AUSTRIAN JOURNAL OF EARTH SCIENCES
[MITTEILUNGEN DER ÖSTERREICHISCHEN GEOLOGISCHEN GESELLSCHAFT]

AN INTERNATIONAL JOURNAL OF THE AUSTRIAN GEOLOGICAL SOCIETY
VOLUME 99 2006

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www.univie.ac.at/ajes
EDITING: Grasemann Bernhard, Wagreich Michael
PUBLISHER: Österreichische Geologische Gesellschaft
Rasumofskygasse 23, A-1031 Wien
TYPESETTER: Copy-Shop Urban,
Lichtensteinstraße 13, 2130 Mistelbach
PRINTER: Holzhausen Druck & Medien GmbH
Holzhausenplatz 1, 1140 Wien
ISSN 0251-7493

Separation of discharge components at a karst spring on the basis of event investigations (Wasseralmquelle, Austria)

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KEYWORDS

discharge-component separation
precipitation events
karstic spring
snow melting
^{18}O

Abstract

Isotope measurements were used to separate discharge components for the Wasseralmquelle (a spring) in the Schneealpe karst massif, Austria. This spring represents a clear two-component case with relatively old reservoir water (about 26 years mean residence time) and a short-term component of event water (precipitation, snow melting), which reaches the spring through "quick" channels. The results show that event water appears in the spring after a few hours, simultaneously with the first increase in the discharge. From the very first increment, the additional discharge consists mainly of event water. In the case of the Wasseralmquelle, it was found that electrical conductivity is probably not a suitable parameter for calculating the amount of event water, because it leads to unrealistically low contributions of short-term discharge components. The work is in progress, some preliminary results are presented in this paper.

Mit Hilfe von Isotopenmessungen wurde die Abflusszusammensetzung bei der Wasseralmquelle untersucht (Quelle am Fuß des Karstmassivs der Schneealpe, Österreich). Diese Quelle repräsentiert einen ausgeprägten Zweikomponentenfall mit verhältnismäßig altem Reservoirwasser – ungefähr 26 Jahre mittlere Verweilzeit – und einer Kurzzeitkomponente von Ereigniswasser – Niederschlag, Schmelzwasser - , das die Quelle über „schnelle" Kanäle erreicht. Die Ergebnisse zeigen, dass in der Quelle Ereigniswasser bereits mit dem ersten Schüttungsanstieg einige Stunden nach Ereignisbeginn eintrifft. Der zusätzliche Schüttungsanteil besteht am Anfang hauptsächlich aus Ereigniswasser. Im Fall der Wasseralmquelle erweist sich die elektrische Leitfähigkeit nicht als geeigneter Parameter zur quantitativen Ermittlung des Ereigniswasseranteiles, sie führt zu unrealistisch niedrigen Anteilen der schnell abfließenden Schüttungskomponenten. Die Untersuchungen sind noch nicht abgeschlossen, vorläufige Ergebnisse werden in der vorliegenden Arbeit präsentiert.

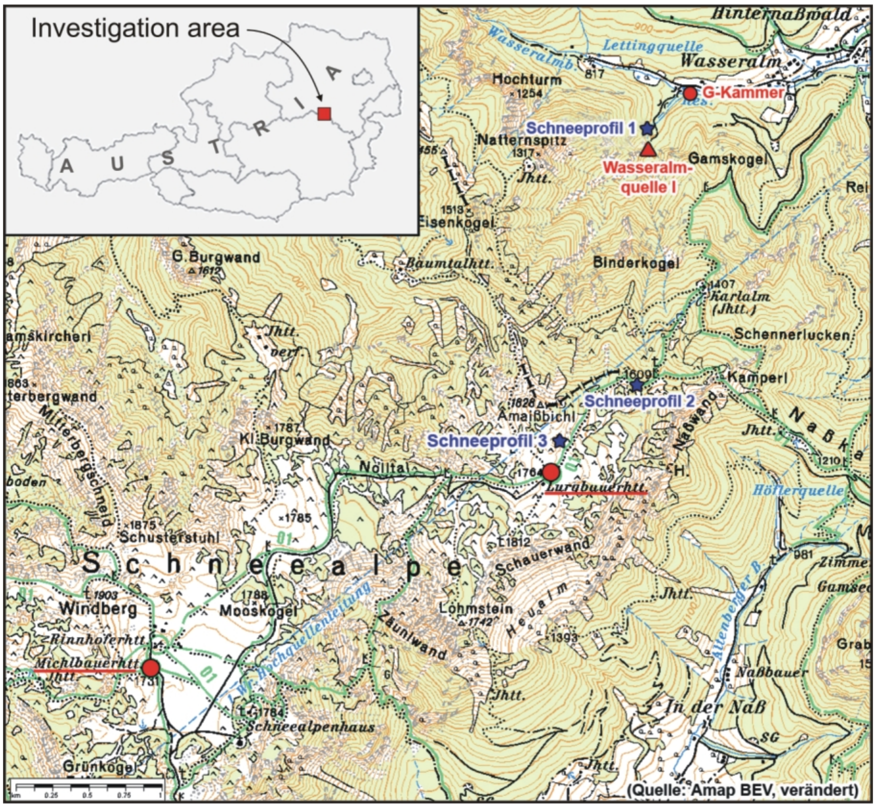

Figure 1: Site plan of the Wasseralmquelle and the precipitation sampling stations in the investigation area (Michelbauerhütte, Lurgbauerhütte and G-Kammer) and the position of the snow profiles (Schneeprofil 1-3).

1. Introduction

The catchment area of the Wasseralmquelle (802 m.a.s.l.) is situated in the NE part of the Schneealpe karst massif, some 100 km southwest of Vienna, in the Northern Calcareous Alps (Fig. 1). The highest point in the catchment area has an altitude of 1828 m, indicating that the karstic limestone aquifer (mainly Middle Triassic carbonates), which is underlain by impermeable shales and sandstones (Lower Triassic Werfen Formation), has a thickness of approximately 1000 m. The mean annual amount of precipitation in this area is 1058 mm/a while the mean evaporation loss is 374 mm/a. The catchment area, which measures 6.7 km², is dominated by (a) a part of the Schneealpe karstic plateau and (b) steep, narrow valleys, in part with little vegetation. The average discharge of the Wasseralmquelle is ca. 200 l/s, with a minimum in winter below 100 l/s and a maximum in summer of more than 1000 l/s (“dolomitic” spring) (Bauer, 1969; Gattinger, 1973; Bryda, 1997).

Isotope measurements have been widely used for the separation of discharge components at karst springs (e.g. Müller et al., 1980; Kranjc et al., 1997). Calculations from long-term isotope records from the Wasseralmquelle showed that the reservoir water in this karst system has a mean residence time of about 26 years, determined from ^{3}H records, while the short-term component has a transit time of 1.2 months, including retention time in the snow cover (Maloszewski et al., 2002).

For these calculations, the karstic reservoir is approximated by two different parallel flow systems, which provide water from the surface to the karst springs. The first flow system, with a high storage capacity, consists mainly of mobile water in the fissures and quasi-immobile water in the porous matrix. This water enters this system through the whole surface of the catchment area and is collected into the drainage channels connected with the karst springs. These channels separately create a second flow system with a high velocity, a small groundwater volume, and a very short mean transit time of water. This system is connected with sinkholes, which introduce precipitation water directly into this system. As a result in the karst springs, there is a mixture of two water components: (1) water flowing from the surface through fissured/porous medium to the drainage channels and then to the springs; and (2) water flowing directly from the sinkholes through the drainage channels to the springs. The conceptual model of the water flow in the karstic catchment area of the Wasseralmquelle is shown in Fig. 2.

This special form of the model for the Wasseralmquelle system also includes some infiltration of water from the channel system into the fissured-porous aquifer, since low precipitation depths (< 20 mm) do not lead to any increase of the discharge at the spring (Steinkellner, 1997). In this case, all the precipitation water infiltrates into the fissured-porous matrix. Regarding isotopic composition, precipitation events may be understood as natural areal tracing experiments. The more the isotopic composition of precipitation water differs from the isotopic signature in the karst system, the more suitable is this event for the investigation of discharge components, provided that the amount of precipitation is not too low. Fig. 3 shows the variation in isotopic composition measured in prominent precipitation events in the infiltration area of the Wasseralmquelle karst system during the investigation period (karstic system δ^{18}O value about -11.6 ‰ VSMOW). If we consider the general pattern of the seasonal δ^{18}O variations in precipitation (Fig. 4), we can expect the most sgnificant differential signals between precipitation and system value to occur either in winter or in summer. Since winter precipitations are usually retained in the snow cover in the Alps, the most suitable time for the investigation of a direct precipitation/discharge relationship is during the summer.

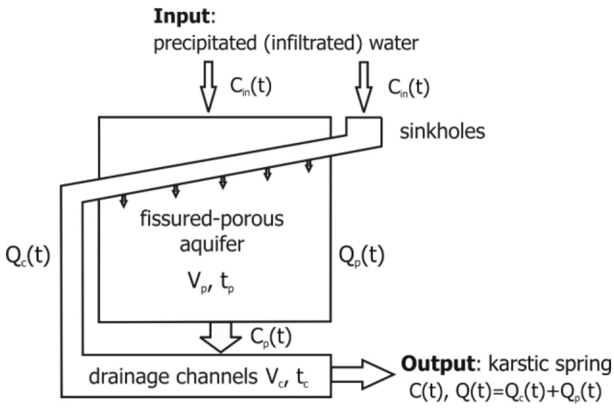

Figure 2: Conceptual model of water flow in the karstic system of the Wasseralmquelle, modified after Maloszewski et al. (2002). C = isotopic concentration, Q = discharge, V = volume, t = (mean residence) time.

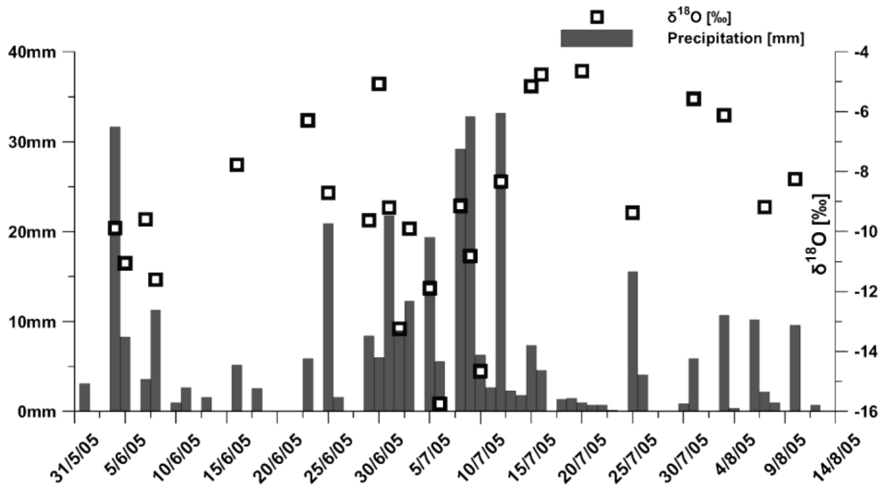

Figure 3: Amount of daily precipitation and δ^{18}O values of prominent precipitation events during the sampling period from June to middle of August in the Schneealpe area (sampling station Michlbauerhütte). The average δ^{18}O value in the karstic system is about –11,6 ‰ (Wieselthaler, 2006).

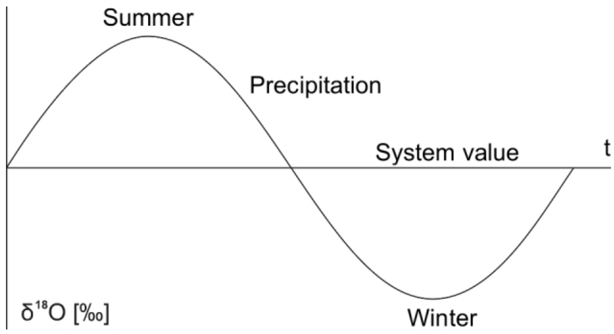

Figure 4: δ^{18}O in precipitation and in the karstic system (schematic diagram).

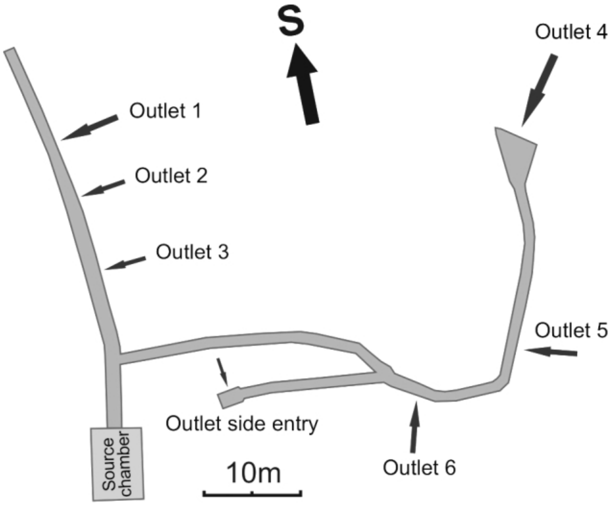

Figure 5: Ground plan of the two spring galleries of the Wasseralmquelle with source chamber and side entry. The arrows indicate the outlets used for water sampling (Wieselthaler, 2006).

2. Some preliminary results of the Wasseralmquelle study in spring and summer 2005

Two spring galleries collect the water of the Wasseralmquelle from two different faults (Fig. 5). Samples were taken from different outlets in these galleries during base-flow conditions (dicharge 90 l/s) in winter, to determine whether the water from different outlets has the same origin or not. The analytical results for the different sampling points do not differ significantly, neither in electrical conductivity and temperature nor in isotopic composition (Table 1). This is evidence for a bigger, well mixed karstic reservoir, at least in the vicinity of the spring and when base-flow conditions are prevailing. Further, a second sampling at the beginning of the snow-melting period (discharge 200 l/s) brought no significant differences between the different outlets. At that time, however, the west gallery was no longer accessible due to the high water levels, so only a total sample could be collected there.

Snow-melting periods with daily variations in discharge and heavy rainfalls in summer were selected for event investigations (Wieselthaler, 2006). Sampling with a time resolution of one or two hours was provided in the source chamber of the Wasseralmquelle. Snow samples and rain samples, respectively, were collected for the determination of the input data.

An example for the snowmelt investigations is shown in Fig. 6. Air temperature maxima caused snow melting on the plateau of the Schneealpe during the day. This led to an increase in discharge at the spring and a decrease in electrical conductivity in the spring water, with a delay of approximately 16 hours (daily variations). The graph of the $\delta^{18}O$ values develops similarly to the graph of electrical conductivity and indicates times of higher melt-water content in the discharge. At the end of the sampling period, the air temperature dropped, the melt-water content decreased and therefore $\delta^{18}O$ values and electrical conductivity rose again.

The investigations of rain events in the summer, when the most significant ^{18}O signals can be expected, give information about the direct precipitation/discharge relation. An example of such an investigation is shown in Fig. 7 and Fig. 8. Heavy rainfalls during July 7 and 8, 2005, led to a discharge increasefrom 300 l/s up to 800 l/s (Fig. 7). ^{18}O content and electrical conductivity changes at the same time showed that event water contributed to the increase in discharge from the beginning.

The separation of discharge components yielded a content of up to 50 % of event water in the discharge of the Wasseralmquelle during the discharge peak (Fig. 8). After the discharge peak, the increase in base flow persists. The karst-water level in the matrix is obviously raised by infiltrated event-water and this leads to a larger base flow component. The results of the separation calculation indicate that about 8 % of the total precipitation water from the drainage area had passed through the spring three days after the precipitation event.

The measurement record during the significant discharge maximum shown in Fig. 9 points out the unique possibilities of isotope investigations. There is a distinct minimum in electrical conductivity in the discharge following a strong precipitation event. Therefore, we would also expect a prominent ^{18}O maximum because of the high $\delta^{18}O$ value of the precipitation water (-9.89 ‰), but the record shows only a sequence of small maxima and minima. The reason for this is that the precipitation event coincides with snow-melting processes; snow melting causes a daily minimum in $\delta^{18}O$ (see also Fig. 6). The isotope record, therefore, enables a distinction between a short-term precipitation and a short-term snowmelting component to be made. Tritium measurements will allow a more detailed interpretation of this record.

Date	Sampling point	EC [µS/cm]	T [°C]	δ²H [‰]	δ¹⁸O [‰]	d [‰]
2005-03-01	Outlet 1 (east gallery)	282	5,8	-80,5	-11,61	12,4
	Outlet 2 (east gallery)	282	5,9	-80,9	-11,62	12,1
	Outlet 3 (east gallery)	281	5,9	-79,0	-11,60	13,8
	Outlet 4 (west gallery)	283	5,8	-80,9	-11,63	12,1
	Outlet 5 (west gallery)	283	5,9	-80,8	-11,62	12,2
	Outlet 6 (west gallery)	283	5,8	-80,7	-11,62	12,3
	G-Kammer (total discharge)	283	5,9	-80,2	-11,63	12,8
2005-04-06	Outlet 1 (east gallery)	260	5,8		-11,98	
	Outlet 2 (east gallery)	260	5,7		-12,07	
	Outlet 3 (east gallery)	260	5,7		-12,00	
	West gallery (total)	260	5,7		-11,98	
	Outlet side entry (west gallery)	260	5,7		-11,97	

Table 1: Wasseralmquelle: Electrical conductivity, temperature and isotope data of water samples from different outlets in the spring galleries (Fig. 5) taken during base flow conditions (2005-03-01, discharge 90 l/s) and at the beginning of the snow-melting period (2005-04-06, discharge 200 l/s), respec-tively. Limits of error for isotope measurements: < +/- 1 ‰ for δ^2H, < +/- 0,1 ‰ for $\delta^{18}O$, d = deuterium excess.

An important outcome of the preliminary evaluation of the measured data is that, at least at Wasseralmquelle, electrical conductivity does not seem to be a suitable parameter for the separation of short-term discharge components. The separation calculation using electrical conductivity led to much lower estimate of the contribution of event water than the use of ^{18}O data (see example in Fig. 10). The electrical conductivity of the infiltrating precipitation water obviously increases relatively quickly in the karstic system. One reason for this might be that it takes several hours for the short-term component of the infiltrating precipitation water to reach the spring and increase the discharge.

3. Conclusions

Although the data presented here and their interpretation is essentially preliminary, some general conclusions may be drawn:

The discharge of the Wasseralmquelle during hydrological events shows a clear two-component case. Although the baseflow water has a mean residence time of 26 years (calculated from ^{3}H records), event water from precipitation or snow melting appears in the spring after a few hours, contemporaneous with the first increase in the discharge. Most of the additional discharge at the beginning consists of event water. Apparently, this water reaches the spring through “quick” channels in the karst system.

Low precipitation depths (< 20 mm) do not lead to any increase of the discharge at the spring, when base flow conditions are prevailing. In this case, all precipitation water infiltrates into the fissured-porous matrix.

Regarding isotope ratios, electrical conductivity and temperature, the spring waters from the different outlets in the spring galleries show the same origin. This is evidence for a relatively large, well mixed karstic reservoir, at least in the vicinity

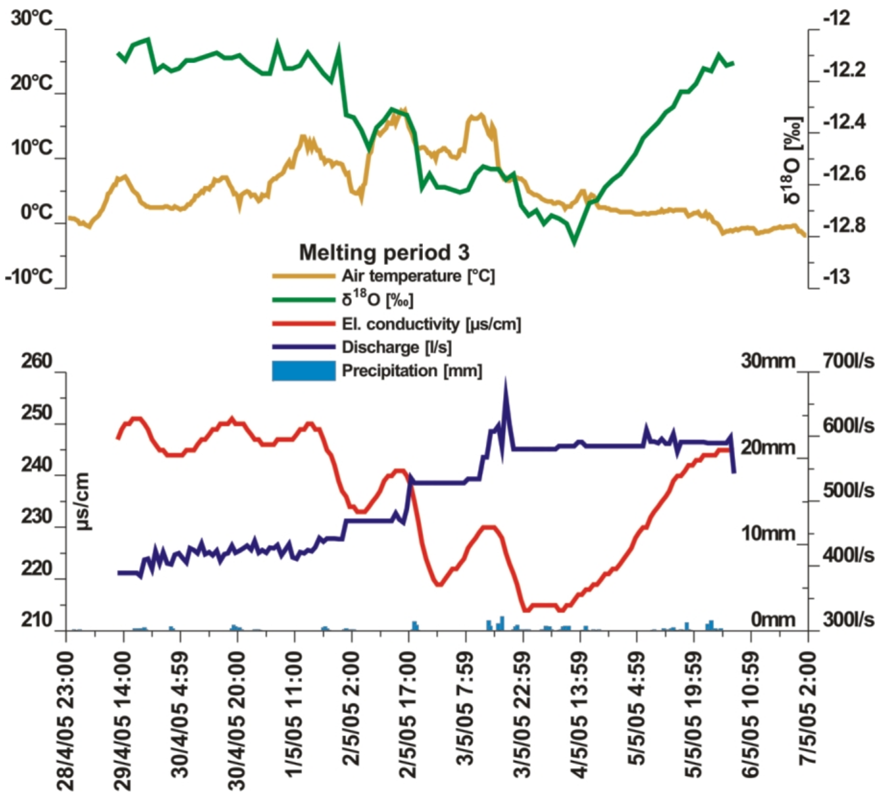

Figure 6: Example of the evolution of the discharge, electrical conductivity and $\delta^{18}O$ in springwater of the Wasseralmquelle, air temperature and amount of precipitation on the plateau of the karst massif during a typical snow-melting period with daily variations (2005-04-28 – 2005-05-07) (Wieselthaler, 2006).

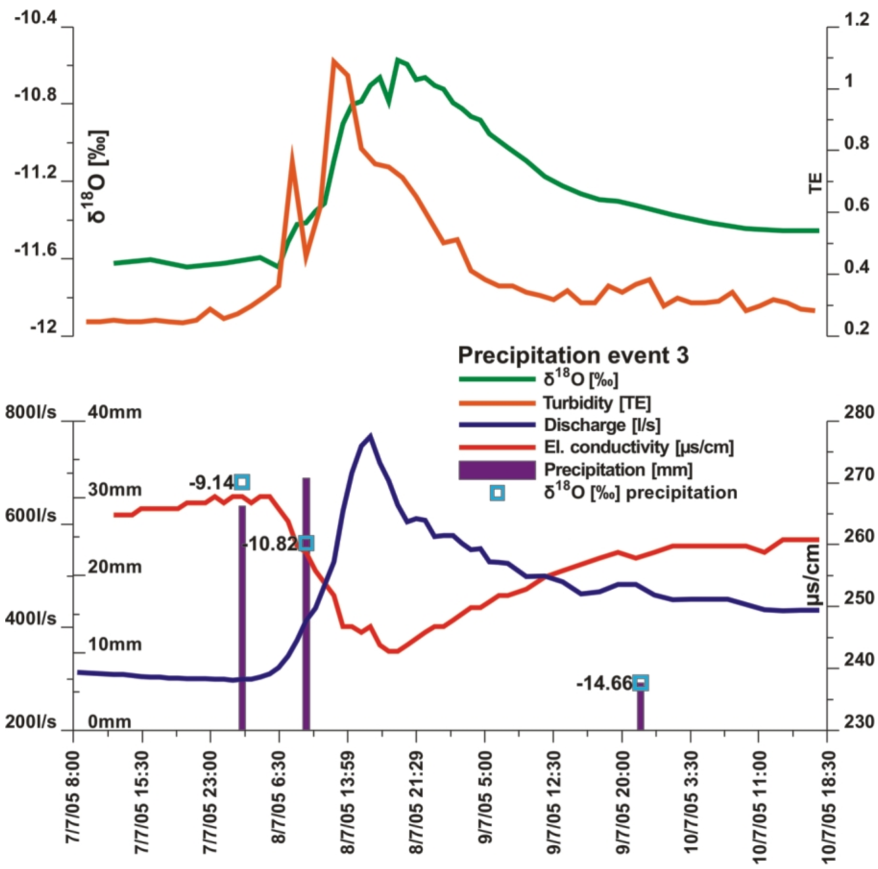

Figure 7: Example of the evolution of the discharge, conductivity, turbidity and $\delta^{18}O$ in springwater of the Wasseralmquelle during a heavy precipitation event, amount of precipitation and $\delta^{18}O$-values of the rainwater samples from the plateau of the karst massif (2005-07-07 – 2005-07-10) (Wieselthaler, 2006).

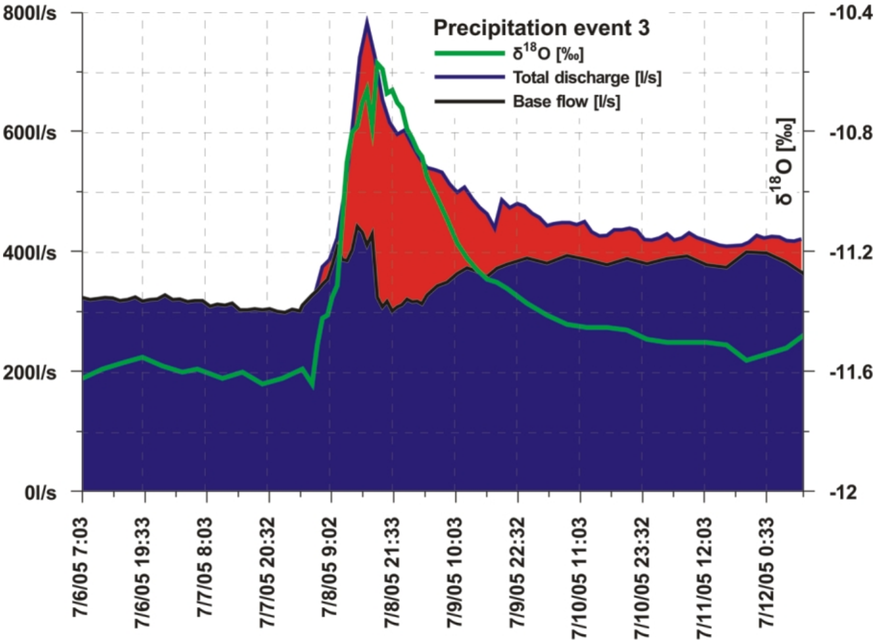

Figure 8: Separation of discharge components for precipitation event 3 (see Fig. 7).

of the spring and when base-flow conditions are prevailing.

At least for the Wasseralmquelle, the data suggest that the electrical conductivity of the spring water is probably not a suitable parameter for the separation of short-term discharge components. The electrical conductivity of the infiltrating precipitation water obviously increases relatively quickly in the karstic system. The calculations using electrical conductivity gave unrealistically low short-term discharge components (50 % or more lower than with ^{18}O).

Acknowledgements

We thank the Vienna Waterworks and the Austrian Research Centers Seibersdorf for their support of this work.

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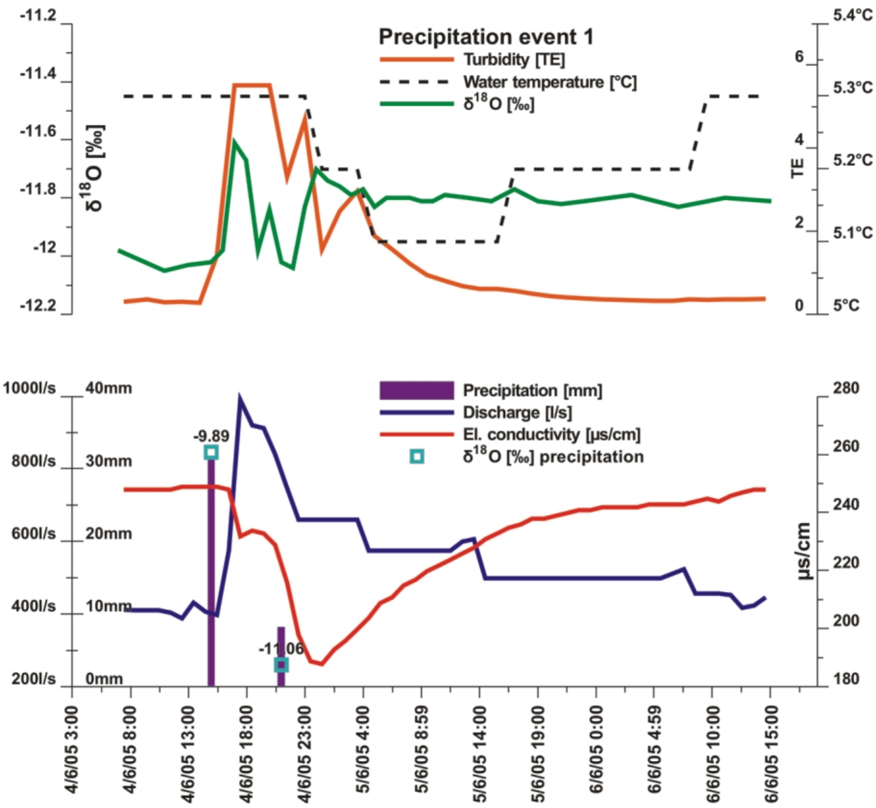

Figure 9: Evolution of the discharge, conductivity, turbidity, temperature and $\delta^{18}O$ in spring water of the Wasseralmquelle during a simultaneous precipitation and snow-melting period, amount of precipitation and $\delta^{18}O$-values of the rainwater samples from the plateau of the karst massif (2005-06-04 to 2005-06-06) (Wieselthaler, 2006).

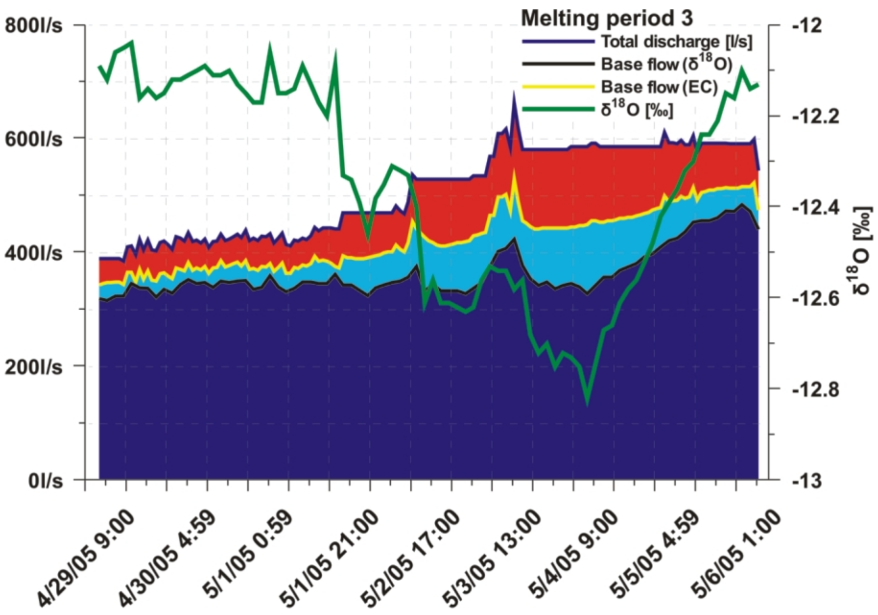

FIGURE 10: Separation of discharge components for melting period 3 (see Fig. 6) on the basis of $\delta^{18}O$ and electrical conductivity, respectively.

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Received: 17. November 2006
Accepted: 20. December 2006

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