thermal gradient. The Río Grande spring (M-9) presents a temperature significantly lower than that forecasted from its altitude and the altitude of its catchment area, a case similar to that described by Mudry (1987) at the Montant spring (Jura), where groundwater drained by the spring is situated higher than the outlet. The other springs studied have groundwater temperatures that can be considered as consistent with their altitudes, and those recorded in their catchment areas according to the data in Table 2.

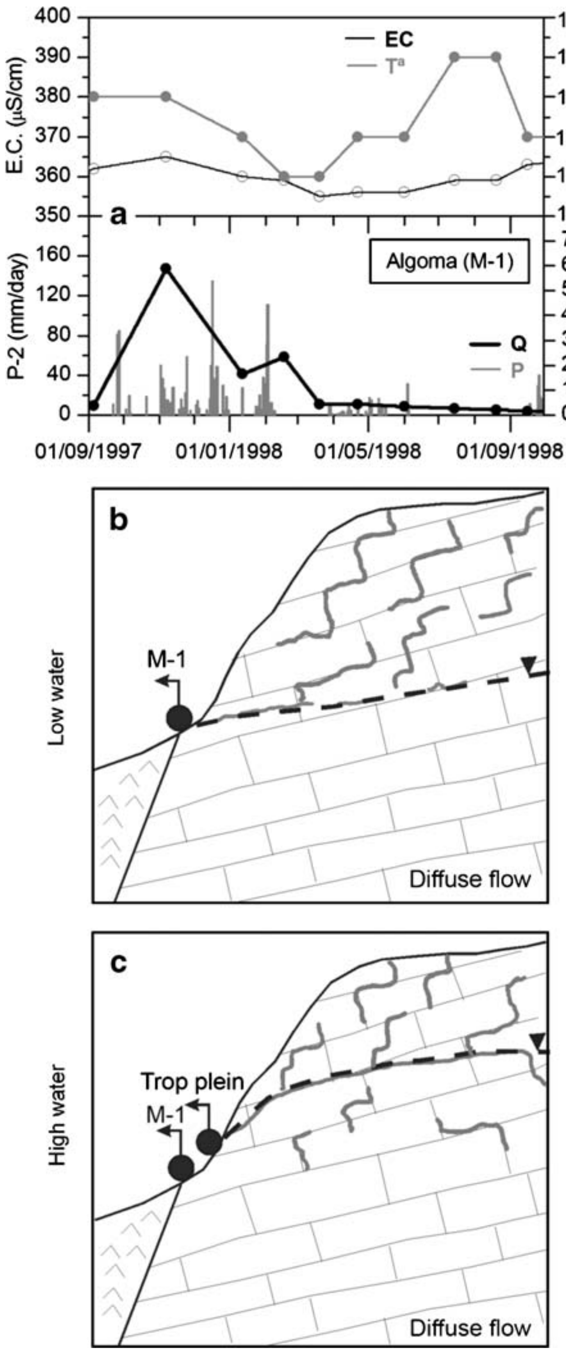

Fig. 6 **a** Electrical conductivity and groundwater temperature in the upper subplot (*top half*) and discharge and precipitation in the lower subplot recorded at the Algoma (*M-1*) spring (*bottom half*). **b** Simplified sketch of the aquifer functioning during low water and **c** high water conditions

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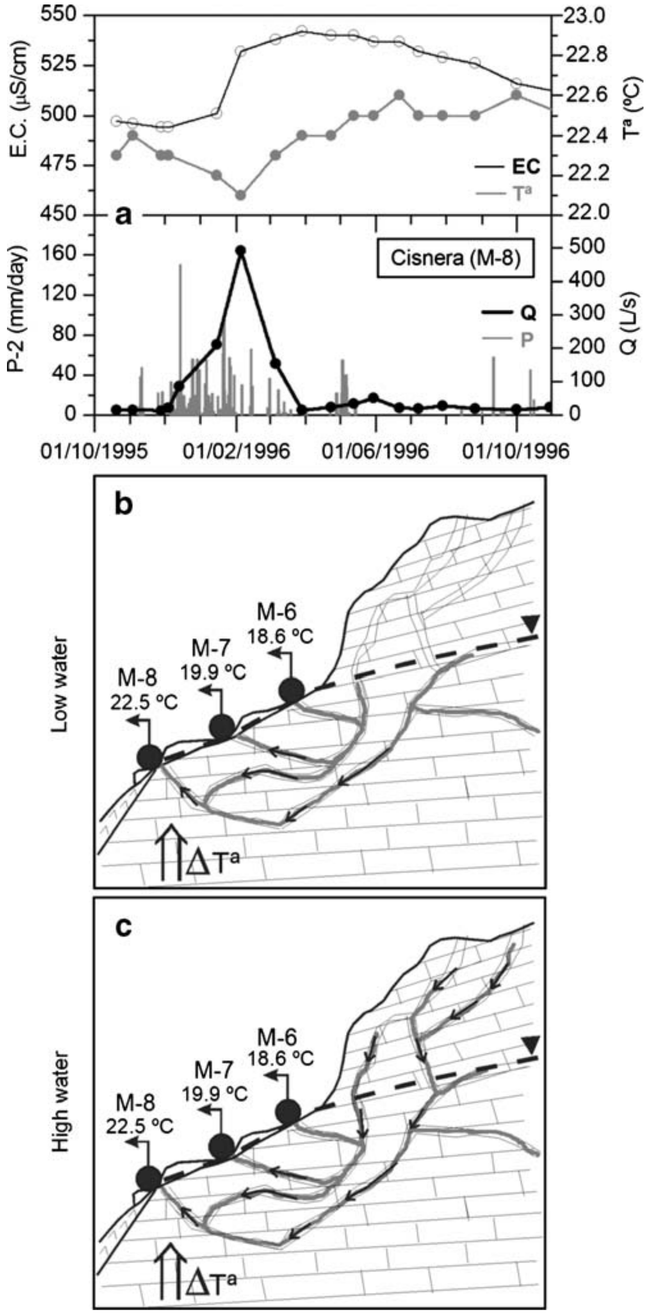

Fig. 7 **a** Electrical conductivity and groundwater temperature in the upper subplot (*top half*) and discharge and precipitation in the lower subplot recorded at the Cisnera (*M-8*) spring (*bottom half*). **b** Simplified sketch of the aquifer functioning during low water and **c** high water conditions

Temporal variations in temperature

Figures 3, 4, 5, 6, 7 display the variations in water temperature versus time at the main springs. At all the springs, except Genal (M-2), temperature decreased during rainfall episodes, with a magnitude varying from one spring to another. Thus, the Río Grande spring (M-9) displayed the maximum difference (about 2°C in Fig. 3a), followed by Cuevas del Moro (M-5) varying between 0.7 and 2°C (Fig. 3b). The Algoma (M-1) and Cisnera (M-8) springs are the least variable (0.2–0.4°C) as can be seen in Figs. 6a and 7a. At the Verde spring (M-4), temperature variations are intermediate, about 0.6°C (Fig. 4a). All these variations are consistent with the EC variations detected.

Springs M-9 and M-5 display the biggest and most rapid variations in groundwater temperature and EC, particularly the former. Both springs show the lowest values of groundwater temperature (and EC) in the autumn and spring. At both springs, an increase in discharge during these periods of low recharge is correlated with a decrease in temperature and EC of the groundwater, reaching the absolute temperature minimum before the other springs, even before the flood peak (1 in Figs. 3a and b). At the Río Grande spring, dilution processes follow a piston effect, which is the origin of high EC values at the spring (2 in Fig. 3a).

At the Río Verde spring (M-4), discharge increases after rainfall (Fig. 4a), whilst EC and temperature decrease, but this response is slower than for the above-mentioned springs. The transit time of the response to the recharge is greater than in the previous springs. The fall in the physico–chemical parameters takes place in a more buffered way, and the temperature recovery during the peaks of flood episodes, similarly, is very slow: 8–12 months are necessary to reach the temperature observed before the recharge episode.

At the Río Genal spring (M-2) discharge increases and EC decreases during rainfall episodes (Fig. 5a). The temperature baseline remained practically constant (13.3°C) during the whole observation period, except during and after the discharge increases, when warmer water peaks (13.5–14.4°C) appear at the spring. Correlated to these

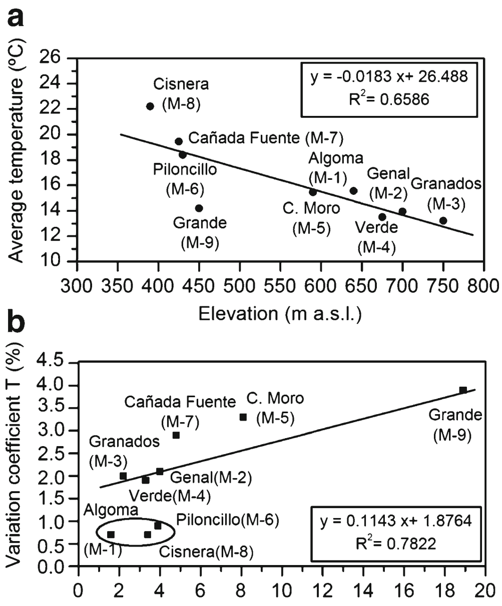

Fig. 8 **a** Relationship between groundwater temperature and elevation. **b** Coefficient of variation of groundwater temperature versus coefficient of variation of electrical conductivity.

peaks, a decrease in EC, alkalinity and the calcium content of water has been observed (Liñán 2005).

The Algoma spring (M-1) responds more slowly to rainfall, and the transit time of recharge water is long. Recharge episodes induce discharge increases, and falls in temperature and EC at the spring, but they appear in a more buffered form, reaching the discharge peak (Fig. 6a). The recovery of both parameters after flood episodes occurs in a very slow way (9–11 months). During flood episodes, the Cisnera thermal spring (M-8) drains more mineralised, but colder waters, whose temperature minima fit the discharge peaks (Fig. 7a).

Variation coefficients and frequency curves

As a general observation, the springs with high variations in discharge have high variations in groundwater temperature and EC, and conversely springs with low discharge variations have smooth variations in the aforementioned parameters (Figs. 3, 4, 5, 6, 7, 8b, Table 2). Thus, the Río Grande spring (M-9) and the Cuevas del Moro spring (M-5) show the highest variations, whilst Algoma (M-1) and Cisnera (M-8) display the lowest variations and Genal (M-2) and Verde (M-4) present intermediate variations. The groundwater temperature shows lower coefficients of variation than does EC (Table 2). Obviously, this result depends on the sensitivity of the probes used (<0.1°C in the present work), but temperature seems less sensitive in showing the karst network development, at least in the experimental site of the present investigation. This is in agreement with the results obtained by Birk et al. (2004), who concluded that EC is better situated for the determination of time lags than is the groundwater temperature.

The coefficient of variation of physical–chemical parameters of groundwater proposed by Shuster and White (1971) is not enough to deduce the functional karstification of carbonate aquifers. Frequency distribution is necessary, according to Bakalowicz (1977). Thus, the Algoma spring (M-1) and the Cisnera spring (M-8) display curves with a single high mode and a small range of values (Fig. 9). Conversely, the curves of the Río Grande spring (M-9) and the Cuevas del Moro spring (M-5) show several peaks, several modes and large ranges of variation. The EC frequency curves (Fig. 9a) show greater variability than does the groundwater temperature (Fig. 9b), which seems to corroborate the hypothesis that temperature is less sensitive than electrical conductivity at the scale of the study area and with the probes used.

Discussion

Discharge, EC and temperature variations of karst groundwaters, which occur as a response to recorded rainfall episodes, demonstrate effective karstification in the carbonate massif studied, which enables the mixing of the groundwater stored in the aquifers with infiltration or "new" rainwater, colder and less mineralised. The fact that the outlets of the same carbonate massif display different responses to the same input highlights differences in the degree of karstification of its aquifer systems and consequently in their hydrogeological behaviour. The degree of karstification influences the flow-path length, water velocity and heat exchange. In particular, heat extracted by groundwater, and temperature both serve as a tracer to identify flow patterns in groundwater basins (Anderson 2005).

In the system that is drained by the Río Grande (M-9) and Cuevas del Moro (M-5) springs, the most rapid and intense EC and temperature variations were recorded, and frequency curves with several peaks and large ranges of variation were obtained (Fig. 3a, b and 9). The seasonal periodicity of the environmental temperature was not clearly detected in the spring groundwater temperature. These data are interpreted as the consequence of high velocity (short transit time) of recharge water through a well-developed karst network (Figs. 3c and d); even if the flow path is relatively long, the heat exchange is low. In low water periods, the spring is recharged by colder rainwater infiltrated in the hillside (1 in Fig. 3c). In high water periods, a rapid and concentrated infiltration occurs in recharge areas situated at a higher elevation (2 in Fig. 3d) provoking a change in the water heads in the conduit system (Genthon et al. 2005) that push (piston effect) deeper waters, with a longer residence time than those which usually flow through the saturated zone, to the Río Grande spring. A similar model has been proposed by Lastennet (1994) for the Ventoux massif (SE France) and by Birk et al. (2004), who interpreted peaks of discharge and EC in the Urenbrunnen spring (S Germany) as being caused by a series of recharge pulses rather than by infiltration at different locations.

A certain drainage network also exists in the area drained by the Río Verde spring (M-4), as can be deduced from the temporal evolution of EC and temperature in comparison with the discharge, but also taking into account the frequency curves. The karst drainage favours rapid infiltration and relatively high velocity (short transit time) of cold rainwater (rapid decrease in water temperature), but with limitations. During low water periods, a slow and delayed infiltration flow exists through epikarst and the unsaturated zone, which recharges the conduits (Fig. 4b) and the phreatic zone and keeps the water temperature low for several months after the flood. In high water periods, the drainage capacity of the conduits feeding the spring increases, and a gradient inversion occurs, meaning that the full conduits recharge less permeable annex blocks (Fig. 4c). These interpretations are consistent with convexities visible in the spring hydrograph (Fig. 4a), according to Liñán (2005). The hydrologic disturbance of the thermal field and the water-table gradient depend, among other factors, on the anisotropy and the permeability of the aquifer formations (Woodbury and Smith 1985; Ferguson 2007). Thus, Genthon et al. (2005) interpreted the rapid changes in temperature during the floods as being due to flow through karst conduits and the slow variations in the groundwater

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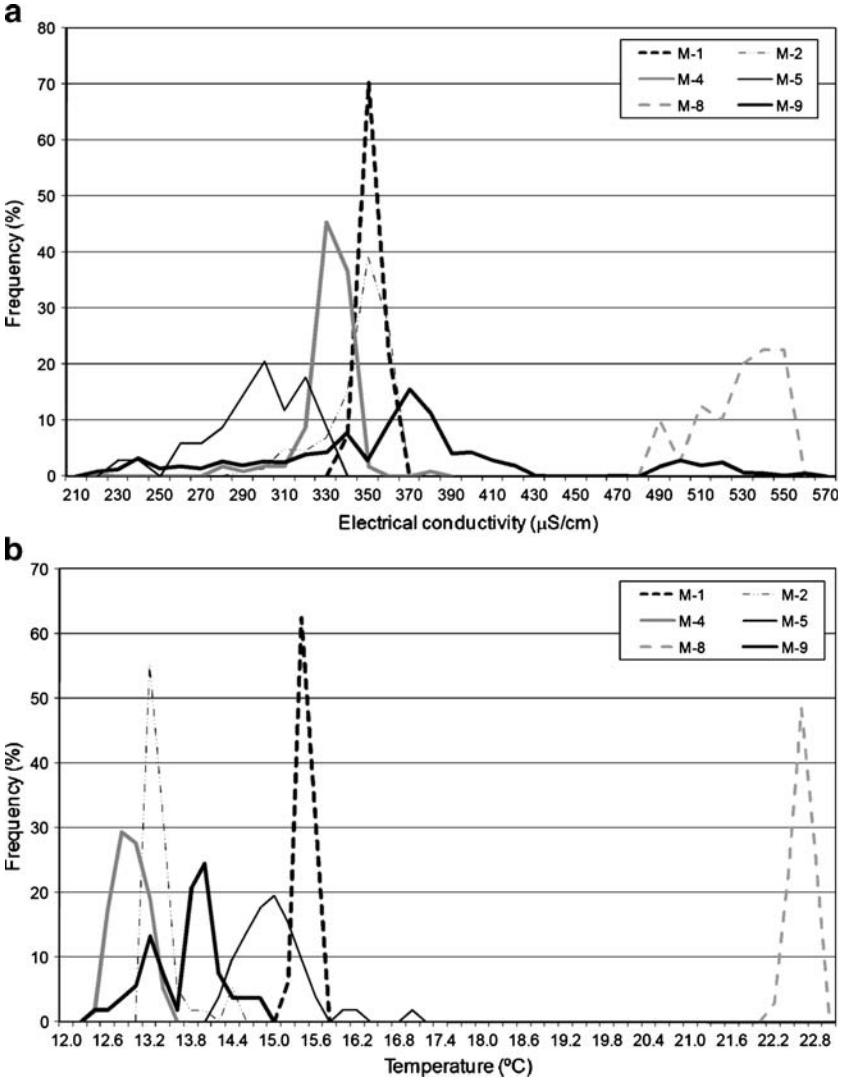

Fig. 9 Frequency curves of electrical conductivity (**a**) and temperature of groundwater (**b**)

temperature after floods as being linked with a component of slow infiltration (longer transit time). Based on the temperature record of the Floridan aquifer (USA), Screaton et al. (2004) demonstrated a net contribution from matrix and low permeable parts of the aquifer into the conduit system during and after flood periods.

The peculiar hydrothermal response that is observed at the Río Genal spring (M-2) also demonstrates drainage limitations in this area. Frequency curves, both of EC and temperature, are asymmetric (Fig. 9), indicating that heterogeneity exists in the media, although lower than in the Río Grande (M-9) and Cuevas del Moro (M-5) springs. In low water periods, the Río Genal spring (M-2) drains waters from the phreatic zone (Fig. 5b), which display a constant temperature, uninfluenced by the outer air temperature. In flood periods, the massive arrival of infiltration water enables hydraulic saturation of the main conduits. A rapid transfer of this poorly mineralised infiltration water occurs then through deeper conduits of the phreatic zone (Fig. 5c), which have little or no transmissive and storage capacity during normal flow conditions, favouring a weak heat exchange and consequently increasing its temperature due to the geothermal gradient. A similar interpretation was given by Mudry (1987) with respect to another French carbonate aquifer.

In the Algoma spring (M-1), low water temperature and EC variations and frequency curves with a single high mode and a small range of values have been detected (Figs. 6a and 9). In addition, a slow recovery of both parameters is observed, related to rainfall episodes. This can be interpreted as the result of a low flow velocity (low transit time), particularly in low water conditions (Fig. 6b), due to the lower development of effective karstification in the catchment area drained by this spring and its diffuse flow pattern. In high waters, a bypass with some speleological development is active (Fig. 6c). Andrieux (1978) interpreted the relatively smooth signal of temperature in Las Hountes spring (Ariège, France) as being due to the mixing of waters of different origin and conductive exchanges with rocks. The seasonal periodicity of spring groundwater temperature is coherent but delayed with respect to environmental temperature and with lower

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amplitude, which means that a constant groundwater influx at low velocity, coming from the diffuse flow system, influences the spring water (Bundschuh 1993; Benderitter et al. 1993).

The highest temperature of the water drained by the Río Horcajos springs (Piloncillo M-6, Cañada Fuente M-7, Cisnera M-8) demonstrates the existence of an inner heat supply in this area of the aquifer (ΔT^{a} in Figs. 7b and c). The average groundwater temperature of the M-8 spring is 4°C higher than the highest value of the air temperature recorded at station T-1, located approximately at the same altitude. According to Smith and Chapman (1983) the knowledge of the complete environment of a site, including the water-table configuration and subsurface flow system, together with heat flow measurements, are necessary to detect heat flux in active flow regions. Accordingly, heat flow should exist around the Río Horcajos springs, probably through a fault at the border, as occurs in other areas (James et al. 2000). In low water periods, the M-8 spring drains relatively warm waters from the phreatic zone (Fig. 7b). In high water periods, rainwater seepage induces a piston effect during recharge: colder infiltration water pushes, down toward the spring, water with a high residence time in the vadose zone (Fig. 7c), meaning that the M-8 spring drains water that is more mineralised and colder. The low variation range of this spring, particularly of temperature (whose frequency curve shows only one mode), corroborates the interpretation of a low effective karstification range in that part of the aquifer.

Conclusions

Analysis of the temperature (and EC) variations of groundwater drained by the main springs of the Sierra de las Nieves karst aquifer, especially during recharge periods, enables us to make a qualitative analysis of the development of the karstic drainage pattern. Thus, the Río Grande and Cuevas del Moro springs display higher variations in groundwater temperature and EC, particularly the former, and frequency curves of both parameters present several peaks, several modes and large ranges of variation. They have conduit flow behaviour because they drain a highly karstified sector of the system.

However, Algoma spring shows low variations in groundwater temperature and EC, and symmetrical frequency curves with a single high mode and a small range of values. This is due to its “diffuse flow” behaviour resulting from the high fracturation and poor karstification of the sector drained by this spring. Intermediate functioning is detected in the Río Verde and Río Genal springs.

Therefore, hydrothermics appears as a physical parameter of the water, which is useful in the hydrogeological investigation of karst aquifers. Even with a low sensitivity record of temperature, for instance that provided by a normal thermometer (0.1°C of precision), the groundwater temperature in karst aquifers give results that are coherent with those obtained with other techniques such as electrical conductivity, hydrochemistry and isotopic data. Temperature records of groundwater supplement information on aquifer functioning obtained from other natural responses such as hydrodynamics and hydrogeochemistry. However, in comparison with the electrical conductivity data recorded in this study, the temperature seems less sensitive for hydrogeological characterisation.

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