HYDROLOGICAL RESPONSE OF THE SMALL CATCHMENT EXAMINED BY ISOTOPIC TRACERS

M. Šanda[1], A. Kulasová[2], M. Císlerová[1]

[1]*Czech Technical University, Faculty of Civil Engineering, Prague, Czech Republic*
[2]*TGM Water Research Institute, Public Research Institution, Prague, Czech Republic*
martin.sanda@fsv.cvut.cz

Introduction

Uhlířská (1.78 km^2), Jizera Mountains, Czech Republic, is a typical catchment with the crystalline bedrock forming Cambisols. It is situated in a humid mountainous region where soils are shallow and highly permeable with preferential pathways. As a result of these facts, outflow caused by storms can be of a quick response and high magnitude. Data collection of the water regime in the soil profile and the subsurface flow accompanied with the standard climatic and hydrological monitoring is performed. Based on the hydrological observations, soil profile plays dominant role in the rainfall-runoff transformation. Quantitative measurements are supplemented by the additional techniques of isotopes tracing: ^{18}O, ^{2}H and ^{3}H. It is becoming evident that stormwater is composed of a high fraction of pre-event water held in soil profile and groundwater. The fluctuation of the ^{18}O in rainfall and stream outflow is fitted by sine function to evaluate mean residence time of water in the catchment. Preliminary groundwater model for the base flow evaluation combines hydrological and geological information to specify the travel time of water in the deep subsurface.

Experimental setup

Isotope ^{18}O is sampled at selected sites in the catchment (Šanda et. al, 2007). These activities cover the sample collection of rainfall, snow melt, snow cover, subsurface stormflow, groundwater, soil water from soil suction cups and the stream outflow at two gauging stations (fig. 1). Isotopes ^{18}O, ^{2}H and ^{3}H are sampled in the rain and stream outflow monthly within the frame of GNIP and GNIR programmes of IAEA (IAEA, 2006).

Observations of the hydrological cycle

The set of the $\delta^{18}O$ in monthly rainfall totals and streamflow is presented on Figure 2. Here the annual fluctuation of rainfall, followed by the response in $\delta^{18}O$ in streamflow is evident. Shallow groundwater, sampled in the valley of the catchment exhibits narrow fluctuation of $\delta^{18}O$ (Figure 3). This is due to the mixing of water masses with varying $\delta^{18}O$ signature during the seasons.

Based on the correlation in between monthly rainfall $\delta^{18}O$ values and monthly air temperature for 2006-2007, synthetic monthly $\delta^{18}O$ values of the rainfall are calculated, according to the correlation of measured monthly temperature averages and monthly values of $\delta^{18}O$ in rainfall for the period of V/06-X/07. The correlation is back propagated using monthly temperature averages for 1997-2007. The development

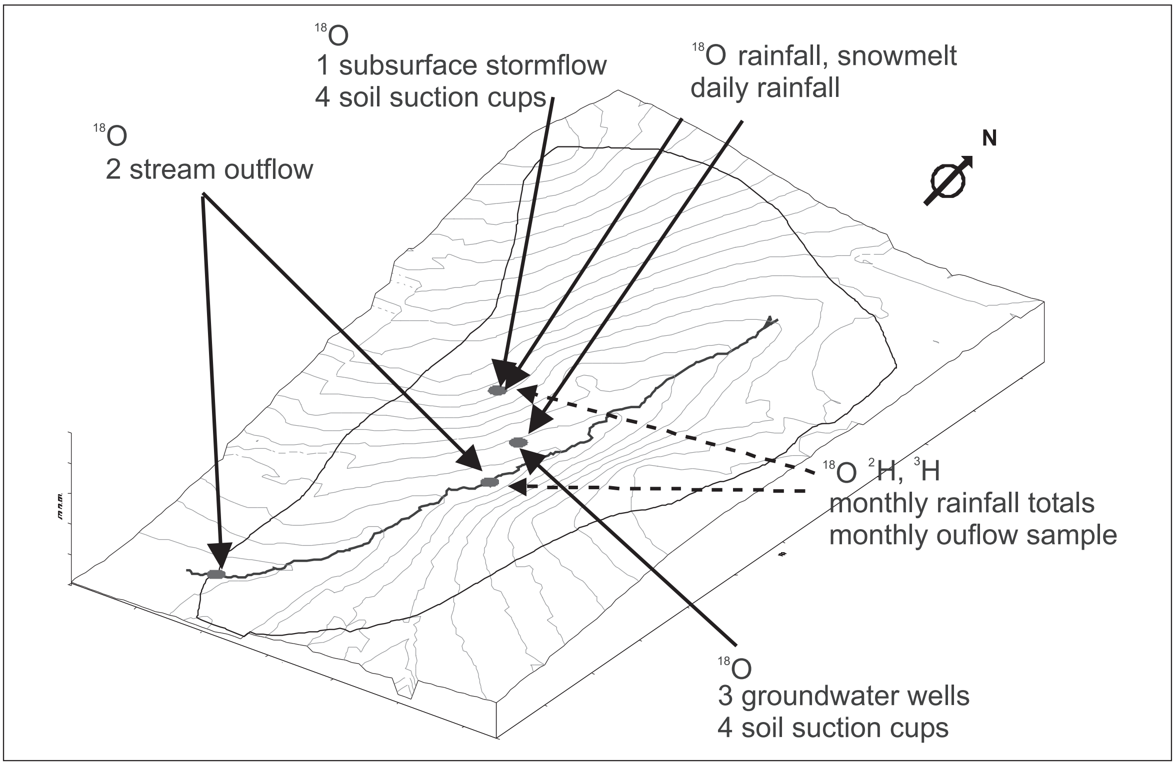

Figure 1. Water sampling locations in the experimental catchment Uhlířská

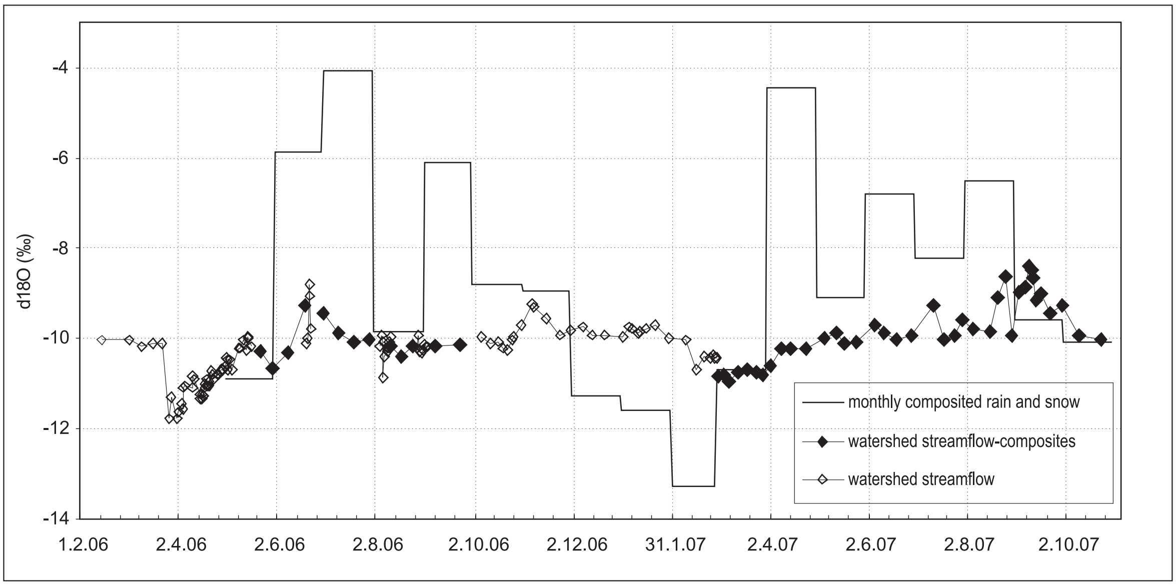

Figure 2. Isotope $\delta^{18}O$ in rain, snow and streamflow

of the monthly temperature values in the long term exhibits periodical sine-like behaviour, thus linearly correlated values of $\delta^{18}O$ show the same behaviour (Figure 4). Both synthetic and measured data of $\delta^{18}O$ in rainfall, along with the measured $\delta^{18}O$ values in the stream outflow were fitted with the sine function. The fit of measured $\delta^{18}O$ rainfall data shows higher mean and smaller amplitude compared to the long term synthetic data, due to warmer winter season of 2006/2007.

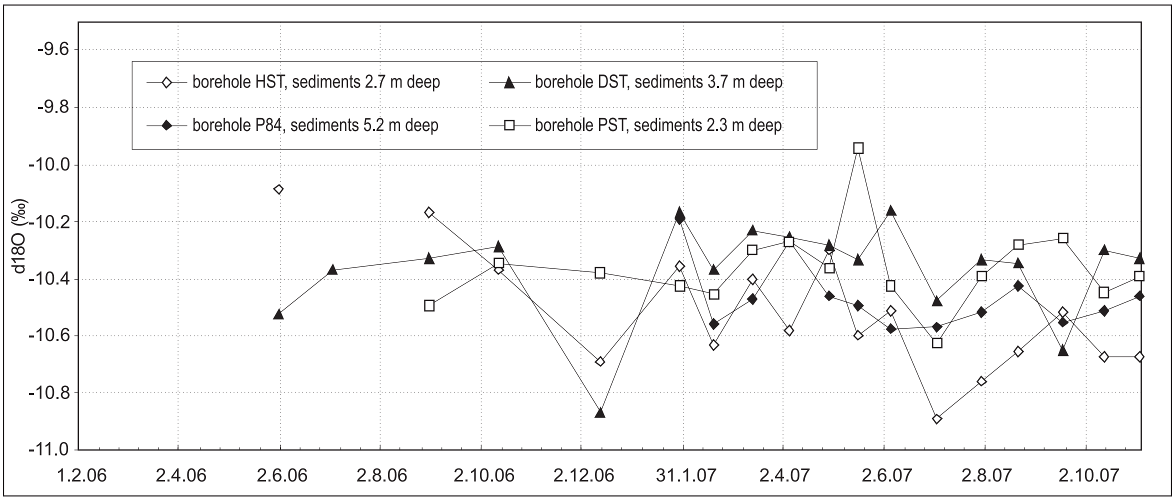

Figure 3. Isotope $\delta^{18}O$ in groundwater

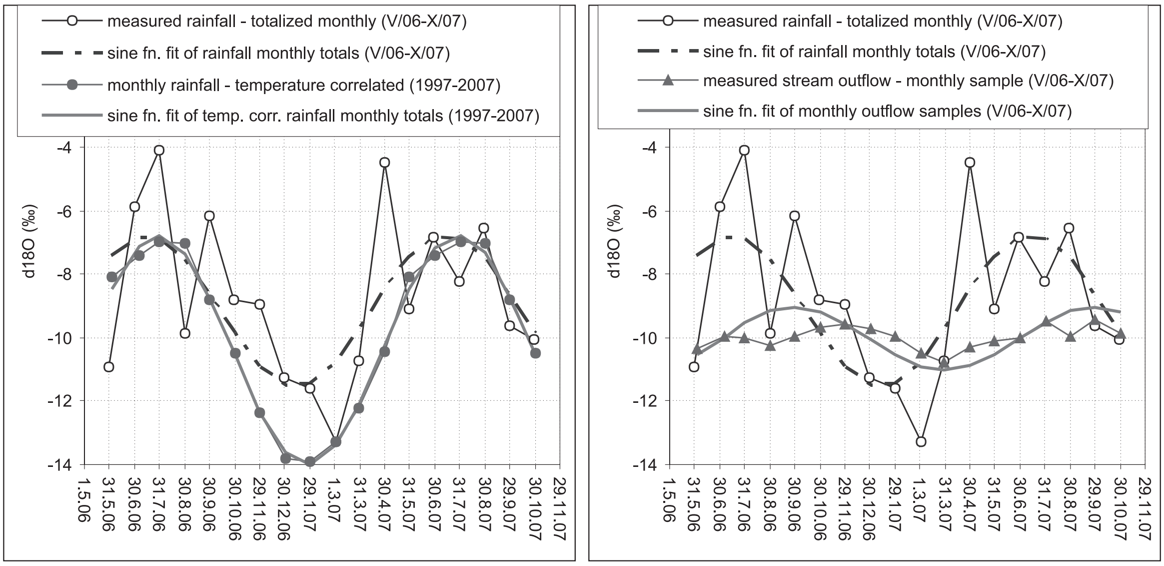

Figure 4. Course of the $\delta^{18}O$ in monthly rainfall totals and synthetic $\delta^{18}O$ in rainfall according to correlation with monthly air temperature averages (1997-2007) fitted by sine functions

Comparison of the fitted sine functions of measured rainfall and stream outflow shows delay in the mean residence time of water in the catchment. The decreased variation of $\delta^{18}O$ in the outflow indicates strong transformation effect by the catchment structures. The higher content of ^{18}O in rainfall impacts delayed the rise of $\delta^{18}O$ stream outflow. Referring monthly rainfall isotopic content at the end of each month, the bulk mean long term response of the catchment is lagged 77 days only. However, due to the limited dataset, possibility of the delayed outflow by addition of the whole year multiple *n* (*n*365 days*) can not be rejected due to the periodic annual fluctuation of the isotopic content of rainfall.

The mean value of the sine fit of $\delta^{18}O$ in streamflow is -10.0‰. Mean of the synthetic rainfall $\delta^{18}O$ content is -10.4 ‰, while mean value of the sine fit of $\delta^{18}O$ in measured rainfall for examined period of V/06-X/07 gives $\delta^{18}O$ = -9.2‰. The values of $\delta^{18}O$ for shallow groundwater range -10.4 to -10.6 ‰ (Figure 3).

This comparison indicates the long term buffering effect of the subsurface in transforming rainfall onto runoff.

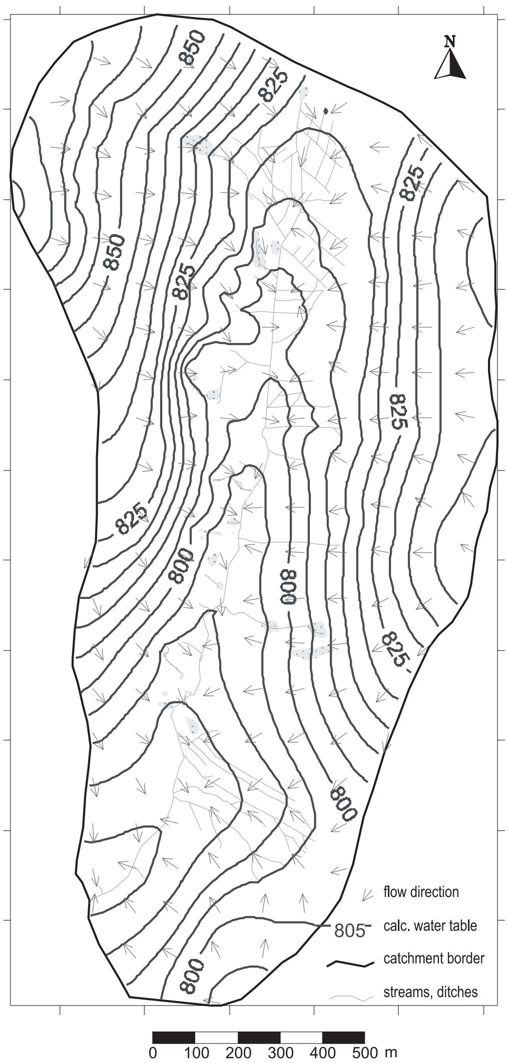

Figure 5. Modeled water table and flow directions

Modelling the groundwater flow

In order to assess the mean residence time of the groundwater within the catchment, preliminary outcomes of the steady state numerical model are presented.

Based on the topographic, hydrological and geophysical information, simple one layer distributed groundwater model is built. Aquifer thickness is evaluated by means of the electrical resistivity tomography (Šanda, 2007) approximating the depth of the sediments to 10-40 m in the valley axis, increasing towards the catchment outlet. Observations of the water table in the shallow wells performed in last decade through the catchment provide information for the water table calibration. Detailed mapping by means of GPS gives the distributed water drainage network data. Hydrological record of the daily outflow values at the gauging stations since 1981 allow several attitudes towards the standard baseflow separation analysis. Combining all of the information, spatial distribution of the water table and flow direction is modeled by MODFLOW model (Figure 5).

Applying the modeled results under steady state condition and assuming evenly distributed porosity=0.1[-] for the weathered structures upslope and glacial sediments in the valley, water particles are tracked. Virtual particle is inserted into each of the active model cells. As a result, the spatial distribution of the mean travel times of the groundwater is obtained. Based on the flow and particle tracking approach, preliminary range of values is obtained for the baseflow residence time. Water travel time in the hillslopes formed by 0-10 m deep weathered granite structures ranges from 0.5-2 years in general, while values for the water residence in the 10-40 m deep sedimentary aquifer is 2 to 5 years. Model indicates residence time of several decades for the deep groundwater in the deepest and/or the flattest part of the aquifer, near the catchment outlet and near the springs of the streams in northern part of the catchment. This estimation of the travel time is strongly affected by the determination of the porosity of the subsurface under saturation and can not be easily obtained. The adopted scenario compromises measured values of porosity in the shallow subsurface at the site - ranging 0.4-0.6 [-], whereas fractured and weathered granite porosity value may typically range 0.01-0.1 [-].

Conclusions

Preliminary analyses of the fluctuation of ^{18}O in water are shown, with observable trends. Minor response seen in variation of the ^{18}O in the outflow is clear with respect to the development of the isotope content in precipitation and groundwater. Along with the minor variation of ^{18}O content in the groundwater, the significant transformation effect of the subsurface is supported. It is becoming evident that stormwater is composed of a high fraction of pre-event water is held in soil profile and groundwater released during the stormflow. Based on the monthly rainfall and outflow data, bulk response of the catchment is built showing relatively short mean residence time of water in the catchment ranging 2-3 months. Based on the groundwater modeling approach baseflow mean residence time of the deep groundwater within the catchment may range several months to several years.

Acknowledgements

This research has been supported by the Czech Science Foundation 205/06/0375. Groundwater Vistas 4 modeling package was provided free of charge by the developer for the research purposes.

References

IAEA, 2006: *Isotope Hydrology Information System. The ISOHIS Database.* Accessible at: http://isohis.iaea.org

Šanda, M., Hrnčíř, M., Novák, L., Císlerová, M. 2006: *Tracing of the water flowpaths in a mountainous watershed.* In: *Proceedings of the Eleventh Biennial conference of the Euromediterranean Network of experimental and representative basins (ERB)*. CRP - Gabriel Lippmann, Luxembourg: 131-132.

Šanda, M., Sobotková, M., Císlerová, M., 2007: *Water Flowpaths in the Mountainous Watershed Traced by 18-oxygen Isotope*. In: *Advances in Isotope Hydrology and its Role in Sustainable Water Resources Management*. IAEA, Wien: 419-425.