Post event analysis of the flash flood in small basin

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Abstract: - Flash floods are one of the major natural hazards occurring on small streams with negative effect on the country as well as on human lives. Flash floods are mostly local events scattered in time and space. Nevertheless, this type of flood, often affecting ungaged watersheds, remains a poorly documented phenomenon. This paper presents a reconstruction of the catastrophic floods occurred in July 2014 which occurred on the Varinka stream in the Vratna Valley and in Terchova village located at the Mala Fatra National Park, Slovakia. The methodology is based on description of past events from 1941 to 2014. These measurements were focused on documenting of the flood development and on measuring of the flood culmination. Subsequently, the measured results were preliminary evaluated. At the end of this paper, there are described some extreme flash floods which occurred on the Slovak territory. The flash flood on July 2014 on the Varinka stream is there compared with the most extreme flash flood occurred on the Mala Svinka stream in July 1998.

Key-Words: - natural hazards, flash floods, small basin, Vratna Valley, Slovakia.

1 Introduction

Flash floods are defined as strong flows occurring shortly after rainfall [1]. They can be caused by relatively high rain intensity and an intensive watershed response to rainfall. The factors that affect flash flood generation are very complex and mainly include characteristics of the rain (intensity, volume, and time-space distribution), physical and hydrological characteristics of the watershed (area, slopes, shapes, type of soil and land use, vegetation and others) [2]. The intensive rainfall causes not only hydrological response of the basin but also hydro-geomorphic response of the basin. The incorrect use of the land areas, and consequently its negative response to the heavy rainfall, is presented in [3] or [4]. The hydrogeomorphic response of headwater systems to extreme rainfall was published also in [5]. The type, magnitude and intensity of the hydro-geomorphic response may affect hazard and risk in the downstream channel system and floodplains ([6] and [7]). The sensitivities of runoff generation to rainfall variability and initial wetness conditions were examined for a major flash flood event in study [8]. Similar problems had been investigated by several authors ([9], [10], [11] and [12]). For example in the last years the data-based mechanistic (DBM) models were applied to forecast flash floods in a small Alpine basin [13]. The effect of urban land cover on basin flood response was tested using a lumped rainfall–runoff model, and compared flood events from selected UK basins with mixed urban and rural land use, in [14].

Every flash flood (as well as every natural extreme event) is the source of unavailable information, therefore description, analysis and reconstruction of such event is extremely important ([15], [16] and [17] or [18]).

The occurrence of these extreme events of natural hazards entails acute danger not only for properties but mainly for human lives. Jonkman [19] focused on 13 flood events that happened in Europe and the US in order to improve understanding the circumstances of flood deaths and contribute to prevention strategies. Other studies have also focused on defining and understanding circumstances surrounding flood fatalities for different environments such as Australia [20] and Puerto Rico [21]. Analysis of natural hazards and

identification of deficits at natural disaster management is published in [22] from the viewpoint of safe community concept that has been promoted by the EU since 2004.
In the Mala Fatra National Park catastrophic floods occurred in July 2014. This paper presents reconstruction of the flood which occurred on the Varinka stream in the Vratna Valley and in Terchova village. Next, there are presented the experimental measurements after the flash flood on Varinka in the Vratna Valley. The experimental measurements were done to document the flood development.

2 Study area

2.1 The flood area: Varínka River basin and historical flood reports

The Varinka River basin (Fig. 1) is located in the Mala Fatra National Park (in Slovak: Národný park Malá Fatra), in the northwest part of the Mala Fatra mountains called Krivanska Mala Fatra. The mountain is covered mainly with mixed beech forests, and with fir and spruce at higher elevations. Dwarf pine and meadows occur at the highest zone. About 83% of the area is covered by forest. It has an area of 226.3 km² (87.37 mi²) and a 232.62 km² (89.81 mi²) buffer zone. The park was declared in 1988. Between 1967 and 1988 it was a protected landscape area. The highest peak is the Velky Krivan with altitude of 1709 m. A significant hill is the Velky Rozsutec, which is also the logo of the National Park. Gorges, rocky peaks and an attractive ridge tour are among its attractions too.

The records about historical floods we can find in some scientific literature and chronicles in many towns and villages in Slovakia.

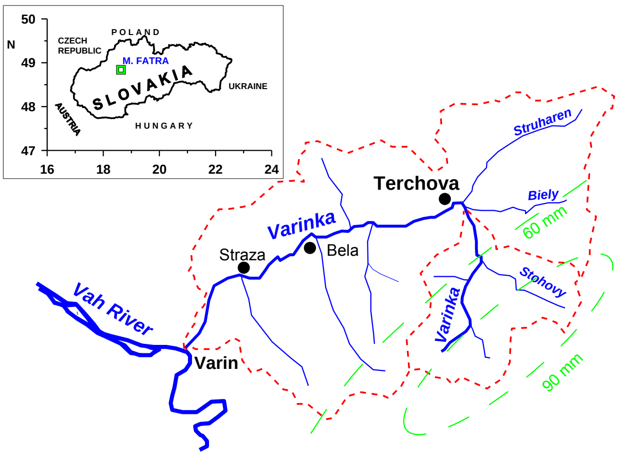


Fig. 1 The location of the Varinka River basin, the Mala Fatra National Park, Slovakia. Rainfall depth during the flood on July 21, 2014.

When we go more into the past, the information about floods are rarer and less precise.
The publication [23] describes a catastrophic flood on Vydrnanka (tributary of the Biela stream from flysch belt of Javorniky, the basin area of the central Vah River), and says: "rain was so heavy that it was not seen in ten steps and valley sides were all covered with water, which flowed into the river, the effect was devastating. The only longitudinal road was completely destroyed; houses were damaged, shattered and washed away. The coarse river load clogged the original stream bed up to 1-1.5 m, so that the water can create a new bed ...." This catastrophic flood occurred on June 17, 1939 and culmination of this flood was estimated around the value of 100 $m^3\ s^{-1}$ and specific yield around value of 10 $m^3\ s^{-1}\ km^{-2}$. It showed again, that intensive rainfall can cause catastrophic runoff from basin in a small basin of flysch belt.
Some other significant historical flash floods which occurred in the Mala Fatra National Park were on the Lubochnianka stream on May 28, 1925 or on June 25, 1893. Floods destroyed roads, railway and bridges in the Lubochnianska Valley and in village Stara Bystrica. According to SHMI archive records the rainfall depth reached value of 193 mm (June 17, 1925) in village Stara Bystrica.
The most interesting and the most valuable information about the catastrophic flash flood of 1848 originates from village Terchova on the Varinka / Vratnanka stream. The information was sculpted into the rock in the valley Tiesnavy in year 1848 by woodsman Ferenz Blaha. In the post - war period, around 1948, was the original table rebuilt to place where it stands today. This mark informs that 14 people died on June 11, 1848 in village Stefanova during the flood on Varinka stream, and it shows the water level of the flood (Fig. 2).

Fig. 2 Detail of the flood mark indicates water level in 1848 (Photos by Pekarova).

2.2 The Varinka stream

The Varinka stream (stream ID 4-21-05-6465) is created from several brooks in the Vratna Valley, near to the community of Terchova (Fig. 1). The Varinka stream is the area of European importance especially for travertine springs and hydrophilic tall herb fringe communities. The basin covers an area of 167.307 km^2 and stream length is 24.46 km. The Varinka originates from Krivanska Fatra, the Mala Fatra subunit. Source of the Varinka is located on the northern slope of the mountain section of the ridge between the peaks Chleb (1647 m. a. s. l.) and Hromove (1636 m. a. s. l.). The Varinka stream flows on bottom of the Vratna Valley and flows into the Vah River in Varin village. The Stohovy stream (stream ID: 4-21-05-6748, area 10.671 km^2, length 5.30 km) is one of the tributaries of the Varinka stream. The next tributaries of the Varinka are Biely Potok (stream ID: 4-21-05-6715, area 17.162 km^2), Struharen stream and Beliansky stream.

Table 1 presents the basic geographical and runoff characteristics of the Varinka stream at Straza and in the Tiesnavy gorge. The most extreme discharge on the Varinka stream in the Vratna Valley occurred in 1958 ([24] and [25]). All the upper basin of the Vah River was flooded in that year. The peak discharge on the Varinka stream reached value of 226 m^3 s^{-1} (q_{max}= 1.62 m^3 s^{-1}km^{-2}) at Straza. Fig. 3 presents the extreme annual discharges which occurred on the Varinka stream at Straza gauge station (basin area 139 km^2) during the period of 1941–2014. Fig. 4 presents the annual peak discharges exceedance probability curve (Log-Pearson, type III). We included here also the peak of the June 2014 flood. From this curve, *T*-year values were derived for the Varinka stream (Tab. 2).

Table 1 Basic geographic and runoff characteristics of the Varinka stream at Straza and at Tiesnavy

Varinka stream	*Tiesnavy*	*Straza*
Basin area [km^2]	28.6	139
Altitude min. [m. a. s. l.]	568.2	400
Altitude max. [m. a. s. l.]	1680	1680
Altitude mean [m. a .s. l.]	979	775
Mean slope [°]	24.46	19.45
Annual mean discharge [m^{3}s^{-1}]	0.71	2.96

Table 2 *T*-year discharges (1941–2014), Varinka stream at Straza (Log-Pearson III. distribution)

T	*20*	*50*	*100*	*200*	*500*	*1000*
Q_T	106	162	222	302	452	610
$Q_{(5)}$	130	211	303	432	686	970
$Q_{(95)}$	89	131	174	229	327	427
Q_T^*	47	66	84	-	-	-

$Q_{(5)}$ *and* $Q_{(95)}$ *are 5 and 95* percentile, Q_T^* is estimated *T*-year peak discharges in the Tiesnavy gorge: Varinka stream

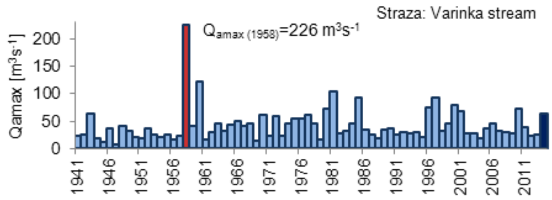


Fig. 3 Annual peak discharges on the Varinka stream at Straza during the period of 1941–2014.

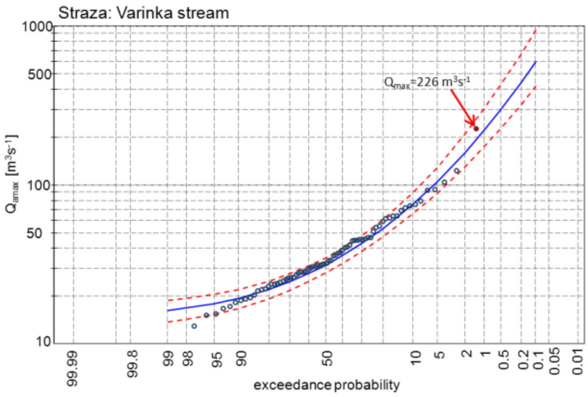


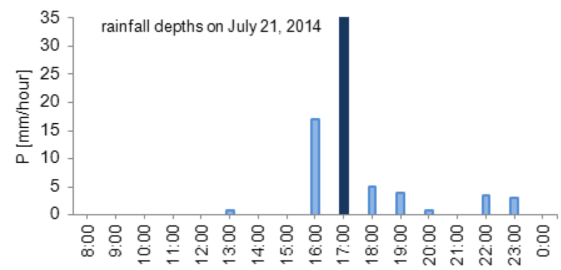
Fig 4 Theoretical exceedance probability curve of annual extreme peak discharges (Log-Pearson, type III.) of the Varinka stream (period: 1941–2014, $Q_{(5)}$ and $Q_{(95)}$ – confidence limits).

3 Results

3.1 Flood on July 21, 2014 on the Varinka stream

In contrast to regional floods from year 2010, which were caused by several days of heavy rains on the large area, floods of July 21, 2014 had the character of flash floods. The flash flood in the Vratna Valley was created as result of heavy rainfall on July 21, 2014 and landslides in the area of Hromove and Steny in the headwater of the Varinka stream (Fig. 5).

Fig. 5 Landslides in the area of Hromove and Steny in the headwaters of the Varinka stream. (Photo Pekarova).



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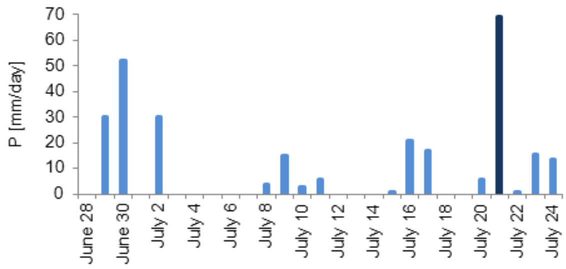


b)

Fig. 6 a) Hourly rainfall depths in the Vratna Valley (at Stefanova station) on July 21, 2014 (Central European Summer Time CEST) and b) Daily rainfall depths in the Vratna Valley (at Stefanova station) on July 2014.

The rainfall on July 21, 2014 was characterized by extreme intensity and extreme rainfall total depth for a very short time. Assessment of the meteorological situation in this northwest area of Slovakia was described in [26]. According to data from the Slovak Hydrometeorological Institute (SHMI), the maximum hourly total rainfall depth reached value of 37 mm in the afternoon on July 21, 2014 at the Vratna Valley (Fig. 6 a) (near the mountain rescue cottage), value of 46 mm in Lubochna village and value of 48 mm at Zilina. SHMI rain gauge station is located in the valley near Stefanova at altitude of 632 m. Maximum precipitation depth per 24 hours in the Vratna Valley (at Stefanova station) was about 66 mm (Fig. 6 b). In the area of maximum intensity of precipitation, directly in Vratna Valley, there is situated no rain gauging station. In calculating the average rainfall for the basin Varinka to Terchova, we additionally took into account the high altitudes in the basin area and the fact that due to rising-altitudes the rainfall totals generally grow (an average of 5 to 10% per 100 meters of altitude). On the windward side of the mountain Hromove in altitude of 1450 m the rainfall might reach 100 mm.
The Slovak Hydrometeorological Institute estimated maximum rainfall depths based on measurements of meteorological radars, as well. According to the maximum radar reflectivity, SHMI estimated the extreme rainfall intensity of 90 mm per 105 minutes (1 hour and 40 minutes) [26]. These rainfall depths would be above average even if they fell per 24 hours.
Such rainfall total depth added the flood on the Varinka stream in 2014 to the group of floods which occurred on July 7, 2011 in the Male Karpaty mountains in village Pila on the Gidra stream and on the Parna stream above the water reservoir Horne Oresany. There we estimated rainfall depth around 95 mm for 3.5 hours. Higher daily rainfall total depths were recorded in the past in Slovakia, e.g.: on June 7, 1873 at Trencin - 267 mm, on July 12, 1957 at Salka - 231 mm, on July 16, 1934 at Zuberec, Zverovka - 220 mm, on June 17, 1929 at Stara Bystrica -193 mm, on August 14, 1944 at Mutne - 190 mm, on June 29, 1958 at the lake Skalnate Pleso - 170 mm.

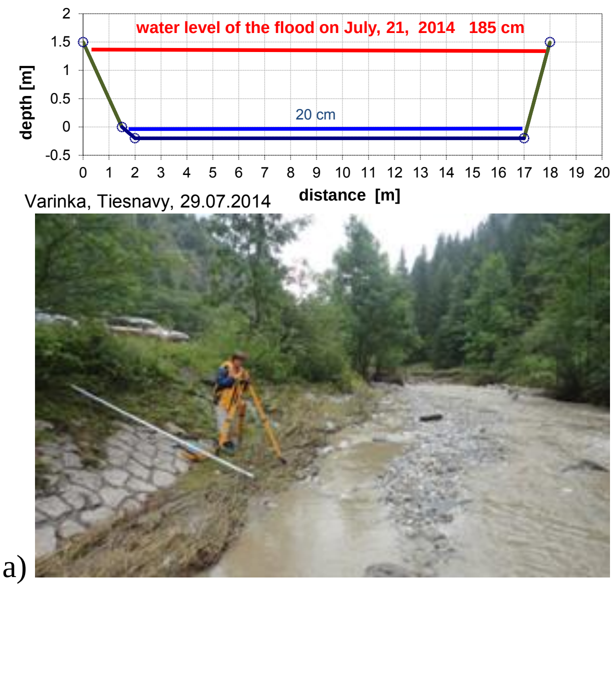
As a first step of the reconstruction of the flood on the Varinka stream experimental measurements and photo documentation were done. During the days of July 29, 2014 and July 30, 2014 we measured characteristics of stream needed to calculate culmination (peak) discharges at three profiles:

a) on the Varinka stream in Tiesnavy gorge (Fig. 7a);

b) on the Varinka stream at lower lift station (Fig. 7b);

c) on the Stohovy stream near the mountain rescue cottage and raingauge station in Stefanova (Fig. 7c).

Subsequently specific yield was calculated according to the defined regional relations of the Sectorial Technical Norm of the Ministry of Environment OTN ŽP 3112-1:03.



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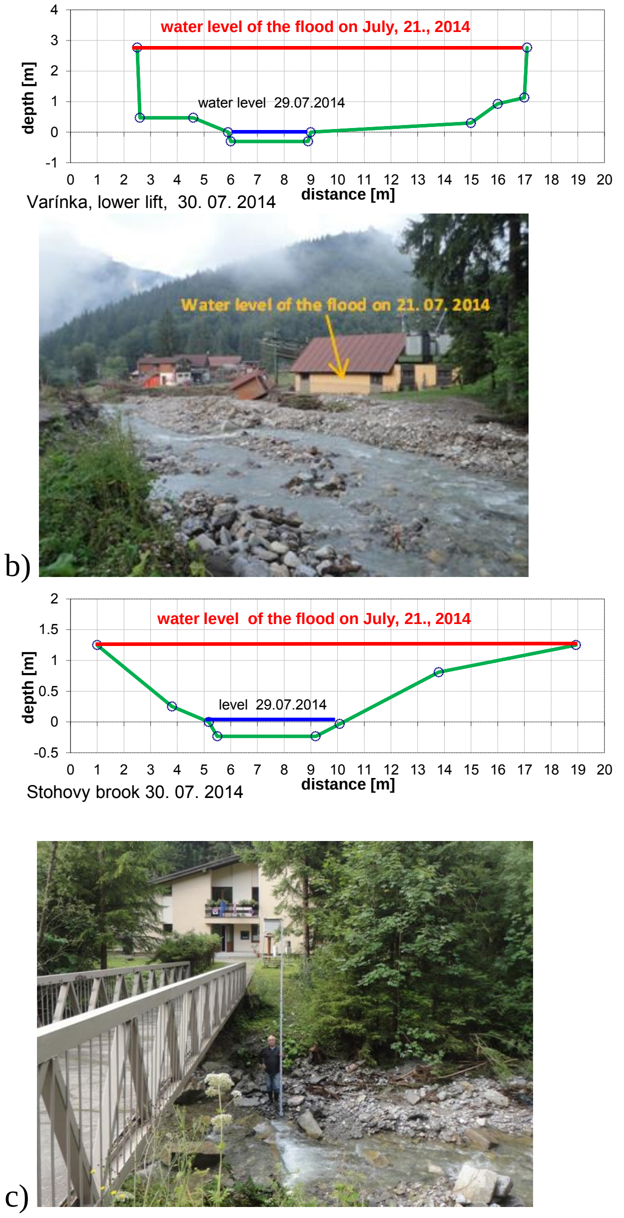


Fig. 7. a-c) Fixation of the cross sections on the Varinka and Stohovy streams according to flood tracks of the flood on July 21, 2014.

According to measurements after the flash flood on Varinka in the Vratna Valley, the peak discharge reached at least value of 56 $m^3.s^{-1}$ and specific yield reached value of 2 m^3 s^{-1} km^{-2} (on the Varinka stream in Tiesnavy gorge, basin area is 28.05 km^2). Peak discharge reached value of 57 m^3 s^{-1} and specific yield reached value of 4.4 m^3 s^{-1} km^{-2} (with respect to smaller basin area) on the Varinka stream at lower lift station. Peak discharge reached value of 6.7 m^3 s^{-1} on the Stohovy stream. Peak discharge reached value of 63.40 $m^3.s^{-1}$ (H= 141 cm, 18:30 CEST and basin area 139 km^2) at Straza gauge station. It corresponds to discharge with return period of 12 years.

3.2 Comparison of some extreme flash floods which occurred in Slovakia

Highlands and mountains, interwoven with streams and rivers, cover about of 89% of the land of the Slovak Republic. Therefore, there are many villages endangered by overflowing with streams from small basins in the territory of Slovakia. All small mountain basins where occur extreme floods cannot be provided with measuring technique. Therefore staff of the Slovak Hydrometeorological Institute (SHMI) performs the hydrological exploration in the basins and measures river profiles after each major flood to estimate the culmination. One of the hydrological problems solved at Institute of Hydrology Slovak Academy of Sciences (IH SAS), are the flash floods that occur on basins with the area of 25-35 km^2. As example two extreme flash floods located in the Small Carpathians area (southwest Slovakia): the Gidra stream at Pila, and the Parna stream at Horne Oresany are presented here. These floods were analysed and evaluated by IH SAS. A flood event on June 7, 2011 on the Gidra stream was caused by 3.5-hours rainfall (95 mm) and the specific yield reached value of 1.36 m^3 s^{-1} km^{-2}, and maximum discharge reached value of 44 m^3 s^{-1}. Other extreme flash floods occurred on tributaries of the upper Vah River (as mentioned above) in 1958, e.g. on the Koprovsky stream at mouth (basin area: 31.24 km^2, Q_{max}=85 m^3 s^{-1}) or on the Jalovecky stream at Jalovec (basin area: 33.45 km^2, Q_{max}=83 m^3 s^{-1}).

But, the most extreme (catastrophic) flash flood during the last twenty years was the flood which occurred on the Mala Svinka stream in Bachuren Mountains (east Slovakia) in 1998 (Fig. 8). Basic geographic and runoff characteristics of the Mala Svinka at Jarovnice are presented in Table 3.

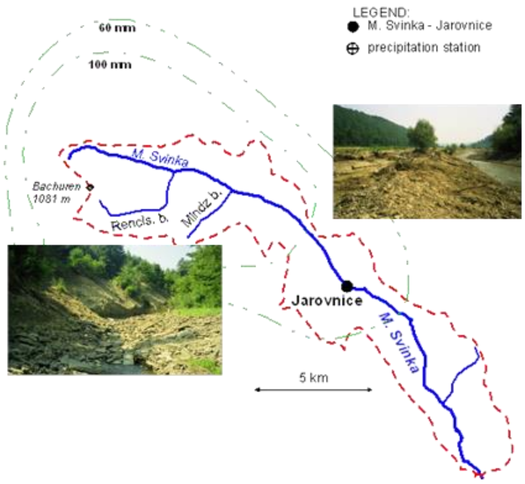
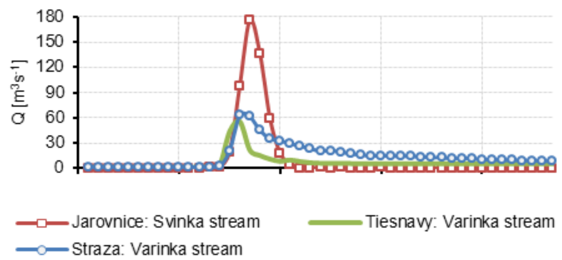


Fig. 8 Basin of the Mala Svinka stream. Rainfall depth between 4 p.m. – 5 p.m. on July 20, 1998.

Table 3 Basic geographical and runoff characteristics of the Mala Svinka at Jarovnice

Mala Svinka stream	*Jarovnice*
Basin area [km^2]	28.79
Altitude min. [m. a. s. l.]	451.85
Altitude max. [m. a. s. l.]	1073
Altitude mean [m. a .s. l.]	727.75
Mean slope [°]	14.2
Annual mean discharge [m^{3}s^{-1}]	0.16

A flood event on July 20, 1998 on the Mala Svinka stream was caused by 1.5-hours rainfall (80 mm) and the specific flow reached value of 6.19 m^3 s^{-1} km^{-2} and maximum discharge reached value of 178 m^3 s^{-1} according to our estimation (SHMI estimated Q_{max}=230 m^3 s^{-1}) ([27] and [28]). Different results (but comparable) are resulting from slightly different measurement profiles and from different methods of the culmination waves estimation. This extreme flood on the Svinka stream was compared with flood which occurred on the Varinka stream at Straza (Fig. 9). Both floods showed the effect of the intensive rainfall dropped on the small saturated basins in flysch area. Runoff during of these flash floods was so extensive and so fast that retention capacity of the shallow soil profile together with vegetation cover was not able to retain or effectively mitigate it.



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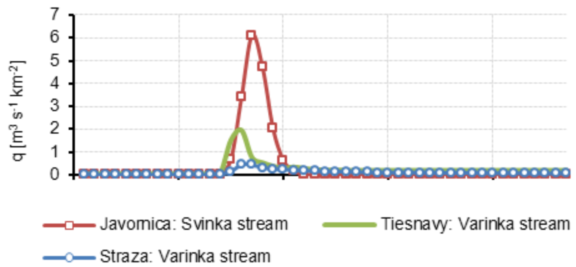

b)

Fig. 9 Hourly flows during the extreme flash floods on the Svinka stream at Jarovnice (July 1998) and on the Varinka stream at Straza (July 2014). Line without points represents estimated flood wave on the Varinka stream at Tiesnavy in 2014 (a) flow [m^{3}s^{-1}] and b) specific yield [m^{3}s^{-1} km^{-2}]).

4 Conclusion

Extreme floods are one type of natural disasters in Europe. Climate change, including an increase of the intensity of heavy rain in some areas, is reflected in the increasing incidence of extreme floods. There is expected mainly the increase in number of unexpected, locally bounded, but heavy floods (flash floods), which may increase the risk of loss of life. For example, in August 2013, 200 years passed since the most destructive floods, which in August 1813 affected the whole Slovakia, northern Moravia, and southern Poland. Neither the 2010 flood withstood the flood of 1813. Economic development in Slovakia after 1813 was slowed for decades.

In the present paper, the post-event reconstruction of the catastrophic flood on July 21, 2014 in the Vratna Valley in the Mala Fatra National Park on Varinka was done. The maximum discharge on the Varínka stream at Straza reached the value of Q=63.40 m3.s-1 with the return period T=12 years. Comparison of the historical records of the floods occurred at the Mala Fatra National Park and the reconstruction of the July 2014 flood on the Varínka stream at Straza showed that the July 2014 flood wasn't the highest flood in this area despite catastrophic consequences. A catastrophic flood on July 21, 2014 in the Vratna Valley in the Mala Fatra National Park on the stream of Varinka, and in Terchova village reminded us once again of the power of water flow. At the end of the paper the flash flood on July 2014 on the Varinka stream was compared with the most extreme flash flood occurred on the Mala Svinka stream in July 1998. Both floods showed main negative factors involved in formation of the flash floods: the high degree of the saturation of the catchment caused by previous rainfall just before extremely heavy precipitation dropped on the basin; shape, size and morphology of the basin (altitude, slope, orientation to the cardinal points, and so on); soil and vegetation cover; land use patterns, and another anthropogenic activities.

Since the flood on July 20, 1998 on the Mala Svinka stream, there occurred several flash floods in Slovakia, and there are suggestions that their number is growing. Answer to the question, whether the current flooding in the Slovak territory actually occurs more frequently than in the past, has been focused for several years in the department of surface water hydrology at the Institute of Hydrology SAS. The present research comes to the conclusion that the catastrophic flash floods that occurred in the past in Slovakia will be repeated with higher frequency and intensity in the future due to climate change.

Historical records (as well as flood marks) of the floods allow to identify the occurrence of the floods in the past. Comparison of the historical records with present measurements lead to better understanding of stream and landscape response to flash flood and to improve effectiveness of forecasts and warning. However, flash floods are locally rare and poorly observed events. Peak discharge data for more than 50% of the studied watersheds derive from post flood measurements in ungauged streams [29]. Knowledge of the previous extreme natural disasters their analysis and improvement of the observation methods and using of the rainfall-runoff models is necessary for the further development of watershed management.

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