# Mean residence time (MRT) of baseflow water in the Upper Danube Basin derived from decadal climatic signals in long-term isotope records of river water

DIETER RANK[1], WOLFGANG PAPESCH[2]

*Keywords: Danube, isotope hydrology, climatic change, mean residence time (MRT), oxygen 18 ($^{18}O$)*

## 1 Introduction

Tracing of hydrological processes by isotope investigations of river water is an actual research trend in isotope hydrology (Gibson et al. 2002). Main topic is the formation and age structure of baseflow (groundwater contribution to river discharge). Knowledge of the residence time of water in a catchment is necessary for a sustainable management of water resources. This paper describes a first attempt to determine the mean residence time (MRT) of water in a catchment by using decadal climatic signals in the $\delta^{18}O$ time series of a large river; the long-term $\delta^{18}O$ record of the Danube at Vienna serves as data base (Figure 1, see also Papesch & Rank 2010).

Long-term stable isotope records of precipitation water exhibit significant decadal changes in the isotopic composition of H and O (Figure 2, Rozanski & Gonfiantini 1990, Kaiser et al. 2001, Rank & Papesch 2005). Isotope ratios in river water are mainly determined by the isotopic composition of the precipitation water in the drainage area (continental effect, altitude effect, seasonal variations, storms; see e.g. Mook 2000, Rank & Papesch 2005). Several hydrological parameters and processes are modifying this isotopic signature and its temporal variations: delayed runoff of winter precipitation (snow cover), residence time of groundwater discharged to the river, confluence with tributaries, evaporation from lakes in the river system, climatic changes (changes in environmental temperature, spatial and temporal changes of precipitation distribution in the drainage area etc.) as well as anthropogenic influences on the hydrological regime (e.g. reservoirs, water abstraction for irrigation).

Since evaporation has minor influence on the isotopic composition in river water it can be neglected in most parts of the Danube Basin (Rank et al. 2009). Hence, isotopic signals of precipitation water are transmitted through the whole catchment and reflected in the isotopic record of river water. A comparison of long-term stable isotope records of precipitation and river water, therefore, should provide information on the residence time of precipitation water in the catchment.

## 2 Determination of MRTs using decadal climatic signals in long-term $\delta^{18}O$ time series of river water

The long-term $\delta^{18}O$ trend of several Austrian rivers – Danube tributaries and the alpine section of the Rhine – is similar to that of the Danube (Figure 3). Thus one can conclude that this trend in the order of decades represents a general climatic long-term isotopic signal – input from precipitation – in all hydrological systems. This suggests to use this signal for the determination of water ages (MRTs) in a similar way like tritium input by nuclear weapons in the past.

As a first attempt we compared $\delta^{18}O$ trends of precipitation and Danube water from Vienna on the basis of 10-year averages (Figure 4). Thus short-term and seasonal variations play only a minor role, short-term

1 Center for Earth Sciences, University of Vienna, Althanstrasse 14, 1090 Wien, Austria. e-mail: dieter.rank@univie.ac.at
2 Austrian Institute of Technology - AIT, Health & Environment department, 2444 Seibersdorf, Austria. e-mail: wolfgang.papesch@ait.ac.at

(event) $\delta^{18}O$ signals (maxima and minima) are eliminated by averaging (see also Figure 3). $\delta^{18}O$ time series of four precipitation stations of the Austrian Network for Isotopes in Precipitation (ANIP) were used for an average input signal: two lowland stations (Vienna 230 m asl, Bregenz 430 m), one medium-altitude station (Feuerkogel 1618 m) and one high-altitude station (Patscherkofel 2245 m, see Figure 2). Absolute values and amplitudes of the average input signal are in agreement with those of the Danube signal (Figure 4).

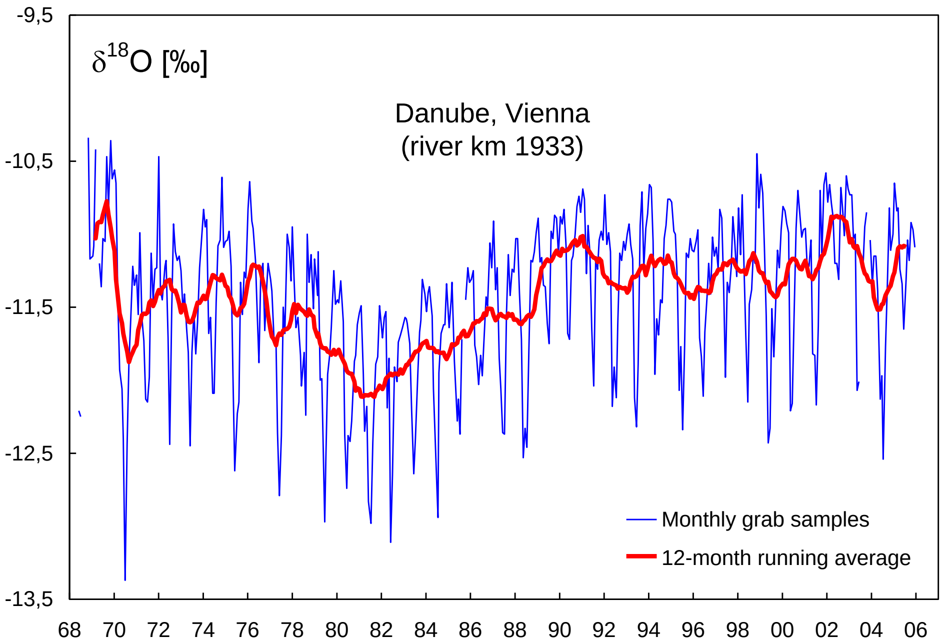


***Figure 1.*** *$\delta^{18}O$ time series of the Danube at Vienna (monthly grab samples, 12-month running average) (Rank & Papesch 1996, updated). The $\delta^{18}O$ pattern reflects the general $\delta^{18}O$ trend of precipitation in Central Europe (Figure 2).*

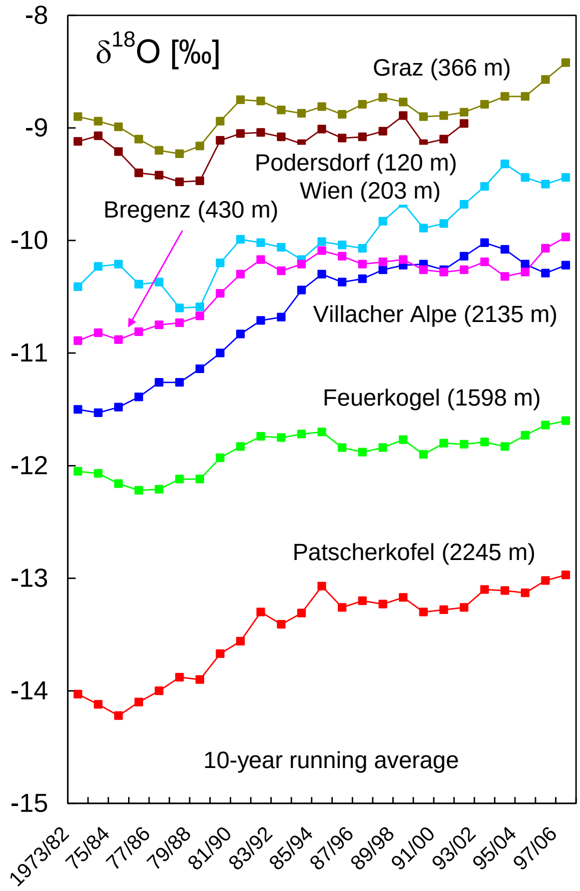


***Figure 2.*** *Long-term $\delta^{18}O$ trend at several stations of the Austrian Network for Isotopes in Precipitation (ANIP) (Rank & Papesch 2005, updated). Mountain stations show lower $\delta^{18}O$ values than valley stations (altitude effect), stations with significant Mediterranean influence (e.g. Villacher Alpe and Graz) higher values than stations with predominant Atlantic influence (e.g. Patscherkofel and Bregenz, continental effect). The general increase of $\delta^{18}O$ values during the last decades is mainly a consequence of the increasing environmental temperature. But also changes in the seasonal distribution of precipitation may play some role (winter precipitation has low, summer precipitation has high $\delta^{18}O$ values). This climatic signal – especially the significant $\delta^{18}O$ increase during the 1980s - is more pronounced in mountain regions.*

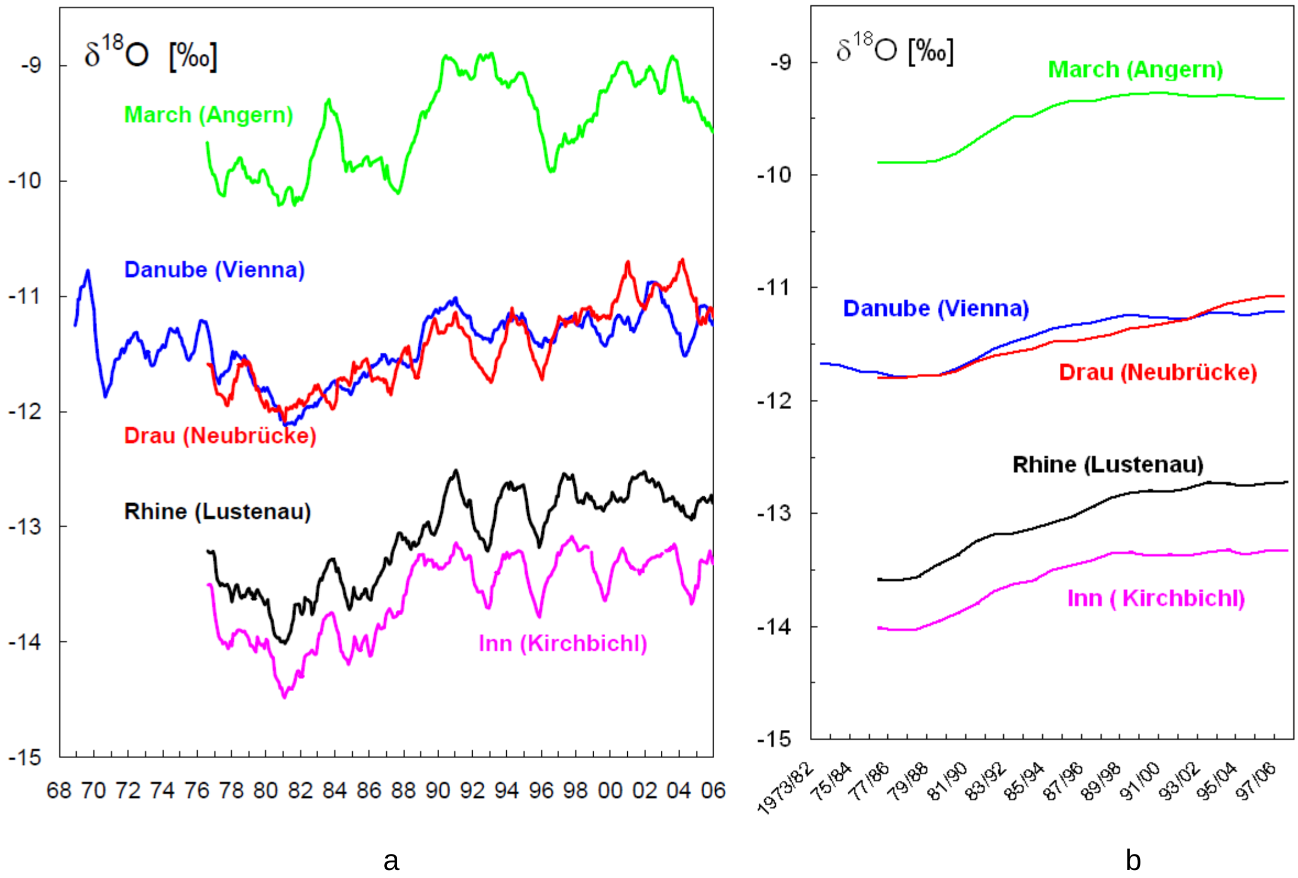


***Figure 3.*** *Long-term $\delta^{18}$O trend in Austrian rivers: (a) 12-month and (b) 10-year running averages*

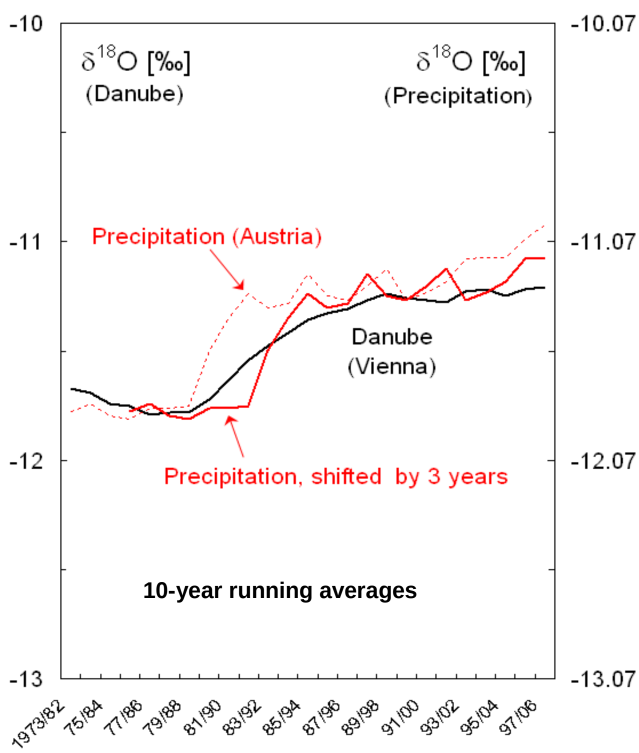


***Figure 4.*** *Comparison of $\delta^{18}$O long-term trends in precipitation in Central Europe and in Danube water at Vienna.*

The best agreement between the two $\delta^{18}O$ trend curves could be achieved with a shift of the precipitation curve (input) by about 3 years (Figure 4). In a simple model concept this corresponds to a MRT of the water in the drainage area of about 3 years. The smoother signal in the Danube reflects the age distribution of river water. As mentioned before, short-term influences were eliminated by 10-year averaging, thus the calculated MRT of about 3 years represents mainly baseflow from the Upper Danube Basin.

It must be emphasized that the MRT of about 3 years found out from $\delta^{18}O$ time series corresponds well with the value calculated from tritium time series of river water (Rank et al. 1998). This good agreement confirms that reasonable MRT values can be achieved by using long-term $\delta^{18}O$ signals.

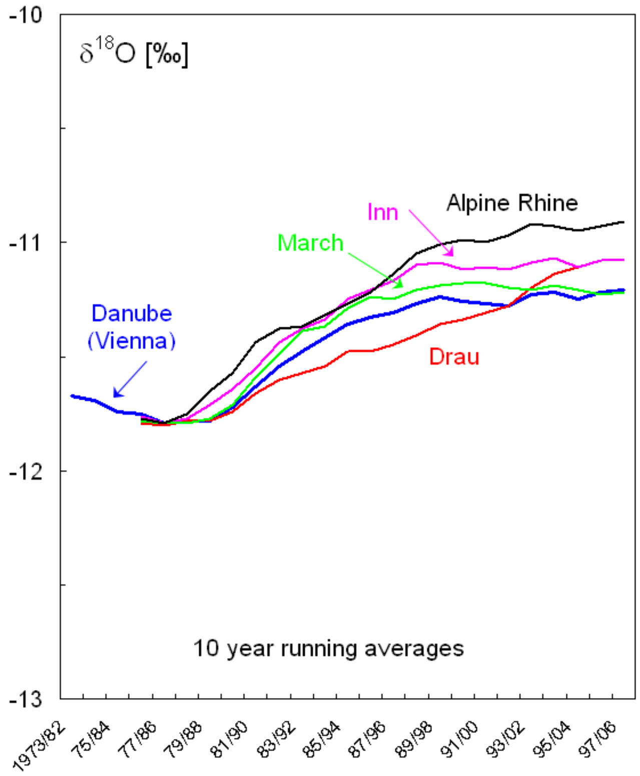


***Figure 5.*** *Comparison of $\delta^{18}O$ long-term trends in Austrian rivers ($\delta^{18}O$ scale is valid for the Danube. The scale for the other rivers is shifted in order to get the same $\delta^{18}O$ baseline in 1986).*

Although different Austrian rivers exhibit a similar $\delta^{18}O$ trend, a closer look at the time series shows a few characteristic differences (Figure 5). The decadal climatic signal is more pronounced in rivers with high-alpine drainage areas (rivers Drau, Inn, Alpine Rhine) than in the Danube and in lowland rivers (March). This corresponds to precipitation where $\delta^{18}O$ variations are more pronounced at mountain stations than in the forelands (Figure 2).

The Drau River shows a much slower $\delta^{18}O$ increase (= higher MRT) than the other rivers (Figure 5). The existence of some reservoirs in the river system could be the reason for this, but also a greater influence of glaciers than in other catchments cannot be excluded.

# 3 Conclusions and outlook

Long-term records of stable isotopes in precipitation exhibit significant decadal climatic signals (more pronounced in mountainous regions). These signals are reflected in the isotope records of hydrological systems, if other influences like evaporation effects have minor influence on the isotopic composition. This is the case for most parts of the river system in the Danube Basin.

The temporal shift of significant sections in isotope records of hydrological systems can be used to determine the MRT (age) of water in the system. First evaluations show a shift of about 3 years for the climatic signal in Danube water at Vienna, most probably the MRT of baseflow water (groundwater discharge to the river) in the Upper Danube Basin. Typical alpine rivers – e.g. Inn, alpine section of the Rhine – exhibit a more pronounced climatic signal, the time-shift of the signal is similar to that of the Danube (except River Drau). The age distribution – residence time of river water in the catchment – is responsible for the shape of the signals in river water.

Decadal stable isotope signals may be used to determine MRTs of river and groundwaters by model calculations in a similar way like tritium input by nuclear weapons in the past. Such applications require long-term isotope records for the investigated water bodies. In this respect, ongoing activities of the Section of Hydrology of the IAEA to establish a global network for isotopes in rivers (GNIR) are an interesting initiative to make more long-term isotope records of river water available. The hydrological use of climatic signals is a strong argument to run networks of isotopes in precipitation and hydrological systems also in the future.

# Acknowledgements

The authors would like to thank Joachim Heindler and Peter Kostecki for sample analyses.

# References

Gibson, J.J., Aggarwal, P.K., Hogan, J.F., Kendall, C., Martinelli, L.A., Stichler, W., Rank, D., Goni, R., Choudhry, M., Gat, J., Bhattacharya, S., Sugimoto, A., Fekete, B., Pietroniro, A., Maurer, T., Panarello, H., Stone, D., Seyler, P., Maurice-Bourgoin, L. ,Herczeg A. (2002): Isotope studies in large river basins; A new global research focus. EOS Trans. AGU 2002; 83: 613-617.

Kaiser, A., Scheifinger, H., Kralik, M., Papesch, W., Rank, D., Stichler, W. (2001): Links between meteorological conditions and spatial/temporal variations in long-term isotope records from the Austrian precipitation network. Vienna, IAEA-CN-80/63.

Mook, W.G. (2000): Environmental Isotopes in the Hydrological Cycle, Technical Documents in Hydrology, 39, Vol. 1, UNESCO, Paris, 280 pp.

Papesch, W., Rank, D. (2010): Investigation of the isotopic composition of Danube water as indicator for hydroclimatic changes in the Danube Basin. Establishment of a representative isotope monitoring near the mouth of the river. This conference report.

Rank, D., Adler, A., Araguás Araguás, L., Froehlich, K., Rozanski, K., Stichler, W. (1998): Hydrological parameters and climatic signals derived from long-term tritium and stable isotope time series of the River Danube. – In: Isotope Techniques in the Study of Environmental Change. Vienna, IAEA-SM-349: 191-205.

Rank, D., Papesch, W. (1996): Die Isotopenverhältnisse im Donauwasser als Indikatoren für Klimaschwankungen im Einzugsgebiet. Limnologische Berichte der 31. Arbeitstagung der Internationalen Arbeitsgemeinschaft Donauforschung, Wissenschaftliche Referate. Göd/Vácrátót,1: 521-526.

Rank, D., Papesch, W. (2005): Isotopic composition of precipitation in Austria in relation to air circulation patterns and climate. In: Isotopic composition of precipitation in the Mediterranean Basin in relation to air circulation patterns and climate. Vienna, IAEA-TECDOC-1453: 19-36.

Rank, D., Papesch, Heiss, G., Tesch, R (2009): Isotopic composition of river water in the Danube Basin – results from the Joint Danube Survey 2 (2007). Austrian Journal of Earth Sciences, 102/2: 170-180.
Rozanski, K., Gonfiantini, R. (1990): Isotopes in climatological studies. Vienna, IAEA Bulletin 32, No. 4: 9-15.