Mountain Watersheds, Torrents, and Torrent Control in Slovakia

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Abstract The Slovak Republic with an area of 49,035.81 km^2 is in most of its territory a mountain landscape and has watercourses with a total length of 61,147 km. From this length, approximately 24,000 km (39.25%) have the character of torrents. The chapter deals with the issues of mountain watersheds, torrent control, and torrents which are in Slovakia in the length of 19,408 km managed by forestry organizations. The chapter provides basic information about Slovakia's mountain watersheds and torrents and about the methods to the determination of watercourse type (river, brook, and torrent) through technical standards or calculation. The chapter includes the history of torrent control and torrent flash floods in mountain

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watersheds of Slovakia. Also, it deals with lessons from the history of flash floods. The chapter analyzes the discharge capacity of natural torrent beds in various geomorphologic units of Slovakia. A part of this chapter deals with forests in mountain watersheds and their impact on runoff formation and water balance of individual forest altitudinal vegetation zones of Slovakia. In a separate part, an example of water balance in mountain watersheds of the highest mountain of Slovakia (the High Tatras) is explained. Finally, we present the calculation procedure to the determination of T-yearly discharges in forestry practice in Slovakia.

Keywords Flash floods, Forests, Runoff, Small catchments, Watercourses

1 Introduction

Water sources in mountain areas create conditions for the existence of the various living organisms. Man living in mountain areas has been in direct connection with the torrents since the beginning of his existence. From a certain degree of intelligence, perception, and logical thinking, we assess them from two fundamental points of view, namely, from their negative and positive impacts on society. On the one hand, the torrents bring and represent great benefits for a man and, on the other, great damages and danger. Most of the water sources in Slovakia and in the world is located in protected natural areas. These protected areas have great importance for the conservation of sustainable water resources. Water resources create appropriate living conditions to preserve the biological diversity of animal and plant species. Together with riparian stands and areas, these create very valuable bio-centers and bio-corridors, which are significant interaction elements in the landscape. The torrents are of the utmost importance because they create appropriate living conditions for some specific species of animals and plants. They bring for man great benefits as a source of drinking water, water for industrial purposes, food, irrigation, energy, raw materials, etc. They have a microclimatic function, act as a valuable aesthetic and landscaping element, and have a significant health-recreational significance. On the other hand, man perceives the torrents as a great potential danger, because under certain conditions they can cause diverse and often very extensive damages in the country, as well as losses of human lives. In the case of neglected torrent and torrent watershed management, they can cause very dangerous flash floods and erosion processes, flooding and damaging of adjacent landscapes and structures, destabilization or complete devastation of associated ecosystems, etc. In order to prevent such disasters, there arose a very purposeful, systematic activity – torrent control. Historical records in connection with mountain watercourses indicate that first flood control constructions have been built by the ancient Greeks and the Romans [1].

Humanity has always been concerned about the causes and consequences of floods. The main causes of the floods in Alpine countries were extreme natural conditions of mountain and alpine areas in where torrents and their watersheds are naturally occurring and deforestation or damage of forest ecosystems in mountain watersheds. Considering to expanding population and infrastructure density in the foothills, more and more people were threatened. Historical data about the beginnings of torrent control in Europe vary. In Central Europe the first local torrent control constructions have been known from the thirteenth and fourteenth century from the territory of today's Austria [1]. In the years 1650–1662, the first continuous torrent control in the South Tirol was built [2]. Author [3] states that on a wider scale, torrent control began in the French Alps after the catastrophic floods in 1856. In 1860 the law on reforestation of mountain soil was created and in 1864 the law about the grassing of mountain soils in France. In Switzerland they began torrent control activities after disastrous floods in 1868. In today's Austria and Czech Republic, they began the systematic activities of torrent control after the creation of law No. 117/1884 on measures for harmless runoff of mountain waters. The organized regulation of endangered areas began on an official basis and had to cover the area of what is Austria today, Northern Italy (Südtirol), Slovenia, Northern Croatia (Dalmatien), the Czech Republic, Slovakia, and Southern Poland (Schlesien, Galizien). Later, the systematic torrent control activities gradually expanded to other European and world countries.

2 Torrents in Slovakia

The Slovak Republic with an area of 49,035.81 km^2 is in most of its territory a mountain landscape (Table 1) and has watercourses extending a length of 61,147 km. Of that length, approximately 24,000 km (39.25%) have the character of torrents (see Figs. 1 and 2).

Within the framework of state forestry organizations, these enterprises manage 19,408 km of small watercourses (31.74% of total watercourses length in the SR), which are predominantly torrents.

The length of managed small watercourses on forest land is 13,818.5 km (71.2%), outside of forest land 4,328.0 km (22.3%), and in the village intravilan 1,261.5 km (6.5%). Other torrents (approximately 5,000 km) are managed by the Slovak Water Management Enterprise. The torrents are characterized by extreme

Table 1 Elevation ranges of Slovakia's surface and their area and percentage of total area [4]

Height zones	Height level (m asl)	Area (km^2)	Representation of area (%)
Lowlands	98–300	20,172	40.89
Low highlands	300–800	22,652	45.92
Middle highlands	800–1,500	6,139	12.44
High highlands	1,500–2,654.4	368	0.75

Fig. 1 Tichý potok torrent in the Western Tatras (photo M. Jakubis)

changes in discharges even in relatively short periods of time and significant creation, transport, and deposition of sediments (with the erosive activity). The torrents are located in the highest situated – alpine and mountain – regions of Slovakia. The watersheds and torrents in these areas are very important as a very significant source of quality fresh water. In the Slovak Republic, all of the torrents are situated in large-scale protected areas (national parks, protected landscape areas). Therefore, torrent control and torrent watershed management are extremely demanding. These activities require experienced experts who are able to integrate landscape protection requirements for floods and erosion and valid legislation in the protection of landscape, nature, and water management. The area of 9 national parks in Slovakia is 317,540.5726 ha (6.48% area of the SR), the area of their protective zones is 262,591.3307 ha (5.36% area of the SR), and the area of 14 protected landscape areas in the SR is 522,581.5090 ha (10.66% area of the SR). This means that the total area of large-scale protected areas is 1,102,713 ha (22.49% area of the SR).

Fig. 2 Natural bed of Studený potok torrent in the High Tatras with damaged riparian stands after wind calamity in 2004 (photo M. Jakubis)

3 Determination of Watercourse Type in Slovakia

In Slovakia, the types of watercourses are most often divided into the following categories: the rivers, brooks, and torrents. Two different technical standards (STN) are used in the integrated watershed management of these watercourses: STN 75 2102 Rivers and brooks regulations [5] and STN 48 2506 Forestry amelioration – torrent and gully control [6]. Deciding on the type of watercourse is very important in terms of integrated watershed and watercourse management.

The difference between the river and the brook is given by the following characteristics in Table 2.

The difference between the brook and the torrent is assessed by visual assessment in terrain with a focus on real erosion processes and discharge characteristics, especially discharge fluctuation and their duration. In disputed cases (brook or torrent), it is possible to use the informative equation to the calculation of watershed torrentivity coefficient (C_{wt}):

$$C_{\mathrm{wt}} = \frac{D \cdot \mathrm{LD} \cdot H_{\mathrm{m}} \cdot P \cdot E \cdot (S_{\mathrm{w}} + 1)^{0.5}}{L \cdot (S_{\mathrm{c}} + 1)^{0.5}} \tag{1}$$

where C_{wt} is the watershed torrentivity coefficient (−), D density of hydrographical network in the watershed (km km^{-2}), LD length of divide (km), H_{m} middle height difference of the watershed (km), P coefficient expressing the soil permeability in the watershed which reached the values 0.3–1.0, E coefficient of recent erosion (0.1–1.0), S_{w} watershed area (km^2), L length of the mainstream from spring to closed discharge profile of the watershed (km), S_{c} area of the anti-erosive vegetation cover in the watershed (km^2), which is the forest and permanent grassland area in the watershed.

On the basis of the previous research carried out in 145 catchments in 9 geomorphological units of the Slovak Republic, we have created (Table 3) the following scale of the watershed torrentivity coefficient (C_{wt}):

Based on the research in 145 mountain watersheds with an area S_{w} from 0.25 to 50.38 km^2 (Fig. 3) and discharges Q_1 from 0.20 to 12.0 m^3 s^{-1} and Q_{100} from 1.0 to

Table 2 Characteristics to determine the watercourse type in Slovakia

River	Brook
W_A[a] ≥ 100 km^2	$W_A < 100$ km^2
Q_{100}[b] ≥ 50 m^3 s^{-1}	$Q_{100} < 50$ m^3 s^{-1}
Q_{90d}[c] ≥ 0.6 m^3 s^{-1}	$Q_{90d} < 0.6$ m^3 s^{-1}
Q_{30d}[d] ≥ 0.15 m^3 s^{-1}	$Q_{30d} < 0.15$ m^3 s^{-1}
Streaming: mostly river	Streaming: river, in shorter section torrential

[a] Watershed area (km^2)

[b] 100 – yearly discharge (m^3 s^{-1})

[c] 90 – daily discharge (m^3 s^{-1})

[d] 30 – daily discharge (m^3 s^{-1})

Table 3 Scale of stream evaluation by watershed torrentivity coefficient C_{wt}

Rate	Name (stream tape)	C_{wt}
0	Brook	<0.10
I	Very slightly torrent	0.10–0.15
II	Slightly torrent	0.16–0.25
III	Middle strongly torrent	0.26–0.40
IV	Strongly torrent	0.41–0.70
V	Very strongly torrent	0.71–1.00
VI	Exceptional strongly torrent	1.01–2.00
VII	Extreme strongly torrent	>2.00

Fig. 3 Tichý potok torrent in the Western Tatras, watershed area of 50.38 km^2, discharge $Q_{100} = 140.0\ m^3\ s^{-1}$, watershed torrentivity coefficient $C_{wt} = 0.81$ (photo M. Jakubis)

$145.0\ m^3\ s^{-1}$ in 9 geomorphological units of the SR, we found that the values of the watershed torrentivity coefficient C_{wt} reflect the real type of the investigated streams. Calculated C_{wt} values ranged, for example, for the torrents in geomorphological unit of Poľana (480–1,458 m asl), from 0.10 to 0.66; of Veľká Fatra (485–1,592 m asl) from 0.18 to 1.69; of Malá Fatra (460–1,709 m asl) from 0.16 to 1.62; of Štiavnické vrchy (230–1,009 m asl) from 0.11 to 0.41; of Kremnické vrchy (270–1,317 m asl) from 0.12 to 0.45; of the Western Tatras (690–2,248 m asl) from 0.24 to 1.82; of the High Tatras (905–2,645.8 m asl) from 0.25 to 2.81; of Nízke Tatry (395–2,043 m asl) from 0.22 to 1.79; of Veporské vrchy (490–1,438.8 m asl) from 0.11 to 0.44; and of Javorie (310–1043.7 m asl) from 0.10 to 0.33.

4 History of Torrent Control in Small Mountain Watersheds of Slovakia

Historical records show that flash floods, torrents, and avalanche disasters have struck mountainous and sub-mountainous villages and landscape on the territory of contemporary Slovak Republic since time immemorial. Heavy deforestation was carried out during the thirteenth and fourteenth centuries (from the negative influence of colonization, settlement, mining, metallurgy, wood-gathering, etc.) in the regions of the present Central Slovakia.

Torrent control originated in the eighteenth and nineteenth centuries and is inscribed in the historical chronicles of various villages and towns. Some traditional measures to control torrents were adopted: such as stone barrages, stone crib dams, temporary ditch plank fences, longitudinal reinforcements of shores with stems, and even afforestation aimed at soil conservation in the mountain watersheds of torrents. Although these measures were quite effective, flash flood disasters in mountainous watersheds were frequent and destructive for both humans and landscape. One of the reasons for these flash flood disasters was the deforestation of the mountainous watersheds in the previous centuries [7].

The area of contemporary Slovak Republic was, until 1918, a part of the Austro-Hungarian monarchy; it then became part of an independent Czechoslovakia. The first notes about torrent control on the territory that is now the Slovak Republic originated in the eighteenth and nineteenth centuries, in the historical chronicles of submontane villages and towns. The first law No. 117/1884 on measures for harmless runoff of mountain waters came into force in 1884, and the first department of what is now called Torrent and Avalanche Control was imperial and royal Forest-Technical Department for Torrent Control.[1] At the beginning of World War I (1914), this Department had 15 subsidiaries covering the area of the monarchy. Modern torrent control activities in Slovakia began in 1923. In that year, a specialized office for torrent control was established in Turčiansky Svätý Martin (now Martin) in Central Slovakia, led by Prof. Dr. Ing. Leo Skatula (1889–1974). That institution operated throughout the whole Slovak Republic. The first systematic torrent control – Jelenec – was situated in Hornojelenecká Valley in Veľká Fatra in Central Slovakia. During the fifteenth and sixteenth centuries, deforestation in Hornojelenecká Valley was severe, leading to fatal flash floods and avalanche disasters in this area. The first historical record about an avalanche in Hornojelenecká Valley was in 1751; it caused the deaths of ten people. During the sixteenth century, professional commissions had been formed (in 1535 and 1563), but while they recognized the importance of the forest of Hornojelenecká Valley, no significant protection effort materialized. This was one of the primary reasons for the large-scale floods and avalanches in later years. In the twentieth

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[1] Wildbach – und Lawinenverbauung (Department) was k. k. (kaiserlich-königlich) forsttechnische Abtheilung für Wildbachverbauungen.

century, there were two major disasters (in 1924 and 1925) that led to the loss of lives and destruction of resources. The first catastrophe was on February 6, 1924. A huge avalanche had a height of 35 m of the front face and about 2,400.000 m^3 of cubage. The next catastrophe was on May 30, 1925, when a gigantic flash flood destroyed this entire valley (houses, roads, equipment, etc.). In the upper part of the Jelenec torrent basin (watershed area of 9.58 km^2, forestation of the watershed 70%), 75 mm of precipitation falls in less than 3 h (the maximum daily rainfall by then was 66.5 mm). This resulted in a flash flood that ravaged the whole Hornojelenecká Valley which was completely devastated. A flash flood in a few tens of minutes flooded all houses and other buildings in the settlements of Horný Jelenec, Valentová, and Rybô. Many houses in the valley were damaged by coarse sediments which flood brought from the upper parts of the watershed. These two catastrophes were the cardinal reason for the beginning of Jelenec torrent control on the territory of today's Slovak Republic. The first systematic torrent control in Slovakia – Jelenec in Hornojelenecka Valley – was built in 1926–1927; this torrent had many peculiarities: longitudinal reinforcement of the torrent bed with wood (pine and fir), stone paving on the slopes of the bed, and the first stone arched correction and sediment storage dam, passages for fish, and others (Figs. 4 and 5). Longitudinal reinforcement of the torrent bed was built only in settlements in the valley; a naturally stabilized torrent bed outside the settlements was left in its natural state. Over the course of more than 90 years since its inception, the torrent

Fig. 4 The weir built in natural rock of oldest torrent control in Hornojelenecká Valley from 1926 to 1927 and the torrent Jelenec in Slovakia (photo M. Jakubis)

Fig. 5 Longitudinal reinforcement by pavement stone, the stone weir, and system of wooden sills in the oldest torrent control – Jelenec in Hornojelenecká Valley from 1926 to 1927 (photo M. Jakubis)

control in Slovakia went through periods of expansion and recession, too. Currently, from the total length of watercourses managed by state forestry organizations (19,408 km), 590 km (3.04%) of them is controlled; it is 2.46% from the total torrent length in the Slovak Republic. From this length of controlled torrents, 131 km (22.2%) is reinforced by longitudinal vegetation reinforcement, 415 km (70.3%) by no vegetation reinforcement, and 44 km (7.5%) by combined longitudinal reinforcement.

5 History of Torrent Flash Floods in Slovakia

The first more precisely documented flash flood in the territory of today's Slovak Republic was the mentioned flood in Hornojelenecká Valley (geomorphologic unit Veľká Fatra) on May 30, 1925. Another documented torrential flood occurred in the watersheds of torrents Račková (35.8 km^2), Tichý potok (54.6 km^2), Kôprovský potok (30.5 km^2), and Belá (85.1 km^2) in the Váh river basin. On August 11, 1929, on the southern slopes of the Western Tatras, 83 mm of precipitation fell in 3 h [8, 9]. The floodplains were affected by a catastrophic flash flood that devastated the area along the sides of the watercourse Belá and caused major flood damages in the municipalities of Pribylina, Liptovská Kokava, Vavrišovo, Dovalovo, Liptovský Peter, and Liptovský Hrádok. In the territory under the confluence of the Tichý potok and Kôprový potok (Belá), the width of the channel reached more than 40–50 m (normally it is about 8–10 m). This flood was an incentive to build a second significant torrent control Račková on the territory of today's Slovak Republic in 1938–1940 (Figs. 6 and 7).

Fig. 6 Highest torrent dam of Slovakia built (1938) in Račková Valley in the Western Tatras (photo M. Jakubis)

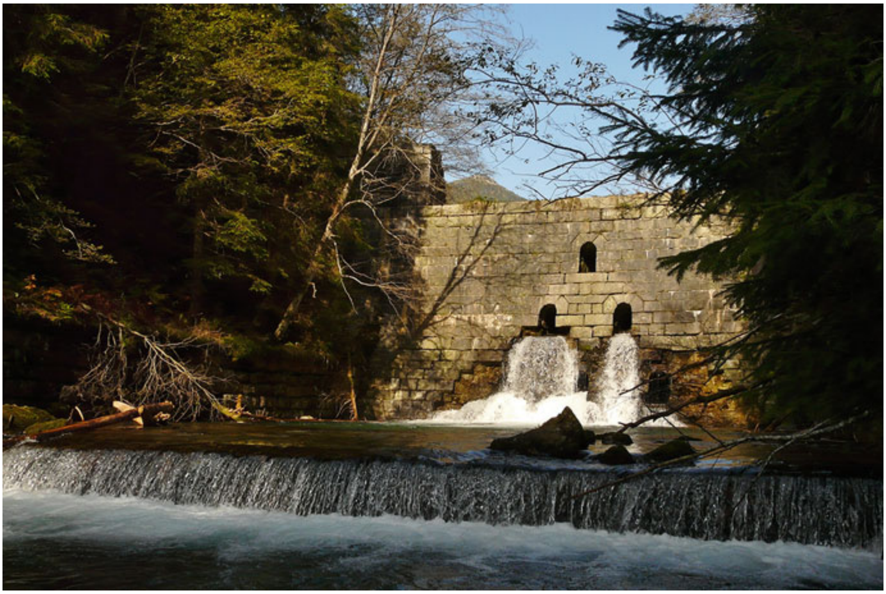

Fig. 7 The old torrent control objects need repairs, Račková in Western Tatras (Photo M. Jakubisová)

In mountain torrent catchments in Slovakia, other devastating flash floods occurred in the past. In the area of Zverovka (1,037 m asl) on the northwest slopes of the Western Tatras (Roháče) in a geomorphological unit of Tatras on July 16, 1934, 220 mm of precipitation fell within 1 day. These precipitations cause extensive local flash floods in the catchments of the torrents Látaná, Roháčský potok, and Studený potok. In the catchment area of the Kôprovský potok, Račková, and Jalovský potok (in the Váh river main basin) on the southern slopes of the Western Tatras, a major flood occurred on June 29, 1958. The flood was caused by precipitation, which in some localities reached over 100 mm in 24 h. On July 25, 1965, a great flash flood occurred near the village of Budča (district Zvolen, Central Slovakia) in the Sietno Valley (altitude 290–525 m asl) in a geomorphological unit of Kremnické vrchy (the Hron river basin). Within 2 to 3 h of rain, 110 mm of precipitation fell. The subsequent flood destroyed more than 3 km of a reinforced valley forest road including five bridges, and at that time the main and important road in the direction of Banská Bystrica – Zvolen – Bratislava, was destroyed which led to the foot of the valley. On July 20, 1998, in the Bachureň geomorphological unit (Hornád river basin), in the eastern Slovakia, catastrophic floods caused intense rainfall in the basin of Malá Svinka (the altitude of the basin 328–1,081 m asl) which caused 60 victims in human lives. During intense rainfall in the watershed (whose geological base forms a flysch), fell within 1.5 to 2 hours from 60 to 100 mm of precipitation; in some locations up to 130 mm. The torrent level has risen from a height of 0.40–0.50 m to 5–6 m and extended from 2–3 m wide to 40–50 m. As a result of extreme precipitation, a peak flow rate was generated over several decades $Q_{\mathrm{culm}} = 190\ \mathrm{m}^3\ \mathrm{s}^{-1}$ ($Q_{100} = 76\ \mathrm{m}^3\ \mathrm{s}^{-1}$ and average long-term flow $Q_{\mathrm{a}} = 0.30\ \mathrm{m}^3\ \mathrm{s}^{-1}$). Significant impacts on flooding have also had collisions that occurred in the period immediately prior to this event. The enormous impact on the number of victims of this flood had a very inappropriate location of dwellings in the immediate vicinity of the Malá Svinka stream, which absolutely did not take into account the potential danger of floods. Intensive torrential rainfall caused a major flood in the district of Krupina (Central Slovakia) in a geomorphological unit of Krupinská planina and Štiavnické vrchy on July 13, 1999. The town of Krupina is located in a valley surrounded by eastern and western slopes. The main watercourse is the river Krupina (Ipeľ river basin) with two torrents from the east (Kňazov potok and Jakubov jarok) and two torrents from the western side (Vajsov potok and Kltipoch) which flow directly into the town's inner city. The storm cloud was located directly above the city, and the floods arose not only on the river Krupinica but on all four tributaries. River Krupinica's level in the city rose from 0.70 to 5.30 m during two and a half hours. The intensity of the hourly precipitation ranged from 50 to 70 mm [10], and the intensity of precipitation during the 2–3 h had reached from 81 to 120 mm [11]. Previous precipitation in the area of town Krupina and its environs from July 8 to July 12, 1999 (5 days before the abovementioned precipitation event), reached a total of 38.9 mm [9] and from July 7 to July 12, 1999 (6 days prior to this event), to 86.2 mm. In the town of Krupina, a discharge $Q = 170\ \mathrm{m}^3\ \mathrm{s}^{-1}$ was achieved which is considered to discharge Q_{1000} ($Q_{100} = 100\ \mathrm{m}^3\ \mathrm{s}^{-1}$, mean long-term discharge $Q_{\mathrm{a}} = 1.22\ \mathrm{m}^3\ \mathrm{s}^{-1}$). On July 17, 2001, a daily sum of precipitation of 142 mm was recorded in Veporské vrchy and Poľana geomorphological units in the area of villages Hronec (492 m asl) and Osrblie (600 m asl) in the Osrblianka and Hronec river basin in Central Slovakia (the Hron river basin). The precipitation triggered a local flood with major damage to citizens' property and infrastructure, especially in the municipality of Hronec. On July 31, 2002, in the Hutná torrent basin in village Ľubietová in the northern part of the geomorphologic unit of Poľana, 80–100 mm of precipitation fell in 90 min (1.00–2.30 p.m.), causing a discharge $Q = 64\ \mathrm{m}^3\ \mathrm{s}^{-1}$ ($Q_{100} = 50.0\ \mathrm{m}^3\ \mathrm{s}^{-1}$) and a flash flood with disastrous consequences. On June 7, 2011, a catastrophic flash flood with a discharge $Q = 44.5\ \mathrm{m}^3\ \mathrm{s}^{-1}$ ($Q_{100} = 23\ \mathrm{m}^3\ \mathrm{s}^{-1}$) in the Gidra torrent basin ($32.9\ \mathrm{km}^2$) was created on the eastern slopes of the geomorphological unit of Malé Karpaty, which was a major flood damage, especially in the village of Pila. During this day, precipitation from 51 to 104 mm fell on the southeastern slopes of the Malé Karpaty geomorphological unit (Western Slovakia). On July 21, 2014, a great flash flood occurred in Vrátna Valley in a geomorphological unit of Malá Fatra. This flash flood was caused by rainfall with intensity of 60 mm for 1.5 hours in the highest part of the watershed (area $6.01\ \mathrm{km}^2$). Subsequent discharge $Q = 36\ \mathrm{m}^3.\mathrm{s}^{-1}$ was equal to 100 – yearly discharge. On July 31, 2016, a flash flood occurred in a geomorphological unit of Kremnické vrchy after torrential precipitation with intensity 70–75 mm h^{-1} (110–125 mm 24 h^{-1}) with subsequent extensive damage to the adjacent infrastructure in the vicinity of the village Kremnické Bane.

6 Lessons from the History of Flash Floods in Mountain Watersheds of Slovakia

Based on the analysis of the 33 flash floods that occurred in the small mountain watersheds of the SR [12, 13] in the period 1925–2016, we found that:

- The main causes of flash floods were torrent rains with intensity 80—-91 mm 0.5 h^{-1}, 65–100 mm h^{-1}, 81–130 mm 2 h^{-1}, 75–130 mm 3 h^{-1}, 130–228.5 mm 4 h^{-1}, and 100–231.9 mm 24 h^{-1}.
- From 33 analyzed flash floods, 3 occurred in May (9.1%), 9 in June (27.3%), 18 in July (54.5%), and 3 in August (9.1%).
- The high forest cover of the watershed (94 or 97.8%) cannot prevent the flash flood [watersheds of torrent Hronček and Osrblianka in geomorphological unit of Poľana (2001), watershed Gidra in geomorphological unit of Malé Karpaty (2011), etc.].

The causes of the increased flood damages were mainly:

- Neglected maintenance of watercourse beds
- Construction in the immediate vicinity of watercourses
- Storage of different materials near the streams
- Neglected tending of riparian vegetation
- Storage of wood near watercourses
- Negligence and irresponsibility of inhabitants and self-government of municipalities (municipal waste in watercourse beds)
- Improperly designed and build construction (pipes, benches, bridges)
- Absent, neglected maintenance or wanting drainage, accelerated runoff, and erosion on unpaved forest roads

7 Discharge Capacity and Bankfull Discharge of Natural Torrent Beds of Slovakia in Relation to T-Yearly Discharges

This question is important from the point of view of the frequency of bankfull discharges and potential flood situations in terms of their recurrence interval. Based on the research in 594 experimental flow profiles on 80 mountain torrents with watershed areas S_w from 0.25 to 50.38 km^2 and discharges Q_1 from 0.20 to

12.0 $m^3 s^{-1}$ and Q_{100} from 1.0 to 145.0 $m^3 s^{-1}$ in 3 geomorphological units of the SR, we found that values of the discharge capacity (bankfull discharge) of natural (unpaved, uncontrolled) torrent beds correspond to certain T-yearly discharges. For the torrents in a geomorphological unit of Poĺana (480–1,458 m asl) with watershed areas from 0.384 km^2 to 48.40 km^2, the recurrence interval of bankfull discharge is from Q_1 to $Q_{7.35}$ (with an average $Q_{2.63}$). It means that the recurrence interval for bankfull discharge is from 1 year to 7.35 years. In geomorphological unit of Kremnické vrchy (270–1,317 m asl) with watershed areas 3.79–21.13 km^2, the interval is from Q_1 to Q_{10} (with an average $Q_{2.33}$). In the Western Tatras (690–2,248 m asl) with watershed areas from 1.20 to 50.38 km^2 in the geomorphological unit of Tatras, the interval is from Q_1 to $Q_{17.2}$ (with an average $Q_{4.21}$). In the High Tatras (905–2,645.8 m asl) in the geomorphological unit of Tatras with watershed areas from 0.25 to 19.34 km^2, the recurrence interval varies from 1–13.17 years (Q_1 to $Q_{13.17}$) with an average $Q_{5.09}$ [14–17].

8 Forest and Runoff in Mountain Watersheds

Since the establishment of forestry activities in torrent control in the Slovak Republic, they are carried out by forest owners, who understand these activities as complex (integrated) management of small mountain catchments. In this management, the water management function of forest ecosystems plays a very important role. Author [18] states that in torrential watersheds, the conservation improvement and establishment of forest tree cover are important for their highly beneficial effect on infiltration and water concentration time, as well as on surface runoff and flood flow control. Wherever possible, any suitable watershed land should be reforested in preference to any other forms of land use.

The forest ecosystem has important functions in relation to runoff and subsequent discharge [19]:

- Retention (water retention) – how and where to retain rainfall water on the surface of forest vegetation, in the humus layer, etc.
- Accumulation (accumulation of water) – as and where in forest land (accumulation function)
- Retardation of surface runoff (slowing down of surface runoff which is delaying the time of runoff) and its turn into a subsurface runoff

In connection with runoff formation, the mountain watersheds are very important:

- Total forest quality (hydric efficiency); existence, absence, and quality of the humus layer; interceptor capacity of the forest ecosystem; and its ability of transpiration and evaporation (i.e., evapotranspiration)
- Saturation of the catchment through the previous precipitation
- Geomorphological characteristics of the terrain (slope, roughness)
- Soil characteristics (permeability)

- Hydrogeological characteristics of the basin (rock permeability)
- Meteorological conditions, etc.

It is generally known that forests affect the process of runoff formation and their development. In connection with the runoff, the forest ecosystems have particular significance in mountain watersheds, but their influence on the runoff formation may be very different under existing conditions. Composite authors [20] reported that in Slovakia the area of forest plots has been continually increasing and reached 2014,731 ha in 2015 (it is 41.4% of the territory of Slovakia, which is 49,035.81 km^2). In the same period, the area of forest cropland, or forest stands, respectively, has similarly shown an upward trend and reached 1,942,567 ha (it is 39.6% of the territory of Slovakia). Forest cover which is calculated as a percentage of the area of forest holdings to the total area of Slovakia reached almost 41.4% in 2015. The authors also report that in addition to forest on forest land, there is in Slovakia a certain percentage of agricultural and other lands covered with stands of forest tree species [20]. The area covered by this type of forest vegetation represented almost 275,000 ha. Thus the Slovakia's forest cover as the proportion of forest on both forest and non-forest land (2,217,567 ha), compared to the total area of Slovakia, stands at 45.2%. In general, each forest ecosystem has a certain hydrological significance. The hydrological efficiency of forest ecosystems is limited (bounded) and depends on many influential factors. One of the most important among them is the current state of saturation of the forest ecosystem (including forest land) by previous precipitation. After the forest ecosystem has fully saturated with previous rainfall, the forest is no longer able to withstand further precipitation. Within interceptions, the forest ecosystem may retain several millimeters of precipitation during one crash event in tree crowns (according to the quality of forest stands). Interceptions are significant, for example, in annual hydrological balances [21, 22]. In this case, the interceptions represent up to several tenths of the total annual rainfall depending on the quality of the forest vegetation, the wood species, etc. This value is 19–46% of the average annual rainfall sum [23]. During one collision, interceptions in the forest ecosystem can be a maximum of 6–9 mm [24]. The forest ecosystem can hold up to 300–350 l (0.3–0.35 m^3) of water per square meter under appropriate conditions in the soil. Another important component of the hydrological balance within the forest ecosystem is transpiration – productive evaporation – drainage of forest water through root systems of forest trees with subsequent growth processes and biomass production. The rainfall sums that the forest ecosystem is able to contain within a single rainfall or 24 h can be very different and depend on many influential factors. Authors [21] report that the hydrological function of the forest, understood as its interceptor capacity, the infiltration capacity of the forest soil and the rock environment, and the ability of the forest to slow out the outflow from a small river basin, can only positively affect precipitation and drainage processes for precipitations not exceeding 20–24 mm in 24 h. The importance of hydrological function of the forest ecosystem grows within the longer term – seasonal or annual hydrological balances. Author [20] states that the actual retention capacity of forest stands is relatively large (30–70 mm), but not so much as to prevent the occurrence of floods, in the event of extreme precipitation or at the time of saturation of forests by previous precipitation. Authors [25] report the retention capacity of forest ecosystems 30–40 mm, after extreme precipitation up to 68 mm. Author [26] indicates the value of rainfall retained by the forest of 50 mm. Author [27] states that the saturation capacity of forest woods by precipitation represents a value of 10 mm. The capacity of shrubs and herbaceous vegetation and the layer of fallen leaves and tree needles is from 5 to 20 mm, and the retention capacity of the soil (for most extended forest land in Slovakia) is from 30 to 40 mm, so the total retention capacity of forest stands can be estimated at about 40–70 mm. However, this value is valid for 100% forest coverage of the landscape and for 1.0 crop density (100% crown canopy, respectively). It follows that even the high forest cover of the watershed cannot prevent the occurrence of floods in the event of extreme torrential rainfall (sometimes in combination with the precipitation of the catchment through previous precipitation), as evidenced by several examples from recent years and also from the territory of Slovakia.

Surface flowing water rate in the concentrated runoff is in the range of about 0.1–3.0 m s^{-1}, in humus layer it is 0.01–0.1 m s^{-1}, and in the forest soil (subsurface runoff), it is 0.000001–0.00001 m s^{-1} [28]. In this context, measures to reduce the risk of floods in forest ecosystems should, in particular, be aimed at avoiding a concentrated runoff, conversion of surface runoff to the subsurface, to protect the humus layer and avoiding damage to forest soil.

Slovak forest falls into three categories (Table 4). Composite authors [20] report that all forests regardless of their category provide a whole host of different services and benefits (over 90% of all forest are so-called poly-functional forests). Most forests fall into production category. Their primary function is the production of high-grade timber without compromising other important ecological and social functions through integrated forest management.

Forests with primarily an ecological nature to their services and benefits are protection forests. The management of the protected forests is primarily focused on various benefits of their ecological functions (soil, water, and infrastructure protection) and to ensure sustainable fulfillment of their ecological services. Social and cultural functions are most important in forests, which due to their specific societal group of benefits have been given the status of special-purpose forests. These forests are under special management with enhancement of one or more functions, for example, water purification, nature conservation, education, research, etc. [20].

From the point of view of water balance of forest stands in mountain watersheds of Slovakia, it is important to divide them into "forest altitudinal vegetation zones."

Table 4 Forest categories in the SR

Category	Area (ha)	Area (%)
Production forests	1,397,000	71.93
Protection forests	334,500	17.23
Special-purpose forests	210,700	10.84

Table 5 Forest altitudinal vegetation zones in Slovakia and their informative average water balance

Zone	A[a] (ha)	A[a] (%)	E[b] (m asl)	P[c] (mm)	∅P[d] (mm)	T[e] (°C)	∅T[f] (°C)	∅ETR[g] (mm)	∅ETR[h] (%)	∅R[i] (mm)	∅R[i] (%)	α[j]
1. Oak	138,907	7.2	≤300	≤600	550	≥8.5	9.0	550	100	0	0	0
2. Beech-oak	265,377	13.7	200–500	600–700	650	6.0–8.5	7.25	442	68	208	32	0.32
3. Oak-beech	460,282	23.7	300–700	700–800	750	5.5–7.5	6.5	487	65	263	35	0.35
4. Beech	404,519	20.8	400–800	800–900	850	5.0–7.0	6.0	510	60	340	40	0.40
5. Fir-beech	428,333	21.9	500–1,000	900–1,050	975	4.5–6.5	5.5	342	55	439	45	0.45
6. Spruce-beech-Fir	183,461	9.5	900–1,300	1,000–1,300	1,150	3.5–5.0	4.25	518	45	632	55	0.55
7. Spruce	40,398	2.1	1,250–1,550	1,100–1,600	1,350	2.0–4.0	3	705	30	945	70	0.70
8. Dwarf pine	21,290	1.1	≥1,500	≥1,500	1,600	≤2.5	2	320	20	1,280	80	0.80

[a] Area (ha, %)
[b] Elevation (m asl)
[c] Precipitation (mm)
[d] Average precipitation (mm)
[e] Temperature (°C)
[f] Average temperature (°C)
[g] Average evapotranspiration (mm)
[h] Average evapotranspiration (%)
[i] Average runoff (mm, %)
[j] Runoff coefficient

Fig. 8 The damaged riparian stands of Kôprový potok (torrent of Western Tatras) after wind calamity on November 19, 2004, need urgent tending (photo M. Jakubisová)

Fig. 9 Map of Slovakia and location of the High Tatras

Forest altitudinal vegetation zones in Slovakia and their informative average water balance [29] is explained in Table 5 for better clarity.

In the mountain, watersheds have an important role in riparian stands as an important part of the forests [30, 31]. The riparian stands (riparian vegetation) need systematic tending (Fig. 8). They have many various functions in flood control, also. Functions of riparian stand can be divided into:

- Ecological: soil protection function on the slopes of torrent beds (slowing the discharge and erosion control, landslide control) and water protection functions (filtration, infiltration, water shading, soil drifting control)
- Environmental: biodiversity enhancing, nature protection, and aesthetic effect in the landscape
- Production: wood and other product production

9 The Equations of Water Balance in Watersheds of the High Tatras

Some authorities consider that mountain regions represent, in practical terms, "the blackest of black boxes in the hydrological cycle" [32]. Therefore, it is very important to know the water balance of the mountain watersheds (basins). In the determination of basic elements of the water balance equation for all of 26 analyzed mountain watersheds in the High Tatras, the highest mountain in Slovakia (Fig. 9) used the simplified relationship:

$$\bar{P} = \bar{R} + \bar{E} \text{ (mm)} \tag{2}$$

where $\bar{P}$ is the mean long-term annual precipitation in the watershed (mm), $\bar{R}$ mean long-term annual runoff in the watershed (mm), and $\bar{E}$ mean long-term annual climatic evaporation in the watershed (mm).

To determination of the elements of Eq. (2) were used the equations which were derived by research [4]. The authors based on the knowledge that the mean annual climatic evaporation $\bar{E}$ can be determined as a function of potential evaporation index EPi (mm) and mean long-term annual precipitation $\bar{P}$ (mm):

$$\bar{E} \cdot \mathrm{EP}_\mathrm{i}^{-1} = f\left(\bar{P} \cdot \mathrm{EP}_\mathrm{i}^{-1}\right) \text{ (mm)} \tag{3}$$

Authors [4] on the basis of relation (3) and measured data of 54 meteorological stations in the Slovak Republic derived for the conditions of SR the empirical relationships which were used in analysis:

$$\bar{R} = \bar{P} - \frac{\bar{P}}{\sqrt{0.809 + \left(\frac{\bar{P}}{\mathrm{EP}_\mathrm{i}}\right)^2}} \text{ (mm)} \tag{4}$$

and

$$\bar{R} = \bar{P} \cdot \left(1 - \frac{\mathrm{EP_i}}{\sqrt{0.809 \times \mathrm{EP_i^2} + \overline{P^2}}} \right) \ (\mathrm{mm}) \tag{5}$$

The potential evaporation index EPi was calculated using the relation:

$$\mathrm{EP_{iSR}} = 260.822 + 37.920\bar{T} + 0.077\overline{T^3} \tag{6}$$

where $\bar{T}$ is the mean long-term annual temperature in the watershed (°C).

The values of mean long-term annual precipitation and mean long-term annual temperature for all of the analyzed watersheds were derived from measured data in eight meteorological stations of High Tatras (Table 6, Figs. 10 and 11). Using the results of Eqs. (4) and (5), respectively, the coefficient $\bar{R} \times S_\mathrm{p}$ was calculated which is substantially the component of the numerator in the formula to the calculation of mean long-term annual runoff:

$$Q_\mathrm{a} = \frac{\bar{R} \cdot S_\mathrm{w} \cdot 10^3}{t} \left(\mathrm{m^3\,s^{-1}}\right) \tag{7}$$

where t is 31,557,600 s (time in seconds for 1 year).

Basic morphological characteristics of the reference watersheds of High Tatras are shown in Table 7. Basic hydrological characteristics of these watersheds are shown in Table 8.

Table 6 The mean annual precipitation and temperature in the High Tatras

Station	H^a (m asl)	$\bar{P}^\mathrm{b}$ (mm)	$\bar{T}^\mathrm{c}$ (°C)
Tatranská Lomnica	832	833	5.2
Starý Smokovec	1,018	930	–
Vyšné Hágy	1,140	864	4.3
Hrebienok	1,285	1,132	–
Štrbské pleso	1,360	976	3.6
Popradské pleso	1,530	1,319	2.2
Skalnaté pleso	1,778	1,380	1.6
Lomnický štít	2,634	2,634	3.7

[a] Height (m asl)

[b] Average long-term annual precipitation (mm)

[c] Average long-term annual temperature (°C)

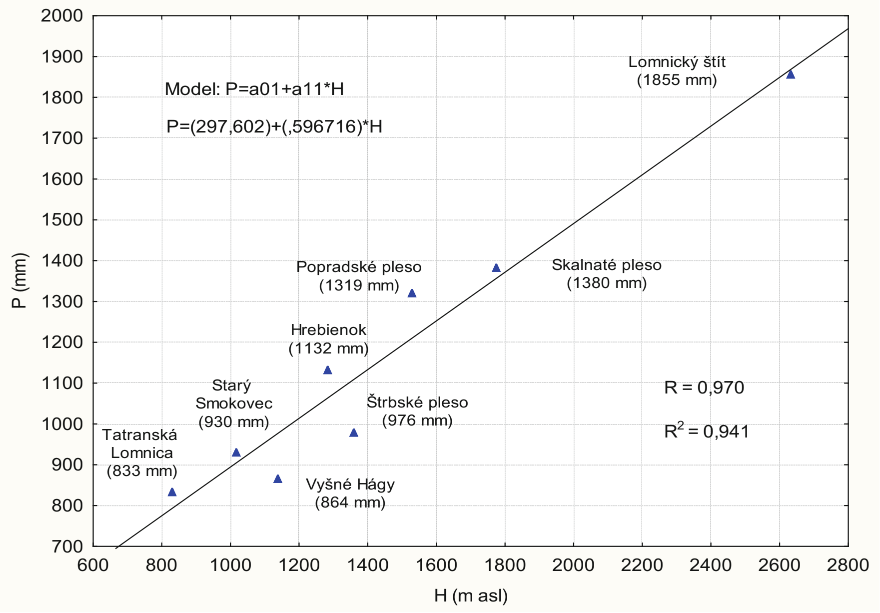

Fig. 10 The mean annual precipitation in the High Tatras

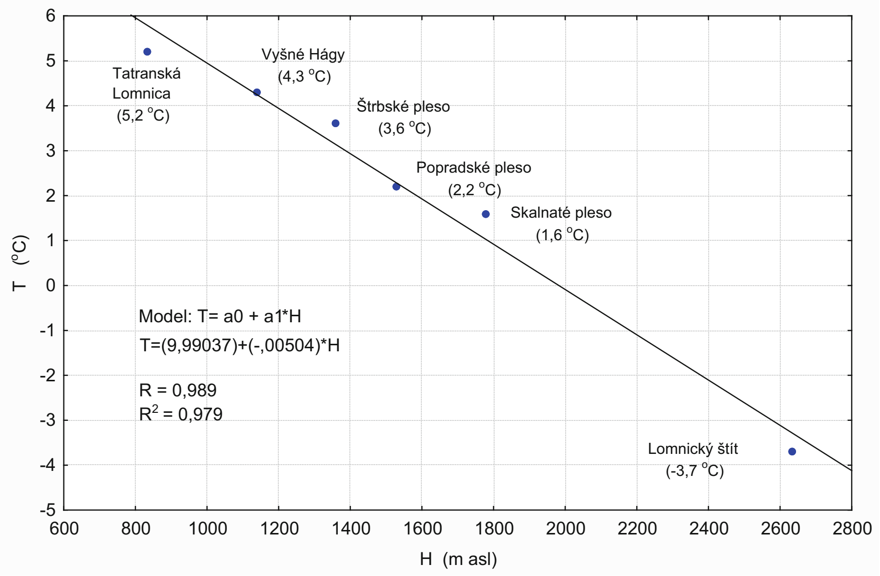

Fig. 11 The mean annual temperatures in the High Tatras

Table 7 Basic characteristics of watersheds and watercourses in the High Tatras

Watercourse	S_{w}[a] (km^2)	S_{f}[b] (km^2)	F[c] (%)	H_{minw}[d] (m asl)	H_{maxw}[e] (m asl)	ΔH_{w}[f] (m)	H_{maxs}[g] (m asl)	ΔH_{t}[h] (m)
Beliansky potok	3.17	2.00	63.1	1,140	2,494	1,354	2,310	1,170
Tri studničky	0.36	0.36	100.0	1,160	1,510	350	1,295	135
Mlyničná voda	2.18	1.86	85.3	1,160	2,310	1,150	1,320	160
Jamský potok	0.60	0.60	100.0	1,200	1,580	380	1,455	255
Važecký potok	0.25	0.25	100.0	1,210	1,600	390	1,536	326
Biely Váh	10.62	6.11	57.5	1,220	2,494	1,274	1,840	620
Lieskovec	1.57	1.56	99.4	1,200	1,840	640	1,325	125
Mlynica	6.90	2.68	38.8	1,260	2,428	1,168	1,800	540
Poprad	19.34	8.72	45.1	1,200	2,499	1,299	1,740	540
Veľký šum	4.86	4.70	96.7	1,122	2,280	1,158	1,618	496
Malý šum	3.07	2.49	81.1	1,080	2,366	1,286	1,840	760
Háganský potok	0.71	0.68	95.8	1,082	1,490	408	1,323	241
Batizovský potok	5.69	3.86	67.8	1,030	2,654	1,624	1,884	854
Hromadná voda	3.25	2.88	88.6	990	2,640	1,650	1,460	470
Velický potok	6.16	3.45	56.0	993	2,654	1,661	1,860	867
Slavkovský potok	5.31	3.58	67.4	1,010	2,452	1,441	1,260	250
Malý Štiavnik	0.88	0.80	90.9	1,005	1970	965	1,129	124
Veľký Jazyk	1.19	0.91	76.5	998	2040	1,042	1,124	126
Štiavnik	1.64	0.91	55.5	997	2,273	1,276	1,315	318
Päť prameňov	0.98	0.87	88.8	990	1,700	710	1,150	160
Pod Hrebienkom	2.73	2.27	83.2	985	2060	1,075	1,173	188
Studený potok	18.13	8.34	46.0	920	2,633	1,713	2057	1,137
Hlboký potok	4.88	4.46	91.4	860	2,230	1,370	1,440	580
Skalnatý potok	9.37	6.47	69.1	890	2,634	1,744	2,500	1,610
Kežmarská Biela voda	18.29	12.16	66.5	910	2,634	1,724	2,100	1,190
Sedem prameňov	4.58	3.82	83.4	905	1946	1,041	1,420	515

[a] Watershed area (km^2)
[b] Forested watershed area (km^2)
[c] Percentage of watershed forestation (%)
[d] Minimal altitude of the watershed (m asl)
[e] Maximal altitude of the watershed (m asl)
[f] Absolute gradient of the watershed (m)
[g] Altitude of the spring (m asl)
[h] Absolute gradient of watercourse (m)

Table 8 Hydrologic characteristics of experimental watersheds in the High Tatras

Watercourse	$øH_w$[a] (m asl)	$\bar{P}$[b] (mm)	$\bar{T}$[c] (°C)	EP_i[d] (mm)	$\bar{R}$[e] (mm)	$\bar{R}$[e] (%)	$\bar{E}$[f] (mm)	$\bar{E}$[f] (%)	Q_a[g] ($m^3\ s^{-1}$)
Beliansky potok	1,614	1,261	1.9	333.40	937	74	324	26	0.094
Tri studničky	1,278	1,060	3.6	400.93	680	64	380	36	0.008
Mlyničná voda	1,544	1,219	2.3	348.97	881	72	338	28	0.061
Jamský potok	1,407	1,137	3.0	376.66	776	68	361	32	0.015
Važecký potok	1,350	1,103	3.2	384.69	736	67	367	33	0.006
Biely Váh	1,812	1,379	0.9	295.01	1,089	79	290	21	0.366
Lieskovec	1,434	1,153	2.8	368.69	799	69	354	31	0.040
Mlynica	1,740	1,336	1.3	310.29	1,032	77	304	23	0.226
Poprad	1,789	1,365	1.0	298.82	1,072	80	293	20	0.657
Veľký šum	1,548	1,221	2.3	348.97	883	72	338	28	0.136
Malý šum	1,665	1,291	1.7	325.66	973	75	318	25	0.095
Háganský potok	1,277	1,060	3.6	400.93	680	64	380	36	0.015
Batizovský potok	1,696	1,310	1.5	317.96	999	76	311	24	0.180
Hromadná voda	1,510	1,199	2.4	352.89	858	72	341	28	0.088
Velický potok	1,736	1,333	1.3	310.29	1,029	77	304	23	0.201
Slavkovský potok	1,655	1,285	1.7	325.66	967	75	318	25	0.163
Malý Štiavnik	1,273	1,057	3.6	400.93	678	64	379	36	0.019
Veľký Jazyk	1,306	1,077	3.5	396.84	700	65	377	35	0.026
Štiavnik	1,528	1,209	2.4	352.89	868	72	341	28	0.045
Päť prameňov	1,239	1,037	3.8	409.14	651	36	386	37	0.020
Pod Hrebienkom	1,308	1,078	3.5	396.84	701	65	377	35	0.061
Studený potok	1,793	1,367	1.0	298.82	1,074	79	293	21	0.617
Hlboký potok	1,304	1,076	3.5	396.84	699	65	377	35	0.108
Skalnatý potok	1,506	1,196	2.5	356.83	851	71	345	29	0.253
Kežmarská Biela voda	1,612	1,259	1.9	333.40	935	74	324	26	0.542
Sedem prameňov	1,241	1,038	3.8	409.14	652	63	386	27	0.095

[a] Mean altitude of the watershed

[b] Average long-term annual precipitation (mm)

[c] Mean long-term annual temperature in the watershed (°C)

[d] Potential evaporation index

[e] Mean long-term annual runoff in the watershed (mm, %)

[f] Mean long-term annual climatic evaporation in the watershed (mm)

[g] Mean long-term annual runoff ($m^3\ s^{-1}$)

10 Calculation of Runoff and T-Yearly Discharges in Torrent Watersheds in Forestry Practice of Slovakia

To determine of runoff and T-yearly discharges (if direct measurements from Slovak Hydrometeorological Institute Bratislava are not available) for dimensioning of the beds in torrent control (in forestry practice) we use the most commonly regional equation by the academician Dub:

$$q_{\max} = \frac{A_0}{(S_w + 1)^{n_0}} \cdot (1 \pm o_1 \pm o_2)\left(\mathrm{m^3\ s^{-1}\ km^{-2}}\right) \tag{8}$$

where $q_{\max}$ is the maximal specific runoff ($\mathrm{m^3\ s^{-1}\ km^{-2}}$), S_w watershed area ($\mathrm{km^2}$), and A_0, n_0 regional characteristics for 11 basic watersheds of main rivers in Slovakia with 67 subregions according to geological structures by Branch Technical Standard OTN ŽP 3112-1:03 [33]; the value of coefficient A_0 varies within the range from 1.00 to 25.00; the value of coefficient n_0 varies within the range from 0.136 to 0.641. o_1 is the coefficient expressing the effect of forestation of watershed on the runoff (from −0.25 to +0.25):

$$o_1 = 0.5 \cdot \left(0.5 - \frac{S_L}{S}\right) \tag{9}$$

o_2 is the coefficient expressing the effect of watershed shape on the runoff (from −0.10 to +0.10).

Then we can calculate:

$$Q_{\max=}Q_{100} = S_w \cdot q_{\max}\ \left(\mathrm{m^3\ s^{-1}}\right) \tag{10}$$

Based on the calculations for 80 watersheds of mountain torrents with watersheds areas from 0.25 to 50.38 $\mathrm{km^2}$, discharges Q1 from 0.20 to 12.0 $\mathrm{m^3\ s^{-1}}$ and Q100 from 1.0 to 145.0 $\mathrm{m^3\ s^{-1}}$ in 3 geomorphological units of the SR, we found that the values of maximal specific runoff $q_{\max}$ ($\mathrm{m^3\ s^{-1}\ km^{-2}}$) for the watersheds in geomorphological unit of Poľana (480–1458 m asl) with watershed areas from 0.384 $\mathrm{km^2}$ to 48.40 $\mathrm{km^2}$ ranged from $q_{\max} = 0.93\ \mathrm{m^3\ s^{-1}\ km^{-2}}$ to $q_{\max} = 4.84\ \mathrm{m^3\ s^{-1}\ km^{-2}}$ (with an average $q_{\max} = 2.93\ \mathrm{m^3\ s^{-1}\ km^{-2}}$). In the geomorphological unit of Kremnické vrchy (270–1317 m asl) with watershed areas from 3.79 $\mathrm{km^2}$ to 21.13 $\mathrm{km^2}$ maximal specific runoff ranged from $q_{\max} = 1.51\ \mathrm{m^3\ s^{-1}\ km^{-2}}$ to $q_{\max} = 3.23\ \mathrm{m^3\ s^{-1}\ km^{-2}}$ (with an average $q_{\max} = 2.24\ \mathrm{m^3\ s^{-1}\ km^{-2}}$). In the Western Tatras (690–2248 m asl) with watershed areas from 1.20 $\mathrm{km^2}$ to 50.38 $\mathrm{km^2}$ in the geomorphological unit of Tatras is this interval from $q_{\max} = 1.65\ \mathrm{m^3\ s^{-1}\ km^{-2}}$ to $q_{\max} = 3.87\ \mathrm{m^3\ s^{-1}\ km^{-2}}$ (with an average $q_{\max} = 2.92\ \mathrm{m^3\ s^{-1}\ km^{-2}}$). In the geomorphological unit of High Tatras (905–2,645.8 m asl), watershed areas from 0.25 to 19.34 $\mathrm{km^2}$ vary from $q_{\max} = 1.62\ \mathrm{m^3\ s^{-1}\ km^{-2}}$ to $q_{\max} = 5.91\ \mathrm{m^3\ s^{-1}\ km^{-2}}$ with an average $q_{\max} = 3.13\ \mathrm{m^3\ s^{-1}\ km^{-2}}$ [14, 15].

11 Conclusions

From the beginning of torrent control activities, many important constructions in the form of various biological and technical measures to the flood and erosion control have been created. These measures protect human lives and health as well as the landscape against devastating floods and erosion. At the same time, they improve the possibilities of securing and using valuable water resources from mountain areas. An indispensable prerequisite for the optimal use of many significant positive benefits of torrents and, at the same time, to limit their harmful activity is the revival of the active activities of torrent control in the Slovak Republic. These activities are currently very limited. The torrents form the highest stretches of watercourses. In these areas (mountain watersheds), the floods begin to form. Although there are large-scale protected areas, there are many ways today, the possibility of sensitive interventions and biotechnical measures, to improve runoff rates while increasing the availability of quality water available for human needs.

12 Recommendations

Recommendations for optimizing on integrated torrent control and torrent watershed management in conditions of the Slovak Republic can be divided into several fields:

- Immediate resumption of torrent control activities
- Improvement of cooperation between the Ministry of Agriculture and Rural Development of the SR and Ministry of Environment of the SR
- Better cooperation between all owners, administrators, and users of torrent watersheds
- Education of university-educated professionals in the field of integrated watershed management
- Expanding scientific research into issues of integrated watershed management, flash floods, torrent erosion impact of forest ecosystems to runoff in mountain watersheds, impacts of climate change to runoff formation, and subsequent implementation of the result into practice

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