

# XXXVIII IAH Congress

Groundwater Quality Sustainability  
Krakow, 12–17 September 2010

## Extended Abstracts

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University  
of Silesia  
Press 2010



abstract id: **335**

topic: **3**  
**Aquifer management**

**3.4**  
**Environmental and artificial tracers in hydrogeology**

title: **Oxygen isotopic composition in a riverbank filtration system — case study on Szentendre Island, Hungary**

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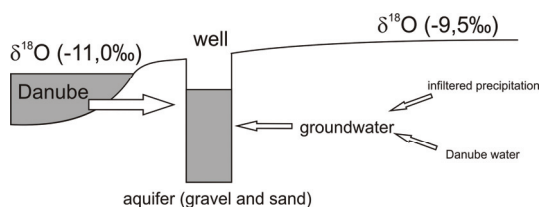
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keywords: riverbank filtration, oxygen isotope, Danube

## INTRODUCTION

Hungary's capital, Budapest and several settlements nearby, are supplied with drinking water from the Danube. The main goal of our study was to improve the knowledge on the riverbank filtration system on Szentendre Island to the north of the city. At first the Vác and Szentendre arms of the Danube, which surround the island, were examined. If the chemical and physical composition of the two arms differ significantly more complex models should be applied. Parallel to this water samples were also taken from a multiple collector well the greater part of whose water supply coming from the Vác arm of the Danube. Besides physical and water chemical components stable isotopic compositions (hydrogen and oxygen isotopes) were also measured. The use of isotopic composition in riverbank filtrated systems was developed by Maloszewski et al. (1990) based on a south-west German aquifer. A general infiltration model on the nearby Csepel Island has been constructed by Fórizs et al. (2005) and Fórizs (2008) (Fig. 1). Their water samples were taken every second week from a water producing well and more frequently (daily or twice a week) from the Danube. By this the transit time of the water from the Danube to the well could be estimated. Although the isotopic composition in our sampled autumn period was supposed not to be very much variable the goal of this study was to improve the mentioned model and apply it to the Szentendre Island by daily sampling.



**Figure 1.** Schematic diagram of a riverbank filtration aquifer with average  $\delta^{18}\text{O}$  values of potential sources (Danube water groundwater from precipitation and older Danube water) (Fórizs, 2008).

## SAMPLING

Daily water samples were taken from the Vác arm of the Danube and the Kisoroszi-2 water supplying multiple collector well from 29 October 2008 to 21 December 2008. Weekly sampling was undertaken from the Szentendre arm as well. Conductivity and temperature were measured in situ. Water samples for chemical analysis were taken six times. Sampling dates are shown on Table 2.

## APPLIED METHODS

Oxygen isotopic measurements were done at the Institute for Geochemical Research of the Hungarian Academy of Sciences on a Finnigan delta plus XP mass spectrometer. Isotopic ratios are reported in  $\delta$  value with respect to the international V-SMOW standard and in permil according to the formula of McKinney et al. (1950):

$$\delta^{18}\text{O} = \frac{\left(\frac{^{18}\text{O}}{^{16}\text{O}}\right)_{\text{sample}} - \left(\frac{^{18}\text{O}}{^{16}\text{O}}\right)_{\text{standard}}}{\left(\frac{^{18}\text{O}}{^{16}\text{O}}\right)_{\text{standard}}} \cdot 1000\text{‰} \quad . \text{ Uncertainty: } \pm 0.1\text{‰}.$$

Chemical compositions and physical parameters were determined at the Waterworks of Budapest Ltd. Twenty chemical components and physical parameters were defined (electric conduc-

tivity, chemical oxygen demand, Cl<sup>-</sup>, NO<sub>3</sub><sup>-</sup>, NO<sub>2</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup>, UV absorption, SO<sub>4</sub><sup>2-</sup>, pH, PO<sub>4</sub><sup>3-</sup>, F<sup>-</sup>, Ca<sup>2+</sup>, K<sup>+</sup>, Fe<sub>sum</sub>, Mn<sub>sum</sub>, Mg<sup>2+</sup>, Na<sup>+</sup>, turbidity, total organic carbon, UV absorption).

## RESULTS AND DISCUSSION

The oxygen isotopic composition of the two arms of the Danube and the K-2 multiple collector well as well as temperature and electric conductivity are shown on Table 1, chemical compositions and physical parameters on Table 2.

**Table 1.** Conductivity, temperature and  $\delta^{18}\text{O}$  values of the Vác and Szentendre arms and the Kisoroszi-2 well between 29 October and 21 December 2008.

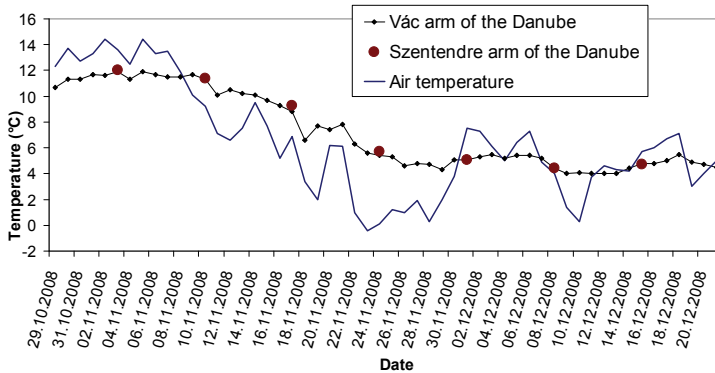
Date	Vác arm			Szentendre arm			Kisoroszi-2 well		
	Conductivity	Temperature	$\delta^{18}\text{O}$	Conductivity	Temperature	$\delta^{18}\text{O}$	Conductivity	Temperature	$\delta^{18}\text{O}$
29.10.2008	412	10.7	-10.45				405	12.5	-10.69
30.10.2008	416	11.3	-10.31				406	12.6	-10.71
31.10.2008	418	11.3	-10.28				403	12.7	-10.65
01.11.2008	425	11.7	-10.30				405	12.8	-10.63
02.11.2008	425	11.6	-10.34				401	12.9	-10.61
03.11.2008	419	11.9	-10.22	421	12.0	-10.30	403	12.9	-10.58
04.11.2008	420	11.3	-10.39				402	12.9	-10.69
05.11.2008	420	11.9	-10.28				399	13.0	-10.55
06.11.2008	425	11.7	-10.31				402	12.9	-10.58
07.11.2008	428	11.5	-10.29				401	13.0	-10.66
08.11.2008	431	11.5	-10.34				405	13.0	-10.60
09.11.2008	428	11.7	-10.39				405	13.1	-10.73
10.11.2008	423	11.3	-10.42	426	11.4	-10.45	407	13.1	-10.71
11.11.2008	424	10.1	-10.44				409	12.9	-10.73
12.11.2008	428	10.5	-10.46				406	13.1	-10.55
13.11.2008	429	10.2	-10.46				409	13.1	-10.67
14.11.2008	429	10.1	-10.41				409	13.2	-10.61
15.11.2008	429	9.7	-10.43				410	13.1	-10.63
16.11.2008	429	9.3	-10.38				408	13.1	-10.75
17.11.2008	436	8.8	-10.31	439	9.3	-10.32	412	13.2	-10.56
18.11.2008	439	6.6	-10.28				411	13.1	-10.62
19.11.2008	432	7.7	-10.34				412	13.0	-10.61
20.11.2008	428	7.4	-10.31				412	13.2	-10.61
21.11.2008	427	7.8	-10.40				415	13.2	-10.65
22.11.2008	431	6.3	-10.43				412	13.1	-10.66
23.11.2008		5.6	-10.41				412	13.3	-10.62
24.11.2008	431	5.4	-10.48	431	5.7	-10.40	413	13.4	-10.68
25.11.2008	428	5.3	-10.28				408	13.6	-10.56
26.11.2008	431	4.6	-10.47				412	13.5	-10.65
27.11.2008	439	4.8	-10.46				410	13.5	-10.60
28.11.2008	430	4.7	-10.57				415	13.3	-10.61
29.11.2008	425	4.3	-10.59				412	13.6	-10.52
30.11.2008	427	5.1	-10.52				415	13.5	-10.40
01.12.2008	434	5.1	-10.48	427	5.1	-10.43	415	13.5	-10.59
02.12.2008	424	5.3	-10.51				416	13.6	-10.59
03.12.2008	422	5.5	-10.33				416	13.5	-10.56
04.12.2008	430	5.2	-10.38				417	13.6	-10.59
05.12.2008	436	5.4	-10.33				416	13.7	-10.53
06.12.2008	440	5.4	-10.15				417	13.7	-10.50
07.12.2008	434	5.2	-10.29				417	13.9	-10.52
08.12.2008	440	4.4	-10.24	444	4.4	-10.23	419	13.7	-10.47
09.12.2008	446	4.0	-10.26				417	13.5	-10.57
10.12.2008	443	4.1	-10.26				421	13.5	-10.59
11.12.2008	444	4.0	-10.28				419	13.5	-10.61
12.12.2008	446	4.0	-10.20				421	13.6	-10.55
13.12.2008	449	4.0	-10.24				420	13.6	-10.54
14.12.2008	442	4.4	-10.16				421	13.8	-10.58
15.12.2008	444	4.8	-10.30	443	4.7	-10.30	421	13.8	-10.47
16.12.2008	443	4.8	-10.33				422	13.5	-10.49
17.12.2008	446	5.0	-10.29				423	13.7	-10.48
18.12.2008	440	5.5	-10.21				423	13.6	-10.52
19.12.2008	427	4.9	-10.24				426	13.4	-10.44
20.12.2008	440	4.7	-10.22				425	13.7	-10.48
21.12.2008	448	4.5	-10.33				424	13.8	-10.39

Table 2. Chemical composition of the Vác and Szentendre arms and the Kisoroszi-2 well between 29 October and 21 December 2008.

Sampling location	Date	Conductivity ( $\mu\text{S}/\text{cm } 20^\circ\text{C}$ )	Chemical oxygen demand <sub>perm</sub> (mg/l)	Cl <sup>-</sup> (mg/l)	NO <sub>3</sub> <sup>-</sup> (mg/l)	NO <sub>2</sub> <sup>-</sup> (mg/l)	NH <sub>4</sub> <sup>+</sup> (mg/l)	UV absorption (1/m)	SO <sub>4</sub> <sup>2-</sup> (mg/l)	pH (°C)	PO <sub>4</sub> <sup>3-</sup> (mg/l)	F <sup>-</sup> (mg/l)	Ca (mg/l)	K (mg/l)	Fe <sub>sum</sub> ( $\mu\text{g}/\text{l}$ )	Mn <sub>sum</sub> ( $\mu\text{g}/\text{l}$ )	Mg (mg/l)	Na (mg/l)	Turbidity (FNU)	TOC (mg/l)	UV (%)
Vác arm	03.11.2008	417	1.9	21.1	7.3	<0.03	<0.04	5.35	35.4	8.08	<0.1	0.12	59.9	3.2	54	11	15.8	14.9	4.45	1.89	
Szentendre arm	03.11.2008	421	2	15.8	5.3	<0.03	<0.04	5.3	29.1	8.1	<0.1	0.13	60.1	3.2	61	18	15.9	15	4.54	1.97	
Kisoroszi-2 well	03.11.2008	401	0.4	18.7	7.3	<0.03	<0.04	1.45	36.2	7.6	<0.1	0.12	61.5	2.7	17	3	15	11.5	0.04	0.77	
Vác arm	10.11.2008	416	2.3	20.1	7.6	<0.03	<0.04	4.95	40.7	8.09	<0.1	0.1	59.4	2.9	72	8	15.6	14.3	4.88	1.81	88.29
Szentendre arm	10.11.2008	418	1.8	20.4	7.6	<0.03	<0.04	4.9	41	8.1	<0.1	0.1	59.4	3	76	9	15.6	14.4	5.6	1.78	88.622
Kisoroszi-2 well	10.11.2008	400	0.8	16.3	5.7	<0.03	<0.04	1.2	29.7	7.6	<0.1	0.13	60.5	2.6	<5	<5	14.6	11.2	0.02	0.72	97.277
Vác arm	17.11.2008	437	2.2	22.1	8.2	0.03	<0.04	6.1	37.9	8.02	0.29	0.20	59.7	3.5	60	7	16.3	17	4.6	2.2	
Szentendre arm	17.11.2008	440	2.3	22.6	8.4	<0.03	<0.04	6.15	43.5	8.1	<0.1	<0.1	59.6	3.5	78	10	16.6	17.8	5.03	2.23	
Kisoroszi-2 well	17.11.2008	414	0.7	16.7	6	<0.03	<0.04	1.8	30.8	7.6	<0.1	0.14	62.1	2.8	9	<5	15.2	11.5	0.06	0.79	
Vác arm	24.11.2008	415	2.1	19.3	8.6	<0.03	<0.04	5.3	33.7	8.10	<0.1	<0.1	60	2.9	145	28	15.4	14.1	16	1.98	
Szentendre arm	24.11.2008	417	1.9	18.7	8.3	<0.03	<0.04	5.35	34.1	7.9	<0.1	<0.1	59.4	3	155	26	15.3	14.3	16.9	2.08	
Kisoroszi-2 well	24.11.2008	404	0.8	16.4	5.8	<0.03	<0.04	2	29.9	7.6	<0.1	0.1	60.8	2.6	160	<2	14.7	11.1	0.02	0.82	
Vác arm	15.12.2008	426	2.2	20.9	9	<0.03	<0.04	6.8	36.4	8.15	<0.1	<0.1	62.5	3	92	14.4	15.8	15.2	6.63	2.23	87.33
Szentendre arm	15.12.2008	427	2.1	20.7	9	<0.03	<0.04	6.1	36.5	8.1	<0.1	0.1	62.9	3	59	11.9	16	15.3	5.08	2.1	87.654
Kisoroszi-2 well	15.12.2008	411	0.7	17.5	6.1	<0.03	<0.04	1.5	39.4	7.7	<0.1	0.12	62.7	2.8	<5	0.5	15.2	11.7	0.02	0.74	96.484
Vác arm	08.12.2008	422	2.1	22.1	10.3	0.06	0.05	7.95	35.4	8.09	0.17	0.12	60.8	3.1	250	21	15.1	15	11	2.66	
Szentendre arm	08.12.2008	427	2.1	22	10.1	0.06	0.04	7.35	34.7	8.1	<0.16	0.11	61.3	3	180	15	15.2	15.4	7.71	2.31	
Kisoroszi-2 well	08.12.2008	410	0.3	17.6	6.4	<0.02	<0.04	2.05	32.5	7.6	<0.16	0.12	61.0	2.7	<5	<5	14.9	11.4	0.06	0.87	

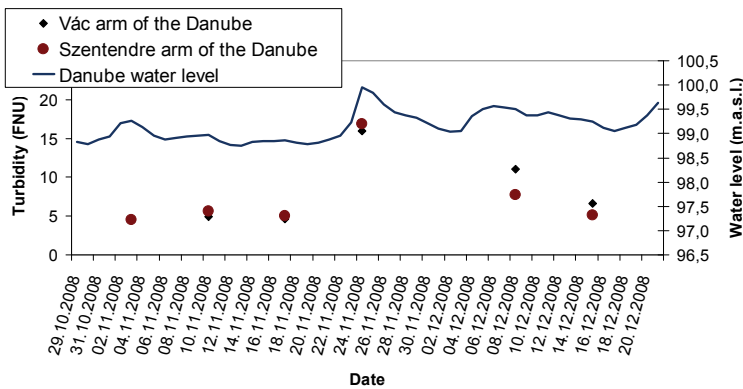
### Comparison of the Vác and Szentendre arms of the Danube

Conductivity (Fig. 4) and temperature (Fig. 2) as well as isotopic composition in both arms are the same within the error of measurement. The average  $\delta^{18}\text{O}$  value was  $-10.35\text{‰}$ . Chemical data of seven weekly water samples (Table 2) also show high similarity at both locations. This means that neither arm experienced additional water or contamination during the sampling period. Sampling sites are located 6 km from the tip of the island on the Szentendre arm and 7.5 km on the Vác arm.



**Figure 2.** Temperature in the Vác and Szentendre arms of the Danube and air temperature between 29 October and 21 December 2008.

Increased turbidity, UV absorption,  $\text{NH}_4^+$ ,  $\text{NO}_2^-$ ,  $\text{Fe}_{\text{sum}}$ ,  $\text{Mn}_{\text{sum}}$  and TOC values on 24 November and/or 8 December are linked to the sudden water level rise of the Danube on 24 November by 1.2 m (Fig. 3).

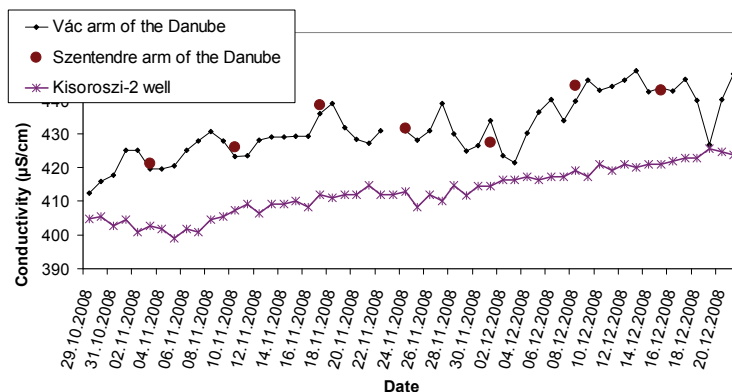


**Figure 3.** Turbidity and water level changes between 29 October and 21 December 2008.

All physical and chemical parameters of both arms of the river agree within error of measurements. Temporal changes also show matching tendencies. This means no separate sampling will be needed in the future and that data can be used in both arms for modelling.

### Comparison of the Kisoroszi-2 well and the Vác arm of the Danube

The trend in conductivity was similar but the changes had smaller amplitudes in the Kisoroszi-2 well. This can be attributed to diffuse filtration (Fig. 4).



**Figure 4.** A Conductivity between the Vác and Szentendre arms of the Danube and Kisoroszi-2 well (29 October and 21 December 2008).

Average conductivity in the well is 18  $\mu\text{S}/\text{cm}$  less than in the river meaning a smaller amount of dissolved ions. Longer sampling periods would be needed to fully understand whether this was only a seasonal feature or not. An amount of 5-10% of limestone and dolomite cobbles the likely source of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in the Szentendre Island gravel has been determined by Serfőző (2001).  $\text{Na}^+$  and  $\text{K}^+$  can be dissolved from degrading feldspars. However this suggested increase in cations was not measurable in the examined well. Almost all physical and chemical parameters showed smaller values in the well than in the river. The decrease in  $\text{Fe}_{\text{sum}}$  and  $\text{Mg}^{2+}$  concentration can be attributed to biological filtration. This is also corroborated by the UV absorption and TOC values. However  $\text{Ca}^{2+}$  concentrations in the well are slightly larger.  $\text{Mg}^{2+}$  values are smaller in the well than in the Danube but no significant differences were seen (Table 2). This means that the aquifer between the river and the well does not affect the cation composition of water a feature yet to be examined by longer data sets.

The hydrodynamic model of Waterworks of Budapest accounts for 37% background water component in the Kisoroszi-2 well during the sampling period (average well production 4800  $\text{m}^3/\text{day}$  average river water level 97.5 m; Zoltán Molnár oral communication). The model gave travel times in the model changed between 24–40 days while the measured oxygen isotopic composition of the Danube varied between -10.59 and -10.15‰, with an average of -10.35‰.

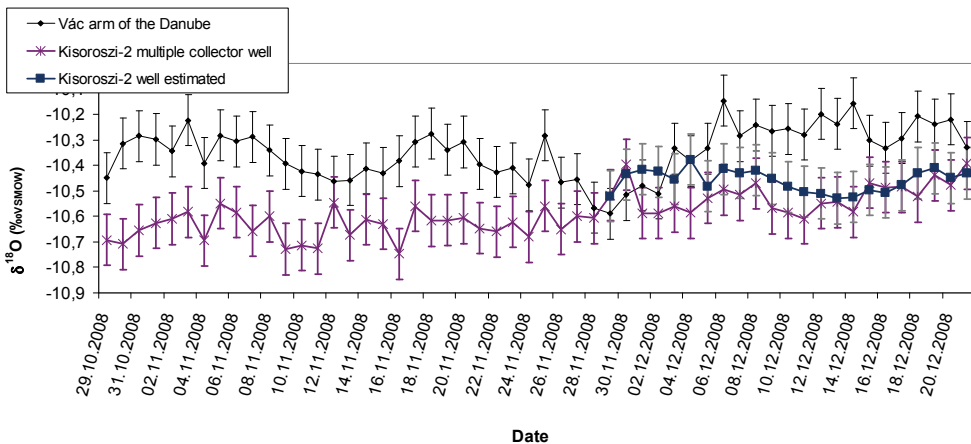
Values in the Kisoroszi-2 well ranged between -10.75 and -10.39‰, with an average of -10.59‰. To interpret isotopic data (Table 1) the above mentioned modelled results were taken into account. Background water consists of local precipitation and old Danube water infiltrated probably during the previous years. Monitoring wells that are more than 0.5 km from the river but within 5 km of the Kisoroszi-2 well were selected. Their  $\delta^{18}\text{O}$  values measured by Fórizs and Deák (1998) and Kármán (2009) were averaged (Table 3). This gives an estimated average  $\delta^{18}\text{O}$  values of -10.64‰ (except for a monitoring well in a special position). Based on the measured  $\delta^{18}\text{O}$  values in the Vác arm the estimated composition of the Kisoroszi-2 well can be calculated as follows:

$$\delta^{18}O_{K-2_{estimated}} = 0.63 \times (\delta^{18}O_{Danube}) + 0.37 \times (-10.64 \text{ ‰})$$

**Table 3.** Oxygen isotopic composition of monitoring wells based on F6rizs és Deák (1998)\* and Kármán (2009)\*\*. The discrepancy of the F.5 well has been omitted from calculation.

Date of sampling	Monitoring well	$\delta^{18}O$ (‰)
August-September 1995 *	F.11	-10.63
August-September 1995 *	F.14	-10.52
August-September 1995 *	F.17	-10.79
August-September 1995 *	F.21	-10.31
August-September 1995 *	F.22	-10.93
May-June 1995 *	F.3	-10.53
May-June 1995 *	F.5	-9.58
May-June 1995 *	F.6	-10.12
May-June 1995 *	F.7	-10.91
May-June 1995 *	F.8	-10.69
May-June 1995 *	F.9	-10.79
May-June 1995 *	F.11	-10.90
May-June 1995 *	F.54	-10.74
24 November 2008 **	F.11	-10.45
<b>Average</b>		<b>-10.64</b>
Deviation		0.25
Minimum		-10.93
Maximum		-10.12

Because travel time range 24 and 40 days dispersion had also to be calculated. Because its equation has not been resolved yet data have been shifted by the average transit time i.e. 32 days (Fig. 5). In this case curves agree within the error of measurement.



**Figure 5.** Measured  $\delta^{18}O$  values in the Vác arm and the Kisoroszi-2 well as well as the estimated values of the Kisoroszi-2 well shifted by 32 days.



## SUMMARY

Clear correlation has been shown between air and river temperature changes. Temperature, conductivity,  $\delta^{18}\text{O}$  data examined physical and chemical parameters between the Szentendre and Vác arms showed a close match meaning that these arms can be treated as equal. Positive peaks in turbidity, UV absorption,  $\text{NH}_4^+$ ,  $\text{NO}_2^-$ ,  $\text{Fe}_{\text{sum}}$ ,  $\text{Mn}_{\text{sum}}$ , TOC can be attributed to sudden rises of the river water level.

Comparing the hydrodynamic model of Waterwork of Budapest with measured oxygen isotopic data a formula for the estimation of  $\delta^{18}\text{O}$  values in the Kisoroszi-2 well has been constructed. This proves the efficiency of the hydrodynamic model.

## ACKNOWLEDGEMENTS

We appreciate the help of Waterworks of Budapest, especially that of László Debreczeny, Dávid Csaba Szabó, Zoltán Molnár, János Davidesz and István Kármán.

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