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SNOW WATER EQUIVALENT MEASUREMENT AND SIMULATION IN MICROBASINS WITH DIFFERENT VEGETATION COVER

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This paper deals with the formation of snowmelt-driven floods in two experimental microbasins located in Slovakia's highlands (300–400 m a.s.l) near the town of Považská Bystrica, Slovakia in March 2006. The first basin (Rybárik) encompasses an area of 0.119 km^2 and is used primarily for agriculture; while the Lesný basin with its catchment area of 0.0864 km^2 is characterized as a forested land. The maximal specific outflow from the Rybárik basin was observed on March 28, 2006, with 281.3 l s^{-1} km^{-2}, peaking at 3 p.m. with 422 l s^{-1} km^{-2}. In the Lesný basin, the maximum outflow was observed on March 29, 2006, with its peak of 523 l s^{-1} km^{-2} at noon. In the second part the long-term trend of snow water equivalent (SWE) modeled by the HBV-light rainfall-runoff model in the Rybárik and Lesný microbasins were evaluated. After the model verification, the daily values of SWE for the period 1965/66–2005/06 were calculated for Rybarik and Lesný microbasins. From the results it follows, that, after a temporal decline in the maxima of snow depth and of SWE in the 1990s, SWE started to increase in 2002 again. The historically highest values of SWE were simulated in both experimental microbasins in the winter season of 2005/06.

KEY WORDS: Experimental Microbasins, Rainfall-Runoff Model, Snow Water Equivalent Simulation, Snowmelt.

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V príspevku je analyzovaná tvorba povodňového odtoku počas povodne z topenia sa snehu v marci 2006 na príklade dvoch experimentálnych mikropovodí lokalizovaných vo vrchovinovej časti Slovenska pri Považskej Bystrici (300–400 m n.m.), konkrétne z poľnohospodársky využívaného mikropovodia Rybárik (0,119 km^2), a zo zalesneného mikropovodia Lesný (0,0864 km^2). Maximálny meraný špecifický odtok z povodia Rybárik bol 281 l s^{-1} km^{-2} 28. marca 2006 (vrchol 422 l s^{-1} km^{-2} o 15.00 hod.). Maximálny meraný špecifický odtok z povodia Lesný 263,7 l s^{-1} km^{-2} bol zaznamenaný 29. marca 2006 (vrchol 523 l s^{-1} km^{-2} o 12.00 hod.). V druhej časti príspevku je analyzovaný dlhodobý vývoj vodnej hodnoty snehu (SWE) v povodí Rybárik a Lesný, modelovanej zrážko-odtokovým modelom HBV-light. Po kalibrácii a verifikácii modelu boli modelom vypočítané denné vodné hodnoty snehu za 42-ročné obdobie 1965/66–2005/06. Z výsledkov vyplýva, že po dočasnom poklese maxím vodnej hodnoty snehu SWE v deväťdesiatych rokoch minulého storočia od roku 2002 došlo k opätovnému zvýšeniu vodnej hodnoty snehu. V zimnej sezóne 2005/06 bola vypočítaná najvyššia hodnota SWE od začiatku pozorovaní v oboch mikropovodiach.

KĽÚČOVÉ SLOVÁ: experimentálne mikropovodia, zrážko-odtokový model, vodná hodnota snehu, topenie snehu.

Introduction

The thick snowcover and intense warming of air, along with elevated rainfall totals in the whole Danube basin at the end of March 2006 resulted in extreme floods on small as well as middle-sized Danube tributaries, and on the middle and lower Danube itself. Therefore, the formation of snowcover in the 2005/06 winter season deserved consideration.

Over the past 20 years, remote sensing research has undergone major advances in its capability of monitoring and measuring snow-related processes (*Rango*, 1993; *Turpin* et al., 1999). *Elder* et al., (1991) analyzed snow accumulation and distribution in an alpine watershed in California, USA. They combined field measurements of SWE with the physical attributes of the watershed to identify similarities between classes of SWE. In Norway, snow distribution was studied, among others, by *Bruland* et al. (2004). They observed a decrease in the mean annual maximum snowpack value and its duration (*Vikhamar Schuler* et al., 2006). Similarly, *López-Moreno* and *Vicente-Serrano* (2007) found a decrease in winter and early spring snow accumulation in the second half of the 20th century in the Spanish Pyrenees. They explained the changes in snowpack by global atmospheric circulation patterns, especially the North Atlantic Oscillation (NAO). Changes of snowcover in the Czech Republic (CZR) were studied by *Němec* and *Zusková* (2005). They processed a series of areal seasonal means of maximum snowpack depths in the Czech Republic for the period 1926–2005. The trend they found in these series indicates a decline in the 1990s. However, over the last years, snowcover in the Czech Republic has been increasing again. Similarly in Slovakia, a decline in snowpack durations was observed in the 1990s (*Holko* et al., 2005). The seasons 2004/05, 2005/06 and 2008/09 were extremely rich in snow in Slovakia and Central Europe also.

In the 1970s, first attempts to simulate snow storage started with the development of the first rainfall-runoff models (*Martinec*, 1985; *Bergström* and *Forsman*, 1973; *Bergström*, 1975). In Slovakia *Turčan* (1978), *Babiaková* (1978), *Svoboda* (1983) or *Mendel* et al. (1993) developed then-novel forecasting methods (designed as ERM model (Empirical Regressive Model), YETI model or NONLIN model).

Over the past few years, many snow models have been developed in the world (*Boone* et al., 2004; *Blőschl* et al., 2005). The degree of complexity of these models is highly variable, ranging from simple index methods to multi-layer models that simulate snow-cover stratigraphy and texture. For example, in the framework of the Snow Model Intercomparison Project (SnowMIP), 23 models were compared using observed meteorological parameters from two mountainous alpine sites (*Etchevers* et al., 2004). This project continues in SnowMIP2 project oriented on forest snow processes (*Rutter* and *Essery*, 2006).

In Slovakia, SWE observation, evaluation, and first of all modelling, has been the centre of attention in the experimental catchment Jalovec Creek of the IH SAS in the High Tatra Mountains (*Holko* and *Kostka*, 2006; *Pecušová* et al., 2004; *Holko* et al., 2003, 2005). Results of the SWE modelling in the upper Váh and Hron catchments by the WaSim-ETH distributed model were summed up in their monograph (*Holko* et al., 2005). Nowadays, in Slovakia SWE observation and the rainfall-runoff models are developed by *Hlavčová* et al. (2006, 2008), *Komorníková* et al. (2008), *Hríbik* et al. (2006), *Hríbik* and *Škvarenina*, (2007), or *Szolgay* et al. (2007).

By the 1960s, the Institute of Hydrology, Slovak Academy of Sciences (IH SAS) initiated a monitoring program aimed at studying snowpack formation processes in its experimental basin drained by the Mošteník Creek near Považská Bystrica, Central Slovakia. Meteorological elements (air and soil temperature, precipitation, wind velocity, interception, evapotranspiration) along with stream flow data were monitored simultaneously in the experimental microbasins Rybárik and Lesný over the whole history of the program. These data were used for calibration of the HBV-light rainfall-runoff model and for simulation of SWE in the Rybárik and Lesný basins for a series of 42 years (1964/65 to 2005/06), based on a daily time-step. Simulated SWE values were used for temporal evaluation of the snowpack formation in the studied region of Slovakia.

The aims of the study are:

1. Analysis of the snowmelt flood in two experimental microbasins (Rybárik and Lesný) with different vegetation covers in March 2006.
2. Evaluation of simulation results of the SWE series (obtained from the HBV-light model) in the Rybárik catchment within the period 1964/65–2005/06.

Analysis of the snowmelt-driven flood in March 2006

Combination of the extreme snow storage even at the lowest and middle locations, the substantial warming up and high precipitation (from 26 March 2006 to 31 March 2006) caused serious floods on several rivers in Slovakia and on the middle and low part of the Danube River, too.

In general, occurrence of floods during the spring snowmelt depends on several factors. Among these the most influential is the development and spatial distribution of air temperature along with the development and distribution of the liquid precipitation during the snowmelt period. The combination of these two factors combined with the effect of frozen ground beneath the snowpack, which inhibits the infiltration and increases the direct runoff, is the main cause of the snowmelt-driven flood events.

Description of the experimental catchments

For evaluation of the March 2006 flood, we used the experimentally observed data from two microbasins – Rybárik and Lesný – located in the Field Hydrological Laboratory (FHL) of the Mošteník Creek. The experimental basin of the Mošteník Creek up to its outlet point at Fapšová has an area of 17.2 km^2. The whole basin has been divided into eight subbasins with a catchment area ranging from 0.0864 up to 12.61 km^2. Water level observations in the Mošteník basin started as early as 1958.

The area of the agricultural Rybárik microcatchment is 0.119 km^2 (90% of agricultural land). The catchment is located at altitudes between 369 and 434 m a.s.l. The length of the mainstream from its spring to the outlet is 256 m, its mean slope is 9.1 %, and the mean slope of the whole basin is 14.9 %. Mean annual precipitation over the Rybárik basin is 738.0 mm, the mean annual runoff is 231 mm, runoff coefficient is 0.313 and the mean annual air temperature is 8.1 ^{o}C (period 1965–2004). The Lesný experimental microbasin is located directly in the vicinity of the Rybárik basin; the vegetation cover is consists of hornbeam forest and the catchment area is 0.0864 km^2. The mean annual runoff in the Lesný basin is 163 mm with a runoff coefficient of 0.221. Geological bedrock of the both microbasins is formed by flysh (marl, slaty marl, sandstone), with low permeability for groundwater flow. A more detailed description of the both microbasins Rybárik and Lesný is e.g. in *Pekárová* et al., (2005, 2006).

The data

In 1958, two Thomson-type weirs were installed at the outlet from the Rybárik and Lesný catchments (small weir (45^{o}) and a large weir (90^{o}) at each site). Water level recorders for each of the weirs are equipped with daily (since 1999 weekly) mechanical clock enabling short time step discharge evaluation for the both microbasins.

There were four meteorological stations in the Mošteník Creek basin (1958–1990). Since 1990, only the MS Kunovec is in operation. In 2000, an automatic meteorological station measuring air temperature with one-hour step was installed. A temperature sensor is located in a standard meteorological booth and checked for accuracy regularly with a conventional mercury thermometer. The mean daily temperature is calculated by the standard procedure from three daily measurements.

Daily precipitation amounts in the Mošteník basin were measured at 8 stations by a standard METRA raingauge with a 500 cm^2 surface area, at 7.00 a.m., and simultaneously also by the mechanical rain recorder. At the MS Kunovec since 2000 also an automatic rain recorder (as a part of the meteorological station) is located with continual rainfall sampling.

Snowpack depth and SWE have been measured at the meteorological station in Rybárik microbasin and since 1975 at the meteorological station Kunovec. Besides these regular observations, five snow observation surveys were conducted in 2006 in the catchments for their detailed mapping of the snow occurrence.

Evaluation of the snowmelt runoff and precipitation in March 2006

In the experimental microbasins Rybárik and Lesný, the first snow occurrence in the winter season 2005/06 was observed on November 11, 2005. The snowmelt in the Rybárik microbasin started on March 20, 2006; whereas in the forested Lesný catchment the snow started to melt some six days later on March 26, 2006. In Fig. 1, the specific runoff is shown in an hourly time step, from the microbasins Rybárik and Lesný. There are shown also the mean hourly air temperatures, and the mean daily precipitation amounts from the meteorological station Kunovec.

The measured maximum mean daily specific flow in the Rybárik basin was 281.3 $l\ s^{-1}\ km^{-2}$ on March 28, 2006; the maximum mean daily specific flow in the Lesný basin was 263.7 $l\ s^{-1}\ km^{-2}$ (March 29, 2006). The peak flow at Rybárik was 50.2 $l\ s^{-1}$ on March 28, 2006, at 3.00 p.m., corresponding to a specific flow of 422 $l\ s^{-1}\ km^{-2}$. The peak flow at Lesný was 45.2 $l\ s^{-1}$ on March 29, 2006, at noon with a specific flow of 523 $l\ s^{-1}\ km^{-2}$. Thus, the flood peak specific flow from the forested catchment was higher than that from the agricultural basin. This indicates, that under certain weather conditions, the influence of forest on the flood attenuation is minimal. In this particular case, the absence of flood peak dampening in the forested microbasin can be attributed, to some degree, to the occurrence of the liquid rainfall after

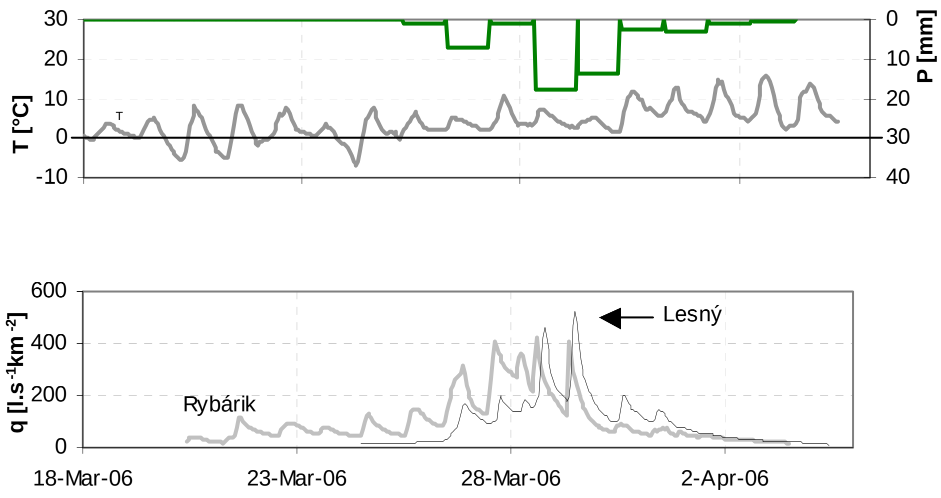

Fig. 1. Hourly specific runoff q during snowmelt in the Rybárik and Lesný basins from 18 March 2006 to 5 April 2006. Hourly air temperature T, and daily precipitation depth P in MS Kunovec.
Obr. 1. Hodinový špecifický odtok q počas topenia snehu z povodí Rybárik a Lesný od 18. marca 2006 do 5. apríla 2006. Hodinové teploty vzduchu T, denné úhrny zrážok P v MS Kunovec.

major part of the snowpack has been melted in the agricultural catchment.

On days with no precipitation (from 20 March 2006 to 26 March 2006), the maximum daily air temperatures occurred around 2.00 p.m., and maximum flow in the Rybárik occurred around 5.00 p.m. The time shift between air temperature and the peak flow is about 3.5–4 hours. In the forested Lesný catchment, this process started some six days later, and was probably enhanced partially by the liquid precipitation. Temporal shift of peaks ranges from 2 to 4 hours.

Daily fluctuations due to the daily snowmelt period caused practically in both catchments on April 1, 2006, when the snow storage in both catchments disappeared, and higher flows persisted up to April 4, 2006.

Temporal evaluation of the simulated SWE by the HBV-light model

In this study, we used the HBV-light rainfall-runoff model to simulate the SWE for the period 1964/68–2005/06. The HBV-light model was developed by *Seibert* (1998) and it has been applied to several catchments. For instance, *Hottelet* et al. (1994) compared the performance of the HBV-ETH model in three different types of catchments: the original alpine basin for which it was developed, and two smaller basins at much lower altitudes with a smaller snowpack and of a shorter duration.

HBV-light model description

The HBV-light model is a conceptual semi-distributed model, enabling rainfall-runoff process to be simulated with a short time-step, yet keeping low the number of input parameters. It uses subbasins as primary hydrological units, and within these an area-elevation distribution and rough classification of land use are made. The option of subbasins is usually used in geographically and climatologically heterogeneous basins. This model version contains following 15 basic parameters for runoff simulation that are determined by calibration. The HBV-light model consists of three main components:

– *standard snow accumulation and snowmelt subroutine*: this routine controls snow accumulation and works separately for each elevation and vegetation zone. (Parameters: TT – threshold temperature [°C], used in this routine to define the temperature above which snow melt occurs and also is used to decide whether precipitation is rain or snow, usual value is round about 0°C; SFCF – snow fall correction factor; CFMAX – degree-day factor [mm day^{-1}°C^{-1}], value: open air area – 3.5, forest – 2; WHC – the snow pack is assumed to retain melt water as long as the amount does not exceed a certain fraction given by this parameter (up to 0.1); CFR – refreezing coefficient, typical value is 0.05),

– *standard soil moisture computation subroutine*: this routine computes an index of the wetness of entire basin and integrates interception and moisture storage. (Parameters: FC – max moisture storage [mm], value: 100–350; LP – controls the shape of the reduction curve for potential evaporation [mm]: LP have to be smaller than FC; BETA – determines the relative contribution to runoff from rain or snowmelt at a given soil moisture deficit, value: 1–4),
– *standard runoff generation and runoff routing subroutine*: transform excess water from the soil moisture routine to discharge, for each subbasins. (Parameters: K0, K1, K2 – are recession coefficients, value: 0–1, K0 defines the higher recession coefficient in the upper zone, K1 the lower recession coefficient in the upper zone and K2 the recession coefficient in the lower zone, K0 ≥ K1 ≥ K2; UZL – threshold parameter, the maximal capacity of the upper zone [mm], value: 0–100 mm; PERC – percolation from the upper zone into the lower zone [mm day^{-1}]; MAXBAS – base (in days) in transformation function, value must be an integer).

It also contains parameters remaining constant during the whole calibration process, describing characteristics of the catchment and of its climate.

For the HBV-light model, the usual time-step is one day; shorter time steps are also possible. The process of the runoff formation is described by two linear storages with several modifications.

Standard snow accumulation and snowmelt subroutine

The snow routine is based on a simple degree-day relation. Threshold temperature TT [°C] is used to define the temperature above which snowmelt occurs and also is used to decide whether precipitation is rain or snow. The equation for the volume of the melting water from the snow pack is:

$$QM = (T - TT) \cdot CFMAX \tag{1}$$

where T – measured mean daily air temperature in the elevation zone [°C];
TT – threshold temperature [°C];
QM – volume of the melting water from the snow pack [mm day^{-1}];
CFMAX – degree-day melting factor [mm day^{-1} °C^{-1}].

Catchments with distinct altitudinal stratification can be subdivided into several zones according to their respective altitudes. This subdivision is influencing the snow- and the soil-moisture- subroutines. Each of these altitude zones can be, in addition, subdivided into more vegetation zones (e.g. forested and forest free subzones).

Input data into the HBV-light model

The HBV-light model was calibrated for both microbasins: Rybárik and Lesný. As input data for the runoff simulation in the microbasins were used the daily precipitation depths, mean daily air temperatures, and monthly averages of the potential evapotranspiration calculated by *Miklánek* (1994, 1995). The input data were obtained from the Kunovec meteorological station.

Model calibration and verification

In both basins, we calibrated the model by the GAP optimisation subroutine, using a comparison of the observed and simulated runoff values from ten water years 1964/65–1973/74. Model parameters used in calibration process for both microbasins are presented in Tab. 1. The time period from 1974/75 to 1983/84 was used for the model verification. The successfulness of the calibration and verification of the HBV-light model for Rybárik microbasin evaluated by different usual methods is presented in Tab. 2.

Simulation of daily snowpack water equivalents

We used the calibrated HBV-light model for a simulation of daily mean SWE values in the Rybárik and Lesný basins for the time period from 1964/65 to 2005/06. We compared the simulated daily SWE values to the weekly observations at the Kunovec meteorological station (Fig. 2a, 2b) (period 1999–2006).

In Fig. 3a), a detailed comparison between the simulated daily SWE and the SWE values measured during five field expeditions in Rybárik and Lesný microbasins (November 1, 2005 to April 15, 2006) is presented. Comparison of modelled and observed daily discharge during 1 November 2005 to 15 April 2006 in Rybárik and Lesný basins is shown in Fig. 3b).

T a b l e 1. Parameters of the HBV-light model in Rybárik and Lesný basins.
T a b u ľ k a 1. Parametre modelu HBV-light pre povodie Rybárik a Lesný.

Parameter	Rybárik	Lesný	Parameter	Rybárik	Lesný
TT	0.250	0.50	PERC	0.4	0.389
CFMAX	2.796	1.57	UZL	8	8.06
SFCF	0.902	0.546	K0	0.234	0.67
CFR	0.03	0.059	K1	0.1354	0.146
CWH	0.001	0.00027	K2	0.0185	0.0018
FC	117.1	240	MAXBAS	1.5	2.66
LP	0.333	0.326	Cet	0.058	0.056
BETA	2.513	4.448			

T a b l e 2. Results of calibration and verification of the HBV-light model in Rybárik basin.
T a b u ľ k a 2. Výsledky kalibrácie a verifikácie modelu HBV-light v povodí Rybárik.

Rybárik, calibration	Rybárik, verification
Water balance [mm year^{-1}]	Water balance [mm year^{-1}]
Sum Qsim = 260	Sum Qsim = 260
Sum Qobs = 260	Sum Qobs = 247
Sum Precip. = 760	Sum Precip. = 751
Sum act. ET = 500	Sum act. ET = 498
Sum pot. ET = 562	Sum pot. ET = 565
Contribution of Q2 = 0.333	Contribution of Q2 = 0.329
Contribution of Q1 = 0.487	Contribution of Q1 = 0.484
R2= 0.618	R2 = 0.678
Efficiency of the model = 0.6147	Efficiency of the model = 0.662
Efficiency (using ln(Q)) = 0.7363	Efficiency (using ln(Q)) = 0.796
Mean difference [mm year^{-1}] = 0	Mean difference l [mm year^{-1}] = –13

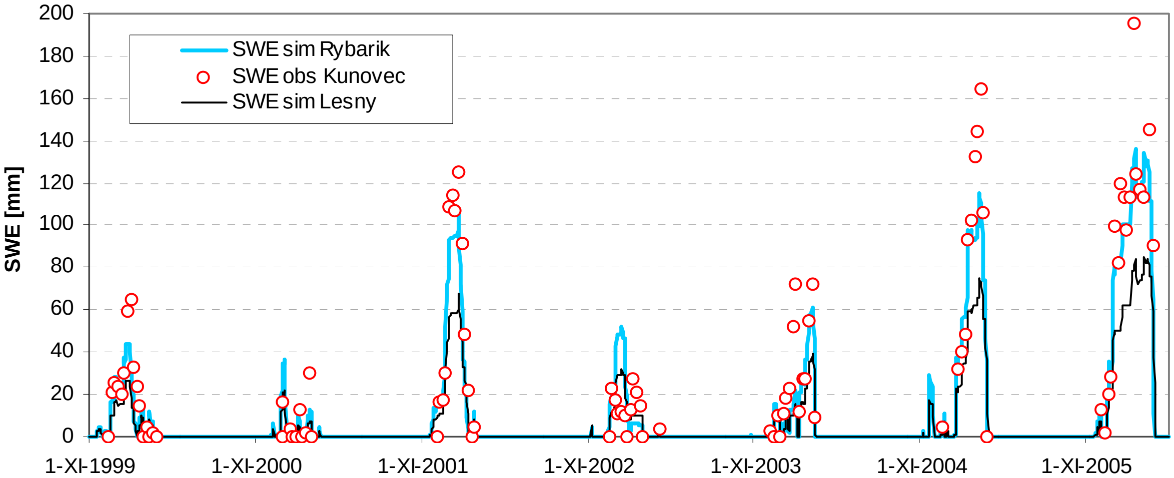

Fig. 2. The course of daily snow water equivalent (SWE) from 1 November 1999 to 31 March 2005 modelled with HBV-light model in Rybárik basin and measured in MS Kunovec.
Obr. 2. Priebeh modelovanej vodnej hodnoty snehu (SWE) v povodí Rybárik a meranej vodnej hodnoty snehu v MS Kunovec od 1. novembra 1999 do 31. marca 2005.

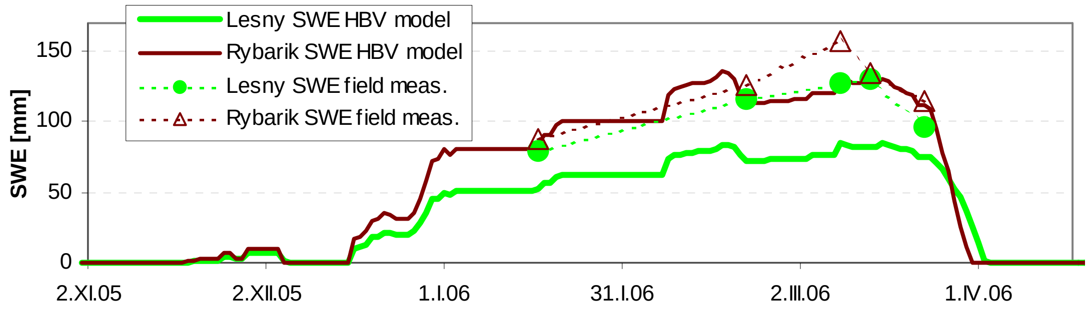

Fig. 3a) Comparison of simulated daily snow water equivalent from 1 November 2005 to 15 April 2006 with field experimental snow water equivalent measurements in Rybárik and Lesný basins.
Obr. 3a) Porovnanie modelovaných denných hodnôt SWE od 1. novembra 2005 do 15. apríla 2006 s meraniami SWE počas piatich expedičných meraní v povodiach Rybárik a Lesný.

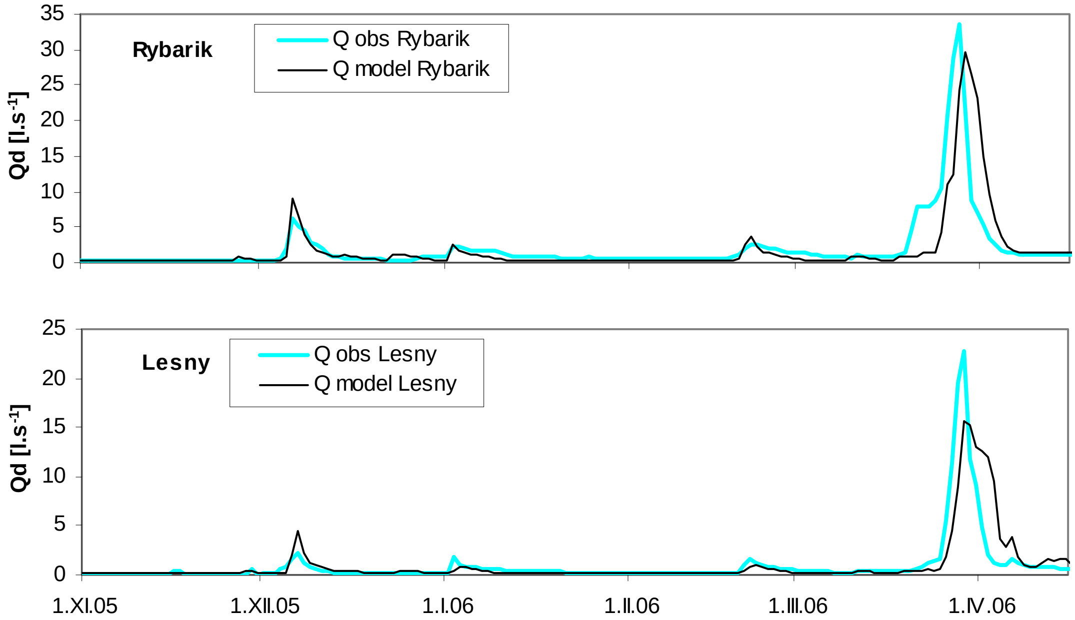

Fig 3b) Comparison of modelled and observed daily discharge 1 November 2005 to 15 April 2006 in Rybárik and Lesný basins.
Obr. 3b) Porovnanie modelovaných a meraných denných prietokov od 1. novembra 2005 do 15. apríla 2006 v povodiach Rybárik a Lesný.

Evaluation of simulation results

The comparison between the observed and simulated discharges and SWE values indicates satisfying fit-goodness of the simulations. It is therefore plausible to use the HBV-light model for calculation of daily SWE values in the Rybárik and Lesný microbasins for the whole period with available data on daily precipitation and mean daily air temperature (after 1964/65), provided that no major changes in climate and land use occurred within the investigated period.

The time series of the mean monthly SWE values in the Rybárik basin for the period of 42 years, modelled by the HBV-light model, are shown in Fig. 4. Tab. 3 indicates that in January, February, and March 2006, the highest monthly means of SWE (considering the whole period of observations) have been attained (88.7; 116.9; 104.9 mm, respectively) in the Rybárik basin. Second in the order is the 2004/05 season, with the highest two-monthly SWE (February–79 mm, and March–78 mm). Third in the row with its highest two-monthly SWE value is the 1969/70 season. In Janu-

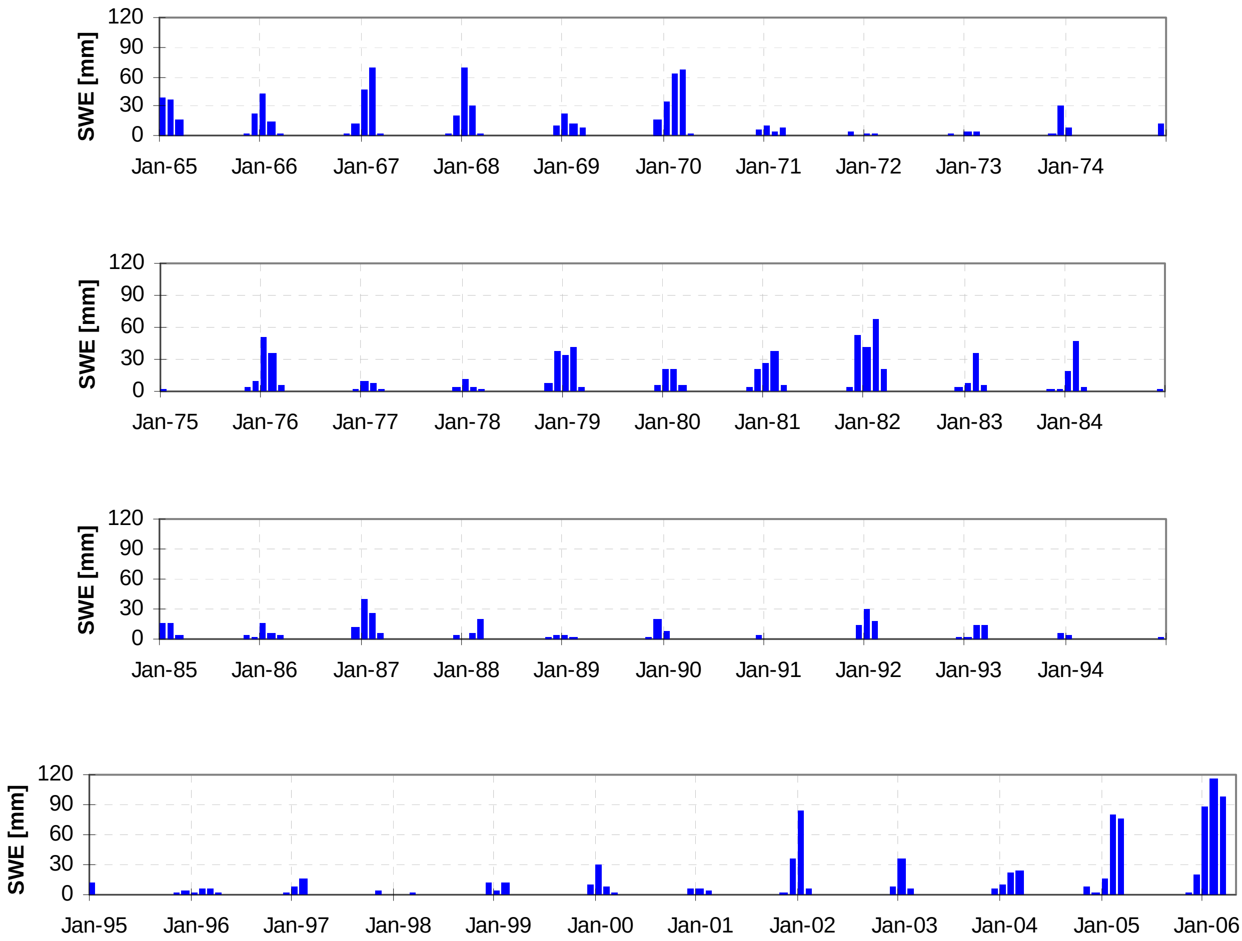

Fig. 4. The course of mean monthly snow water equivalent in Rybárik basin modelled with HBV-light model during 42-yearly period.
Obr. 4. Priebeh priemernej mesačnej SWE v povodí Rybárik modelovanej modelom HBV-light za 42-ročné obdobie.

ary 2002, the second highest SWE value for the whole observation period has been calculated.

In Fig. 5, the percentiles P_{30}, P_{50}, P_{70}, and P_{90} demonstrate the modelled monthly SWE values for the Rybárik basin (see Tab. 3), for the years 1965/66 through 2005/06. From the time series of the modelled SWE values it is evident, that the maximum SWE value can be attained in January (P_{30}, P_{70}) and February (P_{50}, P_{90}). How the simulated maximum daily SWE values evolve in time (1965/66–2005/06) can be seen in Fig. 6.

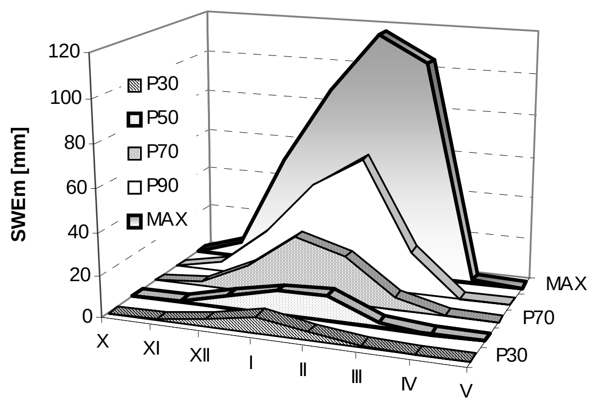

Fig. 5. Maximum modelled monthly snow water equivalent $SWEm_{max}$ and SWEm percentiles P_{30}, P_{50}, P_{70}, P_{90} in Rybárik basin during the period from 1965/66 to 2005/06.
Obr. 5. Maximálna mesačná modelovaná $SWEm_{max}$ a mesačné percentily SWEm P_{30}, P_{50}, P_{70}, P_{90} v povodí Rybárik v období od 1965/66 do 2005/06.

Conclusions

In the first part of this study we analysed the snowmelt pattern in two experimental microbasins operated by the IH SAS: the Rybárik and Lesný

T a b l e 3. Mean monthly snow water equivalent (SWE) in Rybárik basin modelled with HBV-light model during the period 1965/66–2005/06.
T a b u ľ k a 3. Modelované hodnoty priemernej mesačnej vodnej hodnoty snehu (SWE) v povodí Rybárik modelom HBV-light za obdobie rokov 1965/66 až 2005/06.

	July	Aug	Sept	Oct	Nov	Dec	Jan	Febr	Mar	Apr	May	June
1965/66	0.00	0.00	0.00	0.00	1.58	22.29	41.77	13.45	1.30	0.00	0.00	0.00
1966/67	0.00	0.00	0.00	0.02	1.58	11.84	47.65	68.40	2.11	0.00	0.00	0.00
1967/68	0.00	0.00	0.00	0.00	1.73	21.19	69.95	29.85	2.10	0.01	0.00	0.00
1968/69	0.00	0.00	0.00	0.00	0.04	9.76	22.77	13.00	8.95	0.00	0.00	0.00
1969/70	0.00	0.00	0.00	0.00	0.30	15.80	34.10	62.40	67.20	1.18	0.00	0.00
1970/71	0.00	0.00	0.00	0.00	0.37	5.35	10.28	3.05	8.37	0.00	0.00	0.00
1971/72	0.00	0.00	0.00	0.00	4.03	1.00	2.91	1.86	0.00	0.00	0.00	0.00
1972/73	0.00	0.00	0.00	0.00	1.22	0.00	3.56	3.29	0.62	0.00	0.00	0.00
1973/74	0.00	0.00	0.00	0.00	1.29	30.05	8.73	0.23	0.00	0.00	0.00	0.00
1974/75	0.00	0.00	0.00	0.00	0.32	13.14	2.16	0.30	0.66	0.00	0.00	0.00
1975/76	0.00	0.00	0.00	0.00	4.65	10.23	50.66	35.54	4.74	0.00	0.00	0.00
1976/77	0.00	0.00	0.00	0.00	0.25	2.53	9.36	8.36	1.82	0.00	0.00	0.00
1977/78	0.00	0.00	0.00	0.00	0.48	3.27	10.64	3.85	1.02	0.00	0.00	0.00
1978/79	0.00	0.00	0.00	0.00	7.02	37.24	33.44	41.55	3.35	0.00	0.00	0.00
1979/80	0.00	0.00	0.00	0.00	0.12	6.29	21.25	20.23	5.58	0.00	0.00	0.00
1980/81	0.00	0.00	0.00	0.00	3.11	20.76	25.64	37.47	6.38	0.00	0.00	0.00
1981/82	0.00	0.00	0.00	0.00	4.31	52.34	41.95	66.63	20.16	0.00	0.00	0.00
1982/83	0.00	0.00	0.00	0.00	0.00	3.13	7.53	36.45	5.85	0.00	0.00	0.00
1983/84	0.00	0.00	0.00	0.00	2.01	2.06	18.98	47.60	2.98	0.00	0.00	0.00
1984/85	0.00	0.00	0.00	0.00	0.00	2.77	16.09	15.59	4.65	0.00	0.00	0.00
1985/86	0.00	0.00	0.00	0.00	4.12	1.81	15.65	5.51	3.51	0.00	0.00	0.00
1986/87	0.00	0.00	0.00	0.00	0.00	12.56	40.96	25.43	6.66	0.00	0.00	0.00
1987/88	0.00	0.00	0.00	0.00	0.00	4.78	0.11	6.09	19.24	0.00	0.00	0.00
1988/89	0.00	0.00	0.00	0.15	2.95	4.15	4.44	1.71	0.00	0.00	0.00	0.00
1989/90	0.00	0.00	0.00	0.00	2.37	19.80	8.15	0.60	0.00	0.00	0.00	0.00
1990/91	0.00	0.00	0.00	0.00	0.00	3.32	0.05	1.00	0.00	0.00	0.00	0.00
1991/92	0.00	0.00	0.00	0.00	0.00	13.05	30.54	18.10	0.47	0.00	0.00	0.00
1992/93	0.00	0.00	0.00	0.00	0.04	1.15	1.79	14.14	13.88	0.00	0.00	0.00
1993/94	0.00	0.00	0.00	0.00	0.30	6.06	3.46	0.03	0.00	0.00	0.00	0.00
1994/95	0.00	0.00	0.00	0.00	0.00	1.05	11.12	0.39	0.04	0.10	0.00	0.00
1995/96	0.00	0.00	0.00	0.00	1.08	3.11	1.76	5.25	6.01	1.08	0.00	0.00
1996/97	0.00	0.00	0.00	0.00	0.03	1.56	8.26	15.10	0.20	0.00	0.00	0.00
1997/98	0.00	0.00	0.00	0.00	4.05	0.26	0.30	0.79	2.92	0.00	0.00	0.00
1998/99	0.00	0.00	0.00	0.00	0.84	11.04	3.77	12.05	0.18	0.00	0.00	0.00
1999/00	0.00	0.00	0.00	0.00	0.18	10.24	29.25	7.25	1.52	0.00	0.00	0.00
2000/01	0.00	0.00	0.00	0.00	0.00	5.06	5.65	3.60	0.69	0.00	0.00	0.00
2001/02	0.00	0.00	0.00	0.00	2.94	35.68	84.54	6.91	0.00	0.00	0.00	0.00
2002/03	0.00	0.00	0.00	0.00	0.38	8.90	35.81	5.59	0.00	0.40	0.00	0.00
2003/04	0.00	0.00	0.00	0.03	0.00	5.39	9.35	22.49	23.62	0.00	0.00	0.00
2004/05	0.00	0.00	0.00	0.00	7.50	1.11	15.07	79.78	78.45	0.00	0.00	0.00
2005/06	0.00	0.00	0.00	0.00	1.73	19.55	88.74	116.91	104.99	0.00	0.00	0.00
Max	0.00	0.00	0.00	0.15	7.50	52.34	88.74	116.91	104.99	1.18	0.00	0.00
P90	0.00	0.00	0.00	0.00	4.12	22.29	47.65	62.40	20.16	0.01	0.00	0.00
P70	0.00	0.00	0.00	0.00	1.73	12.56	29.25	22.49	5.85	0.00	0.00	0.00
P50	0.00	0.00	0.00	0.00	0.48	6.06	11.12	12.05	2.11	0.00	0.00	0.00
P30	0.00	0.00	0.00	0.00	0.12	3.13	7.53	3.85	0.62	0.00	0.00	0.00
P10	0.00	0.00	0.00	0.00	0.00	1.11	1.79	0.60	0.00	0.00	0.00	0.00
Min	0.00	0.00	0.00	0.00	0.00	0.00	0.05	0.03	0.00	0.00	0.00	0.00
Average	0.00	0.00	0.00	0.00	1.53	10.75	21.42	20.92	10.01	0.07	0.00	0.00

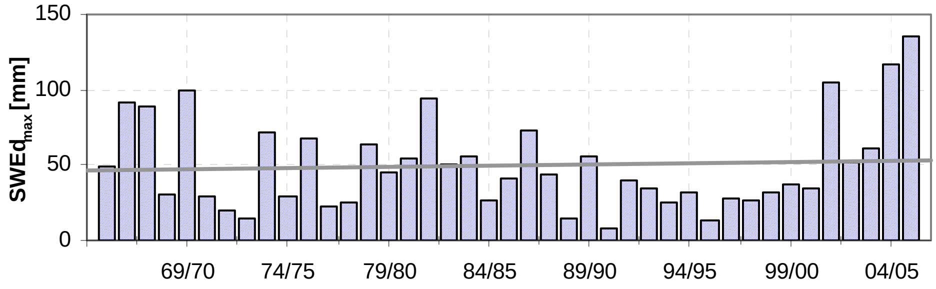

Fig. 6. Maximum modelled daily snow water equivalent $SWEd_{max}$ during individual winter seasons of the period from 1965/66 to 2005/06 in Rybárik basin, long-term trend.

Obr. 6. Maximálna denná modelovaná $SWEd_{max}$ počas jednotlivých zimných sezón v období od 1965/66 do 2005/06 v povodí Rybárik, dlhodobý trend.

microbasin, for the winter season of 2005/06. On March 29, 2006, specific peak flow from the forested catchment was higher than that from the agriculturally utilized basin. This fact shows that under particular conditions, the retention effect of the forest is negligible. Even the specific runoff from the forested catchment can be higher than that from the agricultural basin. Water storage in the snowpack at the onset of snowmelt period in the Rybárik basin was 131 mm, in Lesný basin 105 mm. It is supposed that the rainfall amounts were the same over both catchments over the flood event, i.e. 50.3 mm. The spring flood total runoff of the Rybárik basin was 133 mm, and of the Lesný basin was estimated as 100 mm.

The second part of the study summarizes the simulated daily SWE values modelled by the HBV-light model for the Rybárik and Lesný microbasins for a period of 42 years (1965/66–2005/06). So far, this model has not been used for SWE simulation in small catchments; however, comparison between the simulated and observed values indicates its successful performance in our experimental micro-basins. This model is not demanding in terms of input data, since it requires only data on daily means of precipitation and air temperature.

From the SWE simulation it can be concluded that in the Rybárik basin the highest monthly SWE averages were attained in January, February, and March of 2006 (88.7; 116.9; and 104.9 mm, respectively) over the whole period of observations after 1964.

The years 2004/05 and 2005/06 were exceptional as to the snow storage in the Rybárik and Lesný microbasins and in other sections of Slovakia highland as well.

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MERANIE A MODELOVANIE VODNEJ HODNOTY SNEHU V MIKROPOVODIACH S RÔZNOU VEGETÁCIOU

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Na prelome marca a apríla 2006 sa vyskytli rozsiahle povodne v dôsledku vysokých zásob vody v snehu, prudkého oteplenia a výdatných dažďov na prítokoch stredného toku Dunaja i na samotnom dolnom toku Dunaja. Po jarnej povodni v roku 2006 sa rozvírila diskusia o príčinách povodní a o úlohe lesa pri protipovodňovej ochrane. Cieľom prvej časti príspevku je posúdiť vplyv lesa na zníženie povodňových prietokov. V tejto časti štúdie je analyzovaná tvorba povodňového odtoku počas povodne z topenia sa snehu v marci 2006 na príklade dvoch experimentálnych mikropovodí ÚH SAV lokalizovaných vo vrchovinovej časti Slovenska pri Považskej Bystrici (300–400 m n.m.), konkrétne z poľnohospodársky využívaného mikropovodia Rybárik (0,119 km^2) a zo zalesneného mikropovodia Lesný (0,0864 km^2). Z výsledkov analýzy tvorby odtoku vyplýva, že úloha lesa pri znížení povodňových prietokov počas jarnej povodne v roku 2006 bola minimálna. K topeniu snehu zo zalesneného povodia Lesný v porovnaní s poľnohospodárskym povodím Rybárik (obr. 1) došlo síce o 6 dní neskôr, ale vrcholové prietoky boli dosiahnuté už len s denným oneskorením. Paradoxom je, že vrcholový meraný špecifický odtok bol dokonca vyšší zo zalesneného mikropovodia (vrchol 523 l s^{-1} km^{-2} 29. marca 2006 o 12.00 hod.), ako

z poľnohospodársky využívaného mikropovodia (vrchol 422 l s^{-1} km^{-2} 28. marca 2006 o 15.00 hod.).

V druhej časti príspevku je analyzovaný dlhodobý vývoj vodnej hodnoty snehu (SWE) v povodí Rybárik a Lesný za obdobie 1965/66–2005/06, modelovanej zrážko-odtokovým modelom HBV-light. Model bol kalibrovaný na období 1964/65–1973/74. Testovanie úspešnosti modelu bolo overené porovnaním vypočítaných hodnôt SWE modelom s meranými hodnotami SWE v stanici Kunovec za obdobie 1. november 1999–31. marec 2006 a v roku 2006 aj s meraniami získanými počas piatich experimentálnych meraní v oboch povodiach (obr. 2 a 3). Po verifikácii úspešnosti modelovania prietokov modelom HBV-light bol model použitý na spätnú simuláciu vodnej hodnoty snehu v povodiach za celé obdobie pozorovaní 1964–2006. Z výsledkov vyplýva, že po dočasnom poklese maxím vodnej hodnoty snehu SWE v deväťdesiatych rokoch minulého storočia od roku 2002 došlo k opätovnému zvýšeniu výšky snehovej pokrývky a vodnej hodnoty snehu. Najvyššia hodnota SWE os začiatku pozorovaní v experimentálnych povodiach ÚH SAV pri Považskej Bystrici (obr. 5 a 6) bola zaznamenaná v zimnej sezóne 2005/06.