Modelling of groundwater runoff parameters development in different geological conditions

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Modelovanie vývoja parametrov podzemného odtoku v rôznych geologických podmienkach

Abstract: The main goal of the research was to study differences in groundwater runoff parameters development under different geological conditions, with the emphasis to extreme climatic conditions in dry years. Groundwater runoff parameters, represented by values of the base flow, groundwater recharge, and groundwater storage were modelled using the BILAN model, which is a lumped parameter hydrological model. Three sub-catchments were selected – the Upper Nitra, Upper Poprad and Upper Topľa in the Western Carpathians. The catchments differ not only by geological, but also by climatic conditions. The results showed that the lowest groundwater runoff represented by the specific groundwater runoff values forms in the crystalline rocks of the Vysoké Tatry Mts. The highest values were obtained in the Upper Nitra River sub-catchment. Results obtained by hydrological model were compared with values of groundwater runoff calculated using the method of Kille and the BFI+2 model. Different years were identified in evaluated catchments as the dry years. While in the Upper Nitra River sub-catchment, years 1983 and 1989 were identified as dry years, in the Poprad and Topľa River sub-catchments, the driest years were 1986 (in both catchments) and 1982 (Topľa) and 1993 (Poprad). The highest decrease of the groundwater runoff in the driest year reached 30 % in the Upper Nitra, 41 % in the Upper Topľa and 19 % in the Upper Poprad sub-catchments.

Keywords: Western Carpathians, Upper Nitra sub-catchment, Upper Poprad sub-catchment, Upper Topľa sub-catchment, groundwater runoff parameters, drought occurrence

1. INTRODUCTION

Groundwater runoff is one of the elements of hydrological balance, which represents its subsurface part. Formation of groundwater runoff is dependent on climatic, morphological, hydrological, geological, and hydrogeological conditions of the area. Groundwater runoff changes together with groundwater recharge and storage have a substantial influence on those usable groundwater amounts which can be used for water supply. At the same time, sufficient natural amount of groundwater together with the stream flow discharges create suitable conditions for ecological stability of the area.

Unfavorable climatic conditions can have the serious influence on surface and groundwater amounts in both extremes – surplus in the rainy conditions and lack in the dry ones. The research presented was oriented on the extreme of drought; development of groundwater runoff parameters was studied in three different catchments in Slovakia: the Upper Nitra River, the Upper Poprad River and the Upper Topľa River sub-catchments.

Research results of climatologists (Lapin & Melo, 2004) and hydrologists (Szolgay et al., 1997; Danihlik et al., 2004; Majerčáková et al., 2007) documented changes in hydrological balance elements in the majority of the Slovak catchments during the last 25 years. They show the increase of air temperature which is followed by the increased values of potential evapotranspiration. These factors, together with changes in precipitation amounts (changing differently in various parts of the Slovak territory) influence consequently the amount of water in the water balance – stream flow discharge, groundwater runoff, and storage.

2. NATURAL CONDITIONS

The Upper Nitra River sub-catchment is situated in the western part of Slovakia (Fig. 1). It covers the area of 181 km^2. The area is bordered by mountain range consisting of the Strážovské vrchy Mts. in the west, Malá Fatra Mts. in the north and Žiar Mts. in the east. The central plane with numerous surrounding valleys can be distinguished in the Upper Nitra catchment morphology. The Palaeozoic Tatric crystalline basement can be found in the south-western and south-eastern parts (Strážovské vrchy and Žiar Mts.). The largest part of the catchment consists of Mesozoic rocks of the Central Western Carpathian nappe structures (Tatric, Fatric and Hronic units): Strážovské vrchy Mts. in the west and Malá Fatra Mts. in the northern and eastern parts of the basin (Maheľ et al., 1985; Šimon et al., 1997). The central and southern parts of the Upper Nitra sub-catchment is mostly composed of Neogene fine-grained sediments. The Quaternary

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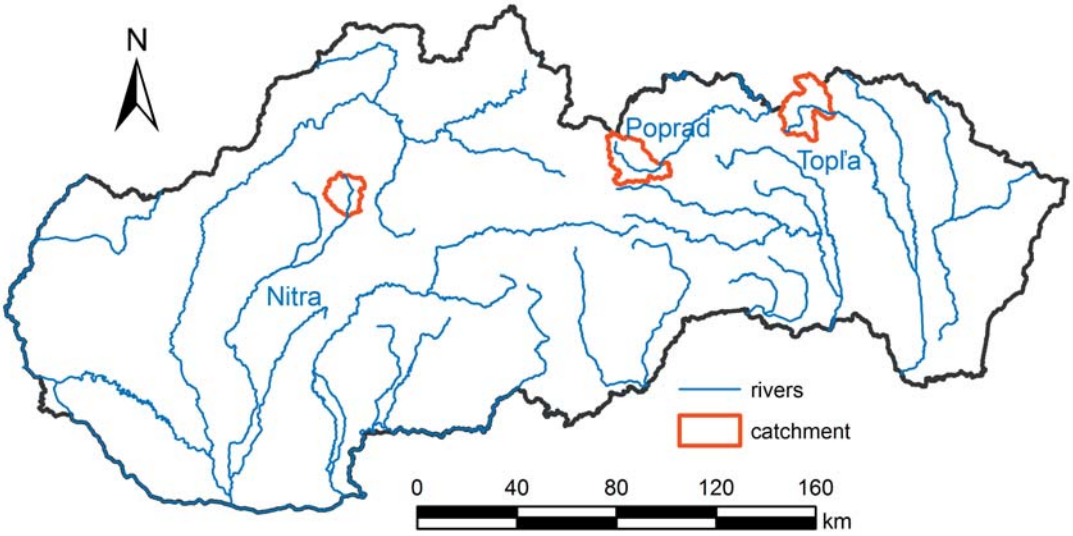

Fig. 1. Location of evaluated catchments.
Obr. 1. Lokalizácia hodnotených povodí.

cover is represented by alluvial sediments of the Nitra River and its tributaries (sands, gravels, loams) and by slope sediments of various compositions depending on the base rock (Šimon et al., 1997). The area belongs to a moderately warm, humid climatic region (Lapin et al., 2002) , with a mean annual precipitation of 650 mm in lower part and 1000 mm in higher altitudes (Faško & Šťastný, 2002). Mean annual air temperature is about 7–8 °C (Šťastný et al., 2002). The closing profile of the basin is situated in Nedožery–Brezany, where a gauging station with daily observations of discharge is located since 1931.

The Upper Poprad River sub-catchment, covering an area of 17.8 km^2 is located in the north-eastern part of Slovakia in the Vysoké Tatry Mts. (Fig. 1). The area is built by Palaeozoic crystalline rocks, mostly granitic (Tatric Unit), covered by the Quaternary glacial and slope sediments (Nemčok et al., 1993). The climatic conditions can be characterized as cold; the area belongs to the cool mountainous climatic sub-region according to the Lapin et al. (2002), with high amount of precipitation of 1600–1800 mm per year (Faško & Šťastný, 2002). The long-term air temperature averages measured at Štrbské Pleso meteorological station reached 3.6 °C for the period 1961–1990 (Šťastný et al., 2002) and the long-term annual precipitation amount was 991 mm for the period 1961–2000 and 1010 mm for the period 1961–2006 (Majerčáková et al., 2007). The discharge gauging profile No. 7990 Poprad at Štrbské Pleso is located in the altitude of 1264.5 m asl. and it is observed since 1977.

The Upper Topľa River sub-catchment, having an area of 265.04 km^2 is located in the north-eastern part of the Slovak territory (Fig. 1). It is smoothly modelled; the altitude varies from the 1157 m asl. up to 265 m asl. at the closing profile of the area in Bardejov. The area is built by Palaeogene flysch sediments (Magura Unit) of the Outer Western Carpathians. The upper part of the catchment is built by thick-bedded sandy flysch, central and lower part by the thick-bedded claystone dominated flysch. Flysch sediments are covered mostly by a thin layer of Quaternary sediments, which are better developed in the alluvial plain of the Topľa River and its tributaries (Nemčok et al., 1990). Hydrogeological conditions are not very favorable for groundwater storage. The area belongs to two climatic regions – the upper part to a moderately cool sub-region, the central part of the evaluated area to the moderately warm and humid sub-region of highlands and the lower part to moderately warm and humid sub-region of valleys (Lapin et al., 2002). The stream flow discharges in the gauging station Topľa-Bardejov are observed since 1967. The basic parameters of all three evaluated catchments are in Tab. 1.

Tab. 1. Basic parameters of evaluated basins.
Tab. 1. Základné parametre hodnotených povodí.

Catchment`s parameter	Štrbské Pleso	Nedožery-Brezany	Bardejov
River name	Poprad	Nitra	Topľa
Altitude (m asl.)	1264.5	288	265.04
Area (km^2)	17.8	181.57	325.5

3. DATA AND METHODS

Three methods of groundwater runoff evaluation were used – hydrological model BILAN (Kašpárek in Tallaksen et al., 2004), BFI+2 model (Gregor, 2008) and classical method of Kille (Kille, 1970; Fendeková & Fendek, 1999), often used for base flow estimation. The obtained results were compared and evaluated.

The BILAN model has been developed to simulate components of the water balance in a catchment (Kašpárek in Tallaksen et al., 2004). The model is based upon a set of relationships, which describe basic principles of the water balance both in the unsaturated and saturated zone. Time resolution is one day. Input data used for water balance computation are daily time series of basin precipitation, air temperature, and relative air humidity. The model simulates daily time series of potential and actual evapotranspiration, infiltration into the soil, and recharge from the soil to saturated zone. The amount of water stored in the snow cover, soil, and in saturated zone (groundwater storage) is also simulated. All variables are simulated for the basin as a whole (lumped physical model).

The model simulates total runoff Rm(i) as a sum of two compounds: direct runoff Dr(i) and the base flow BF(i). The direct runoff, in summer caused by high precipitation intensity, consists of compound of quick flow, which is able neither to evaporate nor to influence the soil water balance, and by interflow. The interflow contains surplus of water in the aeration zone in the assessed period. There is an assumption that the interflow is a part of the direct runoff mostly in the winter season or during the snow melting period. The slow compound of the total runoff is composed of the base flow BF(i), which is created by the outflow from the groundwater storage.

The potential evapotranspiration is calculated from the data on relative air humidity and air temperature. Conditions of winter and summer seasons are distinguished (regime types). Algorithm for the snow cover storage and snow melting is used when the snow cover occurs. Melting snow and rain infiltrate into the soil. The accumulated water is going to be consumed by vegetation in the next period (potential evapotranspiration) until there is a sufficient water amount in the soil. In the case of lack of soil water, the actual evapotranspiration is less than the potential. During the wet months (precipitation amounts are higher than the potential evapotranspiration), precipitation surplus recharges the soil water storage. After reaching the maximum soil capacity, the process of percolation from the soil to groundwater occurs. The percolation can be quick – in the form of the interflow towards the surface stream, or slow – directed down, through the aquifer.

Besides the precipitation, air temperature and relative air humidity, also stream flow discharges were used as the input data, recalculated into the runoff depth value. The evaluated time period was the period 1981–2000.

The following gauging stations were used for the Upper Nitra River sub-catchment: precipitation stations in Nitrianske Pravno (351 m asl.), Chvojnica (435 m asl.), Valaská Belá–Gápeľ (490 m asl.), Slovenské Pravno (500 m asl.), Vrícko (603 m asl.) and Prievidza (260 m asl.). Air temperature and air relative humidity data were used from the nearest climatological station in Prievidza (260 m asl.). The air temperature data were recalculated for the mean catchment altitude using the gradient valid for the Slovak Republic with the value of -0.52 °C/100 m. The discharge data from the gauging station No. 6540 Nedožery–Brezany were used.

The upper part of the Poprad River catchment was modelled using the data from the precipitation stations in Poprad (695 m asl.), Tatranská Lomnica (827 m asl.), Štrba (829 m asl.), Skalnaté Pleso (1783 m asl.), Lomnický štít (2635 m asl.) and Štrbské Pleso (1264 m asl.). The data on air temperature and

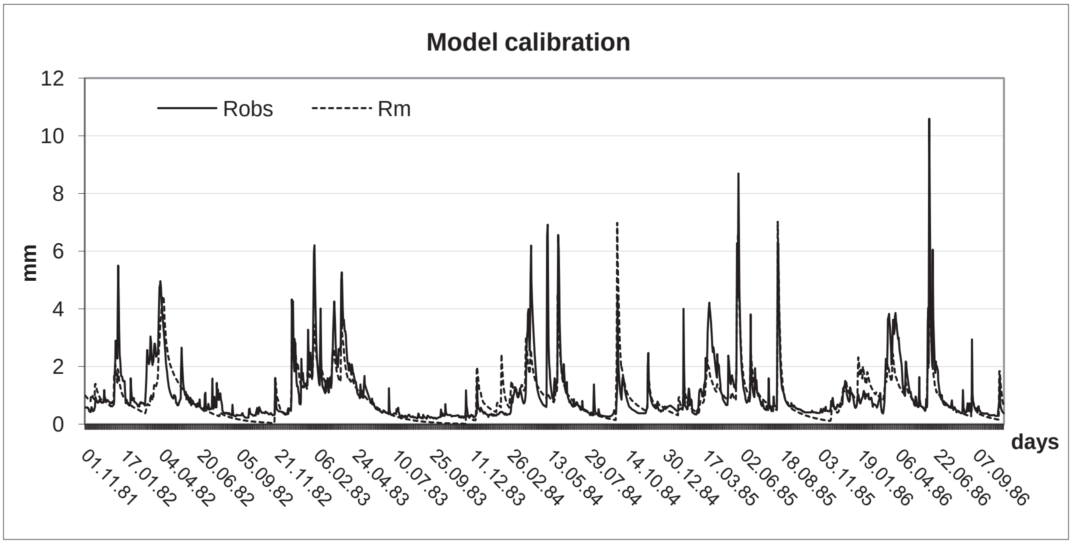

Fig.2. Course of observed (Robs) and simulated (Rm) total runoff in the gauging station Nedožery-Brezany during the calibration period.

Obr.2. Priebeh pozorovaného (Robs) a simulovaného (Rm) celkového odtoku v stanici Nedožery-Brezany počas kalibračného obdobia.

relative humidity were used from the Štrbské Pleso climatological station. The discharge data were taken from the discharge gauging station No. 7990 Štrbské Pleso.

Modelling of the base flow changes in the Topľa River sub-catchment was based on data from precipitation gauging stations in Malcov (282 m asl.), Bardejov (305 m asl.), Sveržov (348 m asl.), Cígeľka (510 m asl.), Kríže (549 m asl.) and Livovská Huta (667 m asl.). Mean air temperatures and relative air humidity were calculated by the nearest neighbor method, based on the data from climatological stations in Stropkov (216 m asl.), Plaveč nad Popradom (485 m asl.), Bardejov (305 m asl.) and Sabinov–Jakubovany (410 m asl.). Stream flow discharges from the gauging station No. 9450 Topľa–Bardejov were used.

The model calibration was based on the time period of 1.11.1981–31.10.1986 for the Nitra and Poprad River catchments. The Topľa River catchment is larger, therefore the shorter period 1.11.1981–31.10.1983 was used as the calibration period. It was necessary to estimate the optimal dispersion of the calibration parameters during the calibration process. The Nash-Sutcliff efficiency (NSE) was used as the optimization criterion (Nash & Sutcliffe, 1970).

The example of the model calibration for the Upper Nitra River sub-catchment is in Fig. 2 where the course of observed (Robs) and simulated discharge (Rm) is showed. The Nash-Sutcliff efficiency was equal to 0.6, which was a quite good efficiency value depending on time series length. The Nash-Sutcliff efficiency values vary between 0 and 1, values closer to 1.0 reflect the good accordance between observed and simulated values. The course of the base flow together with the total simulated runoff is given in Fig. 3.

Model optimization was checked also by comparison of the simulated base flow data and observed groundwater levels,

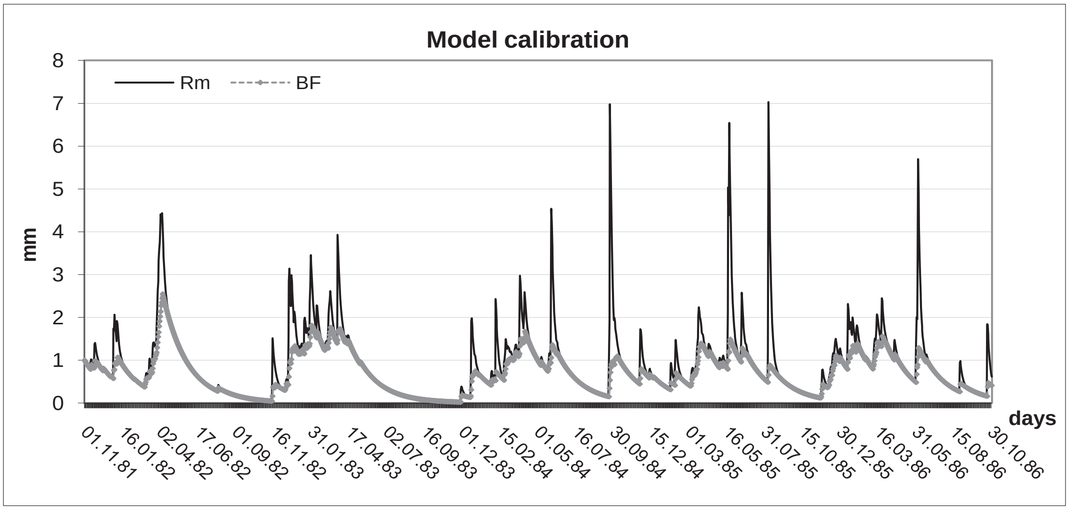

Fig.3. Separation of the baseflow (BF) from the modelled runoff Rm during calibration.

Obr.3. Separácia podzemného odtoku (BF) z modelovaného odtoku Rm počas kalibrácie.

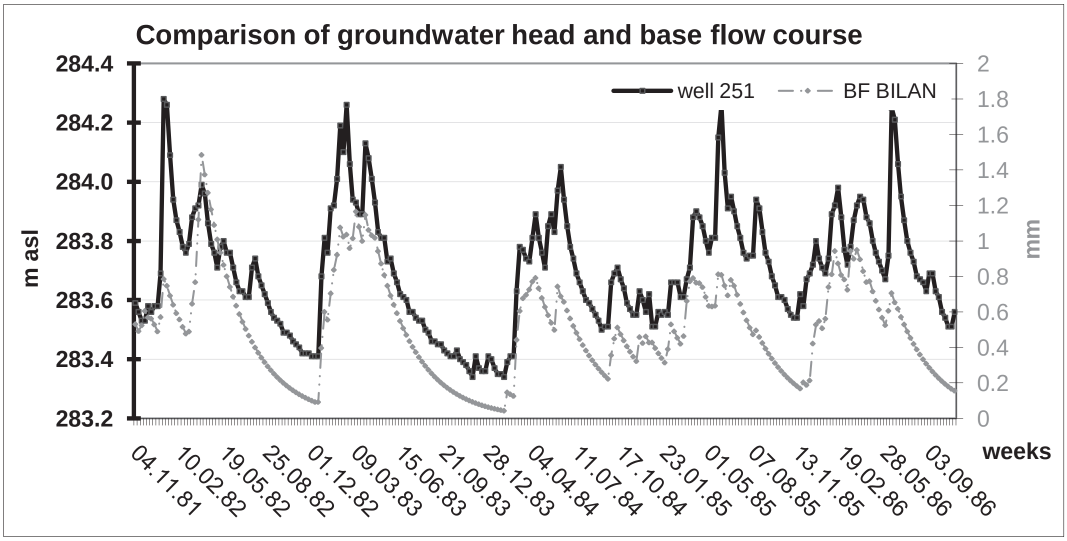

Fig.4. Comparison of the groundwater head (well 251) and baseflow (BF BILAN).

Obr.4. Porovnanie hladiny podzemnej vody (well 251) a základného odtoku (BF BILAN).

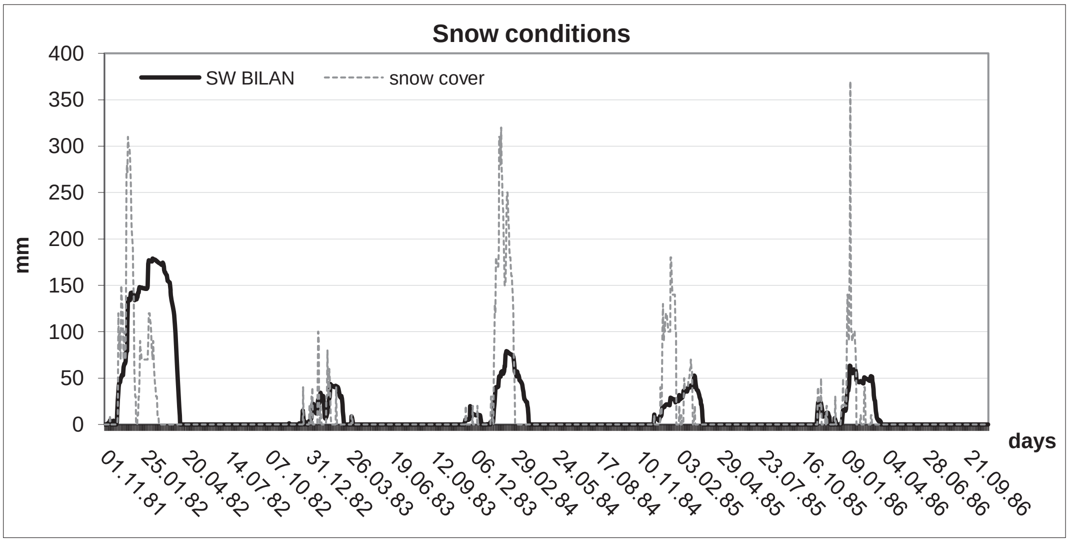

Fig.5. Comparison of the simulated amount of water in snow cover (SW BILAN) with the occurrence of observed snow cover (snow cover).

Obr.5. Porovnanie simulovaného množstva vody v snehovej pokrývke (SW BILAN) s výskytom pozorovanej snehovej pokrývky (snow cover).

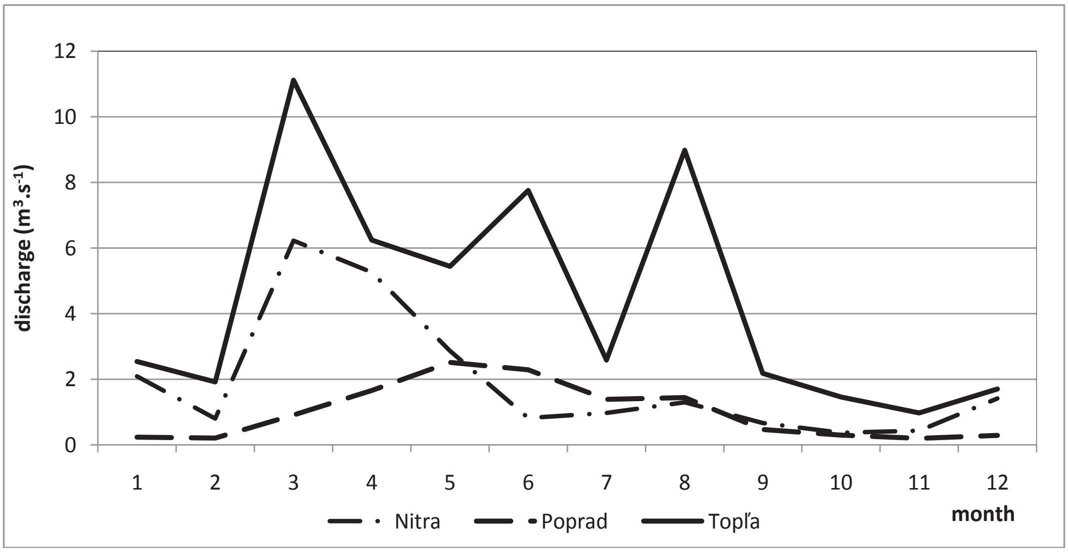

Fig. 6. Seasonal course of discharges.

Obr. 7. Sezónny priebeh prietokov.

if they were at the disposal. The course of the base flow and groundwater heads in Nedožery–Brezany observation well No. 251 is showed in Fig. 4. The well is located in the left side of the alluvial plain of the Nitra River in app. 690 m southeast of the discharge gauging station.

The course of the snow cover thickness for the Prievidza station was compared with the simulated values of snow cover and snow water storage (Fig. 5) in order to check the correctness of the modelled snow cover thickness which influences importantly the snow melting process in the spring.

The same methods were used in the Topľa River catchment. The verification of the base flow course in the Poprad River catchment was done only by comparison of the base flow with the total simulated runoff because there were no data on groundwater head monitoring at the disposal.

The BFI+2 model (Gregor, 2008) was used as another one method for base flow calculation. The method is based on the original model of the Institute of Hydrology in Warlingford (1980), which was re-programmed by Gregor (2008). The base flow value is calculated from a hydrograph smoothing and separation procedure using daily discharges. The model is based on the local minimum method, where the minima of N-days non-overlapping consecutive periods are calculated and turning points of this sequence of minima are identified. A minimum

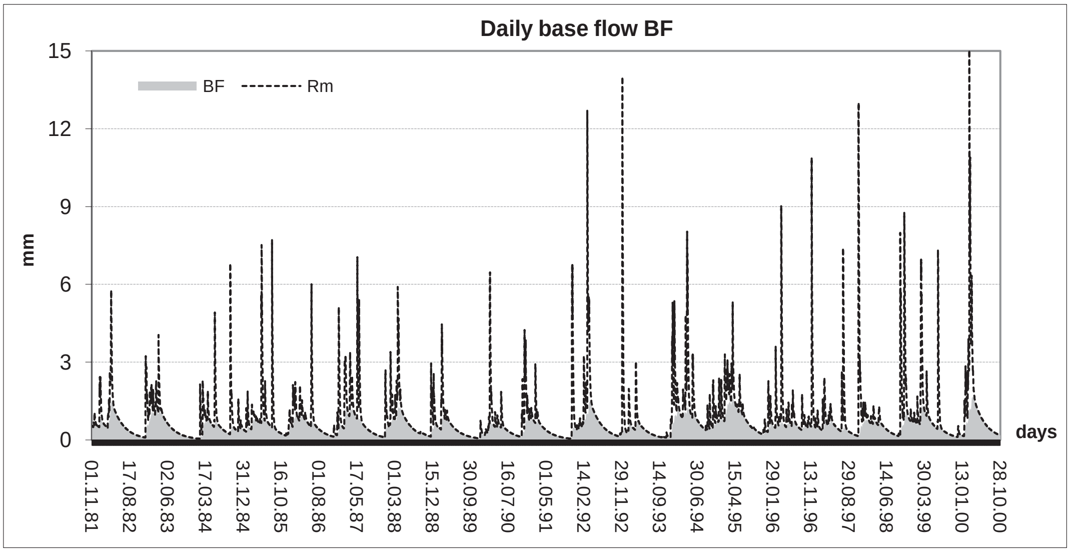

Fig. 7. Course of the daily base flow (BF) in comparison with the simulated total runoff (Rm).

Obr. 7. Priebeh denného základného odtoku (BF) porovnaný so simulovaným celkovým odtokom (Rm).

becomes a turning point if its value multiplied by 0.9 is less than or equal to the neighboring minima. The daily base flow separation line is calculated for the whole period by linear interpolation between all turning points (Tallaksen et al., 2004). The original BFI program (Institute of Hydrology, 1980) used constant length of N-days period being equal to 5 days. The studies performed for Slovak catchments (Stojkovová, 2010; Fendeková et al., 2010); however, showed that the utilization of a 5-days period gives overestimated values of the base flow in comparison with other methods (eg. method of Kille) often used in Slovak hydrogeological practice. Therefore the original BFI program was re-programmed by Gregor (2008) into the version BFI+2, where the length of N-days period can be chosen by the user.

The third method used for calculation of the base flow values is the method of Kille (Kille, 1970) which is based on minimum monthly discharges of a 10-years period. After sorting the data in ascending order, the obtained curve is fitted by a liner regression in the lower part and by the exponential regression in the upper part of the ensemble of points. The use of the method in the Slovak hydrogeological practice was critically reviewed by Fendekova & Fendek (1999). The disadvantage of the method is that using the method of Kille, only long-term values of the groundwater runoff can be obtained. On the other hand, the method is considered to be representative for groundwater runoff estimation in most hydrogeological units of Slovakia.

4. RESULTS

Analysis of discharge data showed the differences in their seasonal course (Fig. 6). While in the Nitra and Topľa River sub-catchments the peak maximum discharges are typical for the early spring months (March), in the higher altitudes of the Poprad catchment they are shifted towards the late spring-early summer months (May–June). However, in all three catchments, the reason of discharge increase is the snow melting in the catchment.

In all catchments the decreasing trends of stream flow discharges were documented. Majerčáková et al. (2007) studied changes in discharges in the Vysoké Tatry Mts., including the Poprad River, Stojkovová (2010) documented similar changes in the Topľa River catchment and Machlica (2010) in the Upper Nitra catchment.

Model BILAN was used first of all for evaluation of the subsurface hydrosphere compounds, as base flow (BF), groundwater storage (GS) and groundwater recharge (RC) with emphasis put on extreme climate situations of precipitation insufficiency.

4.1. Upper Nitra River sub-catchment

Base flow formation

Base flow values (BF) vary according to BILAN model results mostly in the interval of 0.2–1.2 mm per day. The minimum BF value was 0.043 (2.2.1984), maximum value 1.69 mm (2.4.2000) and the mean value was 0.53 mm per day. Maximum BF values occur from the second half of the March up to the first half of the April. Minimum daily values occur mostly in the beginning of November and last until the first half of December (Fig. 7). The long-term BF value for the evaluated period recalculated into volumetric units was 1.09 $m^3.s^{-1}$.

Groundwater recharge and storage

Groundwater recharge (RC) and storage (GS) values are influenced mainly at the end of spring (end of April and beginning of May). In this period, the intense precipitation events occur more often in the area and moreover, they are combined with the snow melting in the catchment. As the consequence, base flow values increase. The second period typical by groundwater recharge occurs at the end of autumn and lasts until the beginning of winter (Fig. 8). Groundwater is recharged when the snow

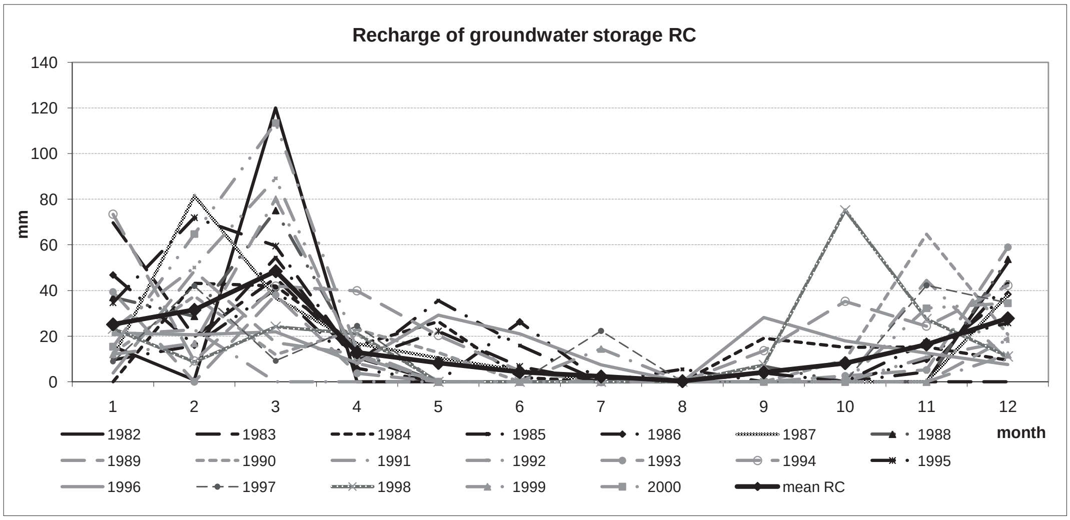

Fig. 8. Average monthly values of groundwater recharge (RC).

Obr. 8. Priemerné mesačné hodnoty napájania podzemných vôd (RC).

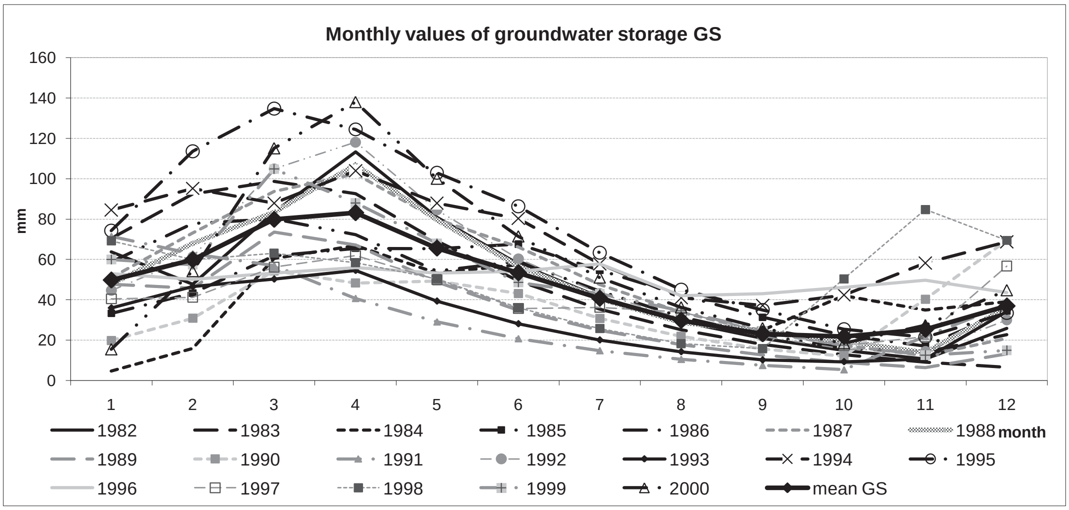

Fig. 9. Average monthly values of groundwater storage (GS) in mm.

Obr. 9. Priemerné mesačné hodnoty zásob podzemnej vody (GS) v mm.

precipitation and temporal snow cover is transforming into the liquid precipitation infiltrating into the soil, recharging the groundwater storage and increasing the base flow values. This process is conditioned by climatic conditions, the air temperature above or close to zero is necessary leading to slow snow melting and water infiltration into the soil. In the case of quick air temperature increase, the majority of water would flow out in the form of direct runoff and only a small part of water would infiltrate into the soil.

When analyzing the monthly groundwater storage (GS) values course within the year, resulting from the BILAN model, the average values in January reach 51 mm, in February 63 mm, in March 81 mm and in April 84 mm. Then the decrease starts – in May the values reach 66 mm, in June 52 mm, in July 39 mm, in August 29 mm, in September 23 mm and finally in October only 22 mm (Fig. 9). The increase in groundwater storage values starts in November, reaching in average 27 mm and in December 38 mm per month. The largest deviations of groundwater storage from the average value of 48 mm occur in February, March, and April. The lowest February value of 16 mm occurred in 1984, the highest values of 114 mm in February and 135 mm in March occurred in 1995. In the rest of evaluated years the GS value varied in the interval 50–100 mm per month. The absolutely highest value of GS was calculated for April 2000 with 138 mm and the second highest in April 1995 with 124 mm.

4.2. Topľa and Poprad River sub-catchments

Base flow

The same analysis as for the Upper Nitra was accomplished also for the Topľa and Poprad River sub-catchments. The base flow in the Topľa sub-catchment reaches from 0.2 to 1 mm per day, similarly to the Upper Nitra area. The daily BF value for the Poprad River makes 0.2 to 3 mm. The long-term base flow value for Topľa River at Bardejov is 2.03 $m^3.s^{-1}$ and for Poprad River at Štrbské Pleso it is only 0.39 $m^3.s^{-1}$.

Groundwater storage and recharge

Groundwater recharge in the Topľa River catchment in January and February makes about 32 mm and reaches the highest values in March and April with 55 mm. Then the decrease in groundwater recharge and storage occurs up to the minimum value of 22 mm at the end of September, and in October. The increase in GS values follows in November and continues in December. The most important months for groundwater recharge are spring months March–April, and then November up to beginning of winter (beginning of December). The groundwater recharge reaches around 40 mm per month. Occasionally, during the summer months in connection with intense storms, the groundwater storage can increase, too. The groundwater storage values course in the Topľa River sub-catchment is similar to that one in the Nitra River area.

The situation in groundwater recharge and storage values in the Poprad River at Štrbské Pleso differs significantly from the previous catchments. Minimum values of groundwater storage are reached in January–March (40–50 mm). The values start to increase rapidly from 50 mm in April to 180 mm in May reaching the maximum in June with the value of app. 200 mm. Then there is a continual decrease until the December with the value of 80 mm. Such a shift of GS values in comparison with the Nitra and Topľa River sub-catchments is caused by different physical-geographical conditions – higher altitude, the highest precipitation amounts, highest number of cold days and the lowest number of warm days in Slovakia.

Groundwater recharge occurs dominantly in snow melting period which is typical for May. The average monthly recharge in this month is app. 175 mm. Then the decrease starts, with app. the same decrease rate as the increase in April to May period. In July–August period the groundwater recharge makes app. 70 mm per month, followed by another decrease up to less than 10 mm in December.

4.3. Base flow values calculated by BFI model and method of Kille

Results of the BFI+2 and method of Kille are given in Tab. 2. In order to obtain comparable data for different catchment areas, the resulting groundwater runoff values in $m^3.s^{-1}$ were re-calculated into the specific groundwater runoff in $m^3.s^{-1}.km^{-2}$. It was clearly showed that the smallest groundwater runoff develops in crystalline complexes in the Upper Poprad sub-catchment, higher values were obtained for hydrogeologically unfavorable flysch sediments in the Upper Topľa River sub-catchment and the highest values were estimated for the geologically variable conditions of the Upper Nitra River sub-catchment.

On contrary, the results of all three methods of groundwater runoff estimation were the most similar to each other for the Poprad sub-catchment, more variable for the Topľa and the highest dispersion of the three different methods utilization for the groundwater runoff estimation was typical for the Upper Nitra River sub-catchment.

4.4. Changes in groundwater runoff values in extreme climatic situations of dry years

Dry periods were identified in evaluated catchments using the classification of year wetness (Majerčáková et al., 2007). Yearly precipitation amounts were compared with the long-term (normal) precipitation value for period 1961–1990. According to the percentage of precipitation, each year was classified as either very wet, medium wet, moderately wet, normal, moderately dry, medium dry or very dry year.

Precipitation amounts from nine stations were analyzed in the Upper Nitra catchment. The years 1983 and 1989 were classified as very dry years in all nine stations. It was supposed that the base flow values, groundwater recharge and storage values would decrease. The model results confirmed this assumption only for the year 1989. The base flow values and groundwater storage was in 30 % lower in comparison with their long-term values, the groundwater recharge was lower in 40 %. The 1983 drought influenced only the groundwater recharge in app. 24 %,

Tab. 2. Comparison of groundwater runoff (BF) values obtained by different methods.

Tab. 2. Porovnanie hodnôt podzemného odtoku (BF) získaných rôznymi metódami.

	Kille	BFI	BILAN
Poprad – BF ($m^3.s^{-1}$)	0.360	0.353	0.390
BF specific ($m^3.s^{-1}.km^{-2}$)	0.020	0.019	0.022
Nitra – BF ($m^3.s^{-1}$)	0.955	0.804	1.100
BF specific ($m^3.s^{-1}.km^{-2}$)	5.259	4.429	6.025
Topľa – BF ($m^3.s^{-1}$)	1.116	1.480	1.510
BF specific ($m^3.s^{-1}.km^{-2}$)	3.428	4.547	4.639

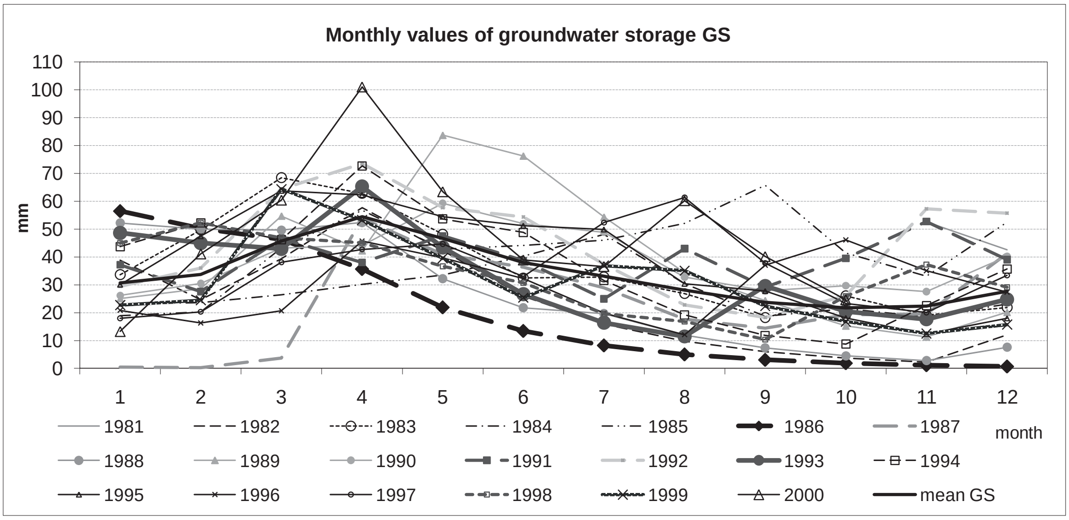

Fig. 10. Average monthly values of groundwater storage (GS) in dry years 1986 and 1993.

Obr. 10. Priemerné mesačné hodnoty zásob podzemnej vody (GS) v suchých rokoch 1986 a 1993.

the base flow values and groundwater storage were at the level of their long-term values.

Meteorological drought occurrence in the Topľa River catchment was analyzed in six precipitation stations. The years 1986 and 1993 were estimated as very dry in all stations, the year 1988 was very dry in five stations from six. The decrease in base flow, groundwater storage and recharge was confirmed by modelling results in both dry years (Fig. 10). The decrease in BF values reached 41 %, in GS 41 % and in RC 72 % in 1986 comparing to long-term values. The decrease in 1993 was much lower – it reached only 5 % in BF, 4 % in GS and 8 % in RC values.

In Poprad River sub-catchment two very dry years – 1982 and 1986 were identified in all four assessed precipitation stations. The decrease in BF, GS and RC values occurred in both years. The decrease in 1982 reached 24 % in BF and GS values and 21 % in RC values. Similar decrease was estimated also in 1986 with the values of 19 % in BF values and 23 % in RC values when comparing with the long-term values. Besides these two years, a very dry year was identified by Majerčáková et al. (2007) also in 1988 in Štrbské Pleso station, similarly to meteorological drought identified in the Topľa River sub-catchment.

5.CONCLUSION

The results of the subsurface hydrosphere elements modelling showed the different temporal development of groundwater runoff parameters in catchments of Nitra at Nedožery–Brezany and Topľa River at Bardejov in comparison with the Poprad River catchment at Štrbské Pleso gauging profile. The groundwater recharge and storage are shifted to late spring months in connection to different climatic conditions.

The groundwater runoff formation is very restricted in the conditions of crystalline rocks in the Upper Poprad River sub-catchment, despite of highest precipitation amounts in this area. The groundwater runoff expressed as specific groundwater runoff is higher in the Upper Topľa River catchment despite of hydrogeologically unfavorable flysch sediments building the catchment. The highest values were estimated for the Upper Nitra River sub-catchment.

The decrease of base flow, groundwater recharge and storage values in dry years occurred in all three evaluated catchments; however, the dry years were not identical. The year 1986 was identified as a dry year in the eastern part of Slovakia (Upper Poprad and Topľa River sub-catchments), but not in the western part (Upper Nitra River sub-catchment). The highest decrease in groundwater runoff, groundwater recharge and storage was estimated in the Topľa River sub-catchment, where it decreased in 41 % in comparison with the long-term base flow value and in 71 % when comparing with the long-term groundwater storage value. It seems that the flysch area is the most sensitive type of the rock environment from all three evaluated types to the occurrence of meteorological drought propagating from the atmosphere through the hydrological cycle up to the its subsurface part.

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Resumé: Hlavným cieľom výskumu bolo analyzovať rozdiely vo vývoji parametrov podzemnej zložky hydrosféry, ktorými boli podzemný odtok, dopĺňanie zásob podzemnej vody a vlastné zásoby v povodiach s rozdielnymi geologickými a hydrogeologickými pomermi. Dôraz bol daný na analýzu extrémnych klimatických situácií – vplyvu meteorologického sucha na tieto parametre. Parametre podzemného odtoku boli modelované pomocou fyzikálneho hydrologického modelu BILAN so sústredenými parametrami v časovom kroku jeden deň. Získané hodnoty podzemného odtoku boli prepočítané na hodnoty merného podzemného odtoku, čo umožnilo porovnanie týchto hodnôt pre tri čiastkové povodia s rôznou veľkosťou plochy. Pre účely výskumu boli vybraté tri čiastkové povodia, a to povodie hornej Nitry po profil Nedožery-Brezany, horného Popradu po profil Štrbské Pleso a hornej Tople po profil Bardejov. Tieto tri povodia sa líšia nielen geologickou stavbou a hydrogeologickými podmienkami, ale aj rozdielnymi klimatickými podmienkami. Získané hodnoty podzemného odtoku boli následne porovnané s výsledkami modelu BFI+2 (výpočet podzemného odtoku v dennom kroku metódou lokálneho minima) a výsledkami použitia Killeho metódy, ktorá umožňuje vypočítať priemernú dlhodobú hodnotu podzemného odtoku za obdobie minimálne desiatich rokov.

Získané výsledky poukázali na veľké rozdiely vo veľkosti merného podzemného odtoku v troch hodnotených povodiach. Najmenší podzemný odtok sa formuje v kryštalických horninách (tatrikum) povodia Popradu, kde dosahuje iba 0,02 $m^3.s^{-1}.km^{-2}$. Vyššie hodnoty boli získané pre povodie Tople budované flyšovými horninami (magurská jednotka) vonkajších Západných Karpát a najvyššie merné podzemné odtoky boli vypočítané pre povodie hornej Nitry budované pestrou škálou hornín od tatrického kryštalinika, mezozických sekvencií v obalovej a príkrovovej pozícii (fatrikum a hronikum) Strážovských vrchov, Malej Fatry a Žiaru až po neogénu výplň Hornonitrianskej kotliny a kvartérny pokryv.

Analýza výskytu suchých rokov dokumentovala rozdielne obdobia ich výskytu v jednotlivých povodiach. Zatiaľ čo v povodí hornej Nitry boli suchými rokmi roky 1983 a 1989, v povodiach horného Popradu Tople bol najsuchším rokom rok 1986 a roky 1982 (Topľa), resp. 1993 (Poprad). Najvyšší pokles v množstve vody v podzemnej zložke hydrosféry počas suchých rokov bol zaznamenaný v povodí Tople, kde v suchom roku 1986 poklesol podzemný odtok o 41 % a dopĺňanie zásob podzemnej vody až o 72 %.