SNOW AS POTENTIAL FLOOD THREAT

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In the physical-geographic conditions of Slovakia, especially in the mountainous areas with an alpine character, snow and snow cover have a great climatic, hydrological, ecological, and environmental and water management importance.
In these places, large amounts of water accumulate during the winter period and are then released in a relatively short time, therefore representing a high potential for spring floods.
Snow melting and its hydrological response are a complex process in which not only the snow water supply of water in the snow cover plays a significant role, but also the meteorological and hydrological conditions such as air temperature, incidence and intensity of liquid precipitation, depth of frozen soil, occurrence of ice phenomena on streams, structure of snow cover and morphology of the territory.
The subject of the contribution is the evaluation of the snow water supply, its development, duration, volume, maximum values in the upper Hron river basin as well as the influence of snow storage and climatic characteristics on the distribution of the runoff, onset of the spring runoff and overall water flow.

Keywords: the Hron river basin, snow storage, climatic characteristics, flood threat

INTRODUCTION

The phenomenon over the last years in our latitude is a succession of periods with a lot of rain and periods without any rainfall as well as periods with high water supply in the snow cover and without snow cover. These facts were fully demonstrated in the last 5 years, which were selected for evaluation of the characteristics of the snow cover and spring outflow in the upper Hron river basin. For the analysis, we chose the most significant left-hand tributary of upper Hron River, the Čierny Hron River. The winters from 2011-12 to 2015-16 were extraordinary from hydrological point of view. In the Čierny Hron river basin the minimum and maximum levels of snow water storage, which were evaluated, significantly influenced the volume and duration of spring outflow. Beside the snow storage, the meteorological conditions also significantly influenced the outflow.

MATERIALS AND METHODS

The Čierny Hron river basin is one of the least affected river basins in the Slovak area, with a relatively dense network of stations (Kyselová et al., 2006). It often serves as a pilot river basin for the assessment of hydrological regime, river basin drainage analysis, water supply assessment in snow cover and hydrological modeling. At the "Hydrologie malého povodí 2014" conference, hydrological extremes from the Čierny Hron river basin were analyzed (Šipikalová et al., 2014). Selected physical-geographical characteristics are in tab.1.

Table 1. Selected physical-geographic characteristics of the Čierny Hron river basin for the outlet section Hronec – Čierny Hron

Water gauging station	Basin area	Average altitute	Forest cover	Flow slope
	km^2	m n. m.	%	‰
Hronec, Čierny Hron	239,4	811	82,5	20,7

For the analysis, we used the measured and processed data for the hydrological years 2012 – 2016, the maximum and minimum monthly flows since 1931 and the long term hydrological characteristics derived from the hydrological and climatological stations for the period 1961 – 2000, which are located in the Čierny Hron river basin. Data on spatial air temperature and atmospheric precipitation were calculated using the weighted average method. Data on snow water content in daily time step in the Čierny Hron river basin was obtained as a secondary output from the HBV rainfall runoff model simulations. The flow data are from the hydrological station Hronec, Čierny Hron.

WATER SUPPLY IN THE SNOW COVER

The snow and snow cover have a great climatic, hydrological, ecological, and environmental and water management importance in the Čierny Hron river basin. Large amounts of water accumulate in the snow during the winter period and then are released in a relatively short time.

The analysis of variability of spring outflow and snowmelt runoff is based on information on the snow water supply in the studied river basin, which has been assessed on the Upper Hron river basin for more than 25 years, since the winter of 1990-91. Fig. 1 shows the maximum snow water per year of the monitored period for the Banska Bystrica profile. The winters of hydrological years 2012 – 2016 were very different in terms of maximum snow water storage. The highest maximum snow water supply since 1991 was recorded in the Upper Hron river basin during the winter 2012-13. The previous winter 2011-12 was also above-average. The winter 2013-14 was the opposite extreme, with the lowest maximum water content in the snow recorded since the beginning of the snow water supply assessment. Likewise, the winter 2015-16 is among those below-average. The winter 2014-15 can be considered as an average winter.

The highest snow water storage in the Upper Hron river basin usually occurs in February, except the winters during which the accumulation of snow is minimal and the water supply in the snow cover insignificant. In such case, the maximum water content in the snow cover can occur in any month from December to April, e.g. in the winter of 2013-14 it was during the first 10 days of December. As a comparison, the lowest maximum water content in the snow cover during the winter of 2013-14 represented only 7 % of the highest water content in the snow cover in the winter 2012-13.

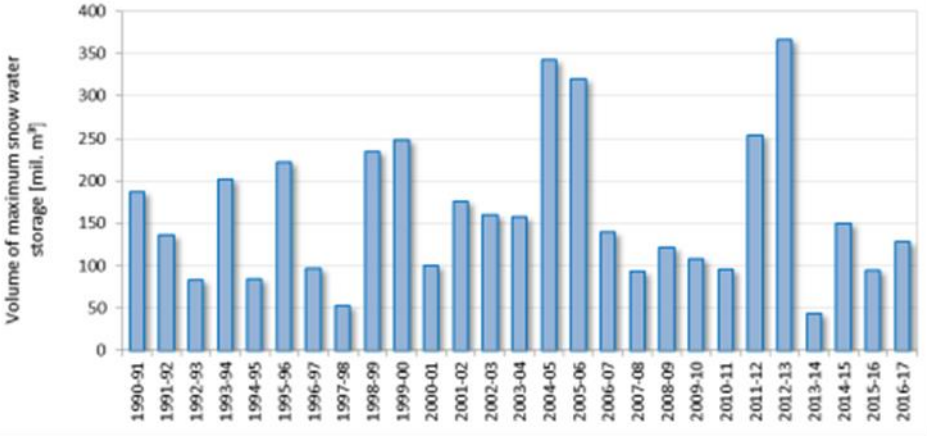


Figure 1. Maximum snow water storage in the Upper Hron river basin, outlet Banska Bystrica for the period 1990-91 to 2016-17

The different process of accumulation and melting of snow during each winter is in Fig. 2. During all years under observation in the Čierny Hron river basin, a continuous snow cover began to appear at the end of November and December. In winter with average to above-average snow water content, the conditions for snow accumulation were formed at the beginning of winter in December and the accumulation process was not significantly interrupted by warming or liquid precipitation.

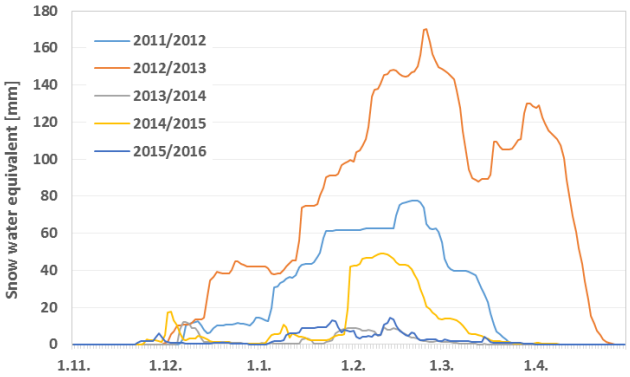


Figure 2. Snow water equivalent in the Čierny Hron river basin from November to April in hydrological years 2012 – 2016

The box plot (fig. 4 left) shows the variability of the mean snow water content in the Čierny Hron river basin. A high variability logically show winters with significant snow water storage (winters 2011-12 and 2012-13). On the contrary, winters during which the snow accumulation is insufficient (winters 2013-14 and 2015-16) are characterized by a low variability of the mean snow water content. The values of the mean snow water content in the river basin are in the range of 0 to 12 mm during the winter 2013-14 and 0 to 14 mm during the winter 2015-16. Even during the winter 2014-15 which is considered as average in terms of maximum snow water supply in the Horehronie region, 75 % of the values were below 8 mm. The maximum mean snow water content in the catchment area is 49 mm. The significant asymmetric distribution of the values was caused by a sudden increase in the average snow water content in the Čierny Hron river basin as well as by the snow reserve due to an intense snowfall at the end of January 2015. On 30th January 2015, the daily rainfall in most of the precipitation stations in the Horehronie region exceeded 30 mm. In the following days, the snow water storage accumulated under favorable meteorological conditions and culminated in mid-February 2015. In the last 10 days of February, due to warming accompanied by liquid precipitation, the melting process of the snow intensified. The mean snow water content in the Čierny Hron river basin dropped to 14 mm and gradually came to zero by the end of March 2015.

RUNOFF DISTRIBUTION, MEAN MONTHLY RUNOFF, SPRING OUTFLOW

Snow melting and its hydrological response is a complex process which is affected not only by the water content in the snow cover but also by meteorological and hydrological conditions such as the occurence and intensity of liquid precipitation, air temperature, sunlight, depth of the frozen soil, snow cover structure, occurence of ice phenomenon in the flow and saturation of the river basin.

The exceptional conditions of these winters were also reflected in the runoff distribution. In neither of the years, the runoff distribution approached the long term values of $Q_{m1961-2000}$ (fig. 3). In long term, the snow runoff accounts for almost 30 % of the total annual outflow during March and April in gaging station Hronec on Čierny Hron River. During the monitored period, the highest spring outflow was recorded in 2013, when a record snow water storage was also evaluated. The spring runoff represented 67 % of the long term annual outflow. The hydro-meteorological conditions during the melting of snow in February and March 2013 are detailed in Kyselová et al. (2013).

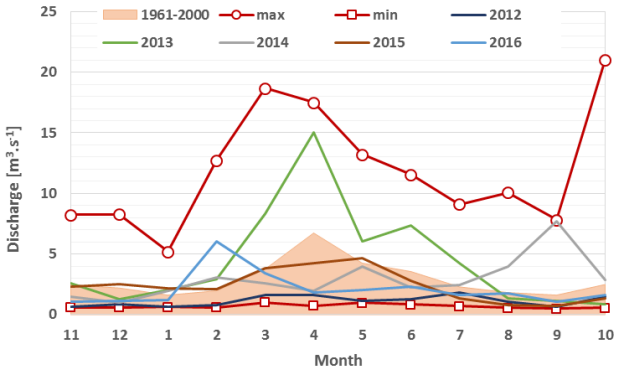
The lowest percentage of the spring runoff (snowmelt-runoff in March and April) was not calculated in 2014, although the winter 2013-14 was evaluated as extraordinary with a record short duration of the snow cover and also the lowest snow water storage. The lowest percentage of spring runoff (9 % of long term annual runoff) was recorded in 2012. The huge snow water storage accumulated during the winter months 2011-12 created basic assumption for the spring outflow. Due to the prevailing meteorological conditions (crossing frontal systems with strong wind, high air temperature, above-average sunshine duration, but especially lack of precipitation, see table 2) which supported an intensive snow sublimation, the typical spring runoff in the Čierny Hron river basin did not occur. In Hronec on Čierny Hron River, slight increase of water level with a peak flow at the level of a 90-day discharge was recorded.

Table 2. Selected climatological characteristics from December 2011 to March 2012 from the meteorological stations Telgárt (901 m a.s.l.) and Chopok (2005 m a.s.l.)

		number of clean sky days	number of overcast days	precipitation >=0,1mm [days]	snowfall [days]	RR [mm]	RR %	SD [h]	SD %
DEC 2011	Telgárt	1	16	17	17	67,3	158	40,5	55
	Chopok		19	20	24	53,5	61	51,6	72
JAN 2012	Telgárt	5	9	19	21	43,5	128	103,7	132
	Chopok	3	22	26	26	139,4	196	61,8	79
FEB 2012	Telgárt	7	5	9	12	10,3	26	129,3	138
	Chopok	4	11	16	18	51,0	77	94,6	108
MAR 2012	Telgárt	**12**	**2**	**1**	**0**	**6,4**	**14**	**238,1**	**180**
	Chopok	7	11	12	12	41,7	57	190,9	187

(Note: RR – monthly precipitation, RR% – percentage of normal 1961 – 1990, SD – sunshine duration, SD% – percentage of normal 1961 – 1990)

There was an atypical runoff in 2015, even though the percentage of distribution was the closest to the long-term values, accounting for 23 % of the year-runoff. It was mostly influenced by the fact that the snow water content was only in higher altitude and the prevailing sunny and windy weather caused the sublimation of part of it.



Figuer 3. Mean monthly discharges in the hydrological years 2012 – 2016, their comparison with long term values for the period 1961 – 2000 and the maximum/minimum mean monthly discharges for the period 1931 – 2000 in the gaging station Hronec, Čierny Hron

The extreme variability of the spring outflow in the Čierny Hron river basin over the last 5 years is also shown in table 3. The mean monthly discharge in March and April was the lowest in 2012 – in March, it was 43 % $Q_{ma\text{-}3/1961\text{-}2000}$ and in April even only 24 % $Q_{ma\text{-}4/1961\text{-}2000}$ although the water content in the snow cover was above average. The highest percentage – 222% $Q_{ma\text{-}3/1961\text{-}2000}$ in March and 223 % $Q_{ma\text{-}4/1961\text{-}2000}$ in April – was recorded in the next year 2013. During the winter 2012-13, the highest volume of snow water supply has been accumulated since the beginning of the measurement in 1991.

Year 2016 was also exceptional. In February, the maximum snow water storage has been usually found in the Čierny Hron river basin. The flood situation, which occured in February 2016 in most of the Slovak territory and mainly affected the catchments of Slana and Ipel Rivers, was exceptional due to the fact that, despite the winter months, it was mainly caused by the liquid precipitation without any contribution of snow melt. In the catchment of the Upper Hron River, part of the precipitation fell in higher altitude in the form of snow and accumulated. Therefore it did not participate in a direct runoff and as a result, the flood situation was there more favorable (Kyselová et al., 2016). A record of temperature and precipitation was achieved in February 2016 (See http://www.shmu.sk/sk/?page=2049&id=697). The mean monthly February discharges were recordable only at the water gaging stations with the beginnig of observation after 1977. February mean runoff in the Čierny Hron river basin was the third highest (after 1966 and 1977)

Table 3. Mean monthly discharges, expressed in % of long term values for the period 1961-2000 at the water gauging station Hronec, Čierny Hron

Hydrological year	11	12	1	2	3	4	5	6	7	8	9	10	rok
2012	27	40	40	39	43	24	26	35	80	59	41	59	39
2013	106	59	128	149	222	223	142	207	186	75	68	33	153
2014	59	44	122	156	68	29	93	63	107	218	478	115	101
2015	93	114	133	108	101	63	110	78	59	44	44	54	83
2016	42	52	74	306	91	28	48	65	72	95	65	66	72

(Note: Red – mean monthly discharge below 50% of the respective long-term average, Blue – mean monthly discharge over 100% of the long-term average)

since the beginning of observation in 1931.

The graph in fig 4 right shows the variability of the spring outflow as the mean daily discharge in March and April during the hydrological years under observation in Hronec water gaging station, Čierny Hron. The greatest variability is in spring 2013. In recent years, there was no significant spring runoff.

A different situation occured in February 2016. The floods in this month are not unusual. Their causes are mainly heavy rainfall, frozen soil, sudden warming and therewith associated snow melt. Although snow water supply did not form in the Čierny Hron river basin in February 2016, the extraordinary flood situation was caused by the record precipitation. Evenly distributed precipitation over time and space, predominant

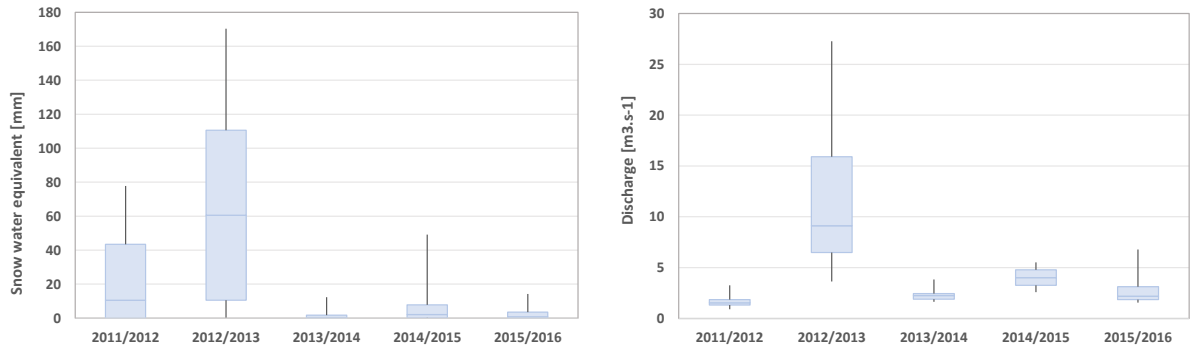


Figure 4. Variability of daily values of snow water equivalent in the Čierny Hron river basin from November to April (left) and mean daily discharge from March to April (right) during the hydrological years 2012 – 2016

Figure 5. shows the evolution of selected characteristics of air temperature and atmospheric precipitation in the period of accumulation and snow melting, the development of snow water supply in the Čierny Hron basin as well as the evolution of the runoff in Hronec gaging station, Čierny Hron, during selected winters of the monitored period.

positive soil temperatures and low groundwater levels, prior to the onset of the flood, have favorably affected the retention characteristics of the river basin and thus the course of the runoff. The volume of precipitation contributed to the runoff has decreased as well as the maximum peak discharges.

Also this year's winter was different from the point of view of the development of snow water supply as the previous ones.

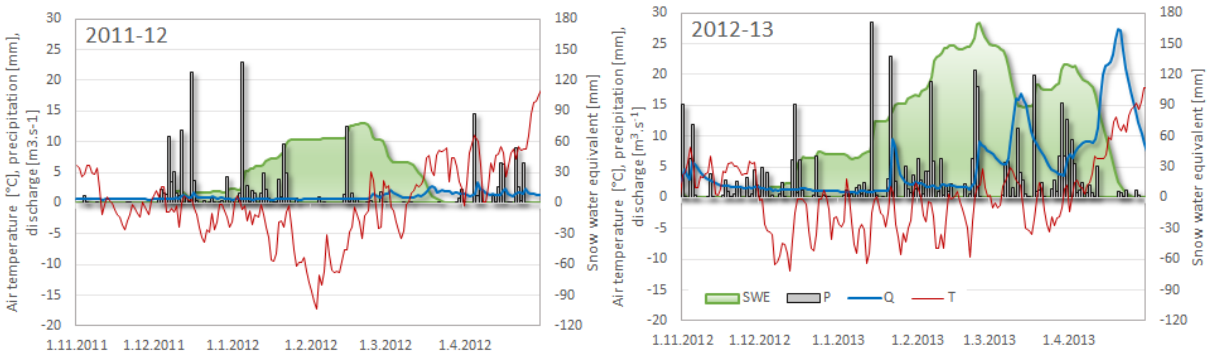


Figure 5. Mean daily air temperature (T), daily precipitation (P) and daily snow water equivalent (SWE) in the Čierny Hron river basin, mean daily discharge (Q) in Hronec gaging station, Čierny Hron, from November to April in selected years

CONCLUSION

The winters of hydrological years 2012 to 2016 were very different in terms of accumulation and melting of snow. The absence of spring runoff in 2012, despite the significant snow water storage, along with lack of precipitation, directly affected the runoff in the following months. During the winter of 2012-13, the highest snow water storage was recorded in the Upper Hron region since 1991. Since the end of February, several significant runoff situations caused by snow melt and rain have occured in the Čierny Hron river basin. From a hydrological point of view, the most significant was recorded at the turn of March and April. In the hydrological years 2014 and 2015, the significant spring runoff did not occur. In 2014, it was due to lack of snow water storage. In 2015, the spring runoff was affected by the fact that snow water supply was only in higher altitude and the prevailing sunny and windy weather in March and April caused its sublimation. Therefore a considerable part of water from melting snow was missing in the runoff.

The monthly precipitation in the upper Hron river basin was rather below normal, and sunshine duration was above normal and so the snow was intensively sublimated during clear days in January 2017. The weather conditions for snow accumulation did not improve even in February, the snow water supply to generate a more significant spring runoff in the Čierny Hron river basin was missing.

However, due to the temperature decrease in the second half of April, the part of precipitation in mountain ranges of the upper Hron river basin fell in the form of snow. Although the main cause of the flood situation at the end of April was heavy precipitation, the course of the flood waves on the right-hand tributaries of Hron was significantly affected by the snow melt. The most significant maximum peak discharges were recorded in gaging stations on the right-hand tributaries of the Upper Hron river basin: in Bystrá on Bystrianka River, in Mýto pod Ďumbierom on Štiavnička River and in Jasenie on Jasenianský creek. Operatively evaluated maximum peak discharges have an average return period of 20 years.

In our physical-geographic conditions snow melt is the main

reason of winter-spring floods. On the other hand, flood situation in the winter-spring time can occure even when the significant snow water storage is missing. Instead heavy rainfall is observed as a result of favorable meteorological conditions as in February 2016.

LITERATURE

Kyselová D., Podolinská J., Šipikalová H. (2006): Reprezentatívne povodie Čierny Hron. Journal of Hydrology and Hydromechanics, 54, č.2, s. 151 – 162.

Kyselová D., Hrušková K., Borsányi P. (2013): Povodne zo snehu a dažďa v roku 2013 v povodiach Hrona, Ipľa a Slanej. [Online]. SHMÚ, 46 s. [cit. 2017-03-23]. Dostupný z WWW: http://www.shmu.sk/sk/?page=128.

Kyselová D., Hrušková K., Trstenský T., Borsányi P., Kolačná Z., Padúch F., Podolinská J., Kováč P. (2016): Mimoriadny február 2016 v povodí Hrona, Ipľa a Slanej. [Online]. SHMÚ, 37 s. [cit. 2017-03-23]. Dostupný z WWW: http://www.shmu.sk/sk/?page=128.

Šipikalová H., Hrušková K., Podolinská J., Kyselová D., Borsányi P. (2014): Hydrologické extrémy v povodí Čierneho Hrona. In: Hydrologie malého povodí 2014. Praha, s. 481 – 487. ISBN 978-80-02-02525-2.

Kyselová D., Hrušková K., Trstenský T. (2017): Povodňová situácia koncom apríla 2017 v povodí Hrona. [Online]. SHMÚ, 19 s. [cit. 2017-03-23]. Dostupný z WWW: http://www.shmu.sk/sk/?page=128.