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Interpretation of causes of a flash flood in the Olešenský potok brook drainage area

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Abstract

The main cause of the so-called flash flood that occurred in the Olešenský potok Brook drainage area on June 10 and 11, 2004, was above all an abnormal rainfall. Human interventions into the natural environment had only a negligible impact on the flood magnitude and thus on the consequent material damages. Substantial flood damages were mainly due to inappropriate development in the floodplain and to the consequent narrowing of the flood discharge profile as well as to the existence of low capacity bridges in the built-up reach of the floodplain. In the upper and middle part of the basin, where the valley has still maintained its natural character, abnormal erosion and accumulation locally occurred, but this is a part of natural development of a valley.

Key words: flash flood, antropogenous impacts

Introduction and methods

On June 10 and 11, 2004, extreme torrential rainfall caused flooding along the Olešenský potok Brook. This was a local flash flooding caused by extraordinarily intensive rainfall during a series of thunderstorms. In the afternoon and evening of June 10, 2004, very strong thunderstorms occurred in an almost 15 km wide and 75 km long belt stretching from Kostelec nad Černými Lesy southeastwards to Havlíčkův Brod, where they were already much weaker. Floods caused significant material damages especially in Ledeč nad Sázavou, where the Olešenský potok Brook mouths from the right to the Sázava River. No victims were reported.

The following article analyses the causes of the flood, i.e. to which degree it was due to purely natural causes or whether impacts of human activities in the landscape, modification of the riverbed, etc., could have manifested as well.

This study is based on field research carried out immediately after the flood, on an analysis of the Olešenský potok Brook basin from the geological, geomorphological and pedological conditions viewpoint done after archive materials (mainly maps), on a description of meteorological situation (after the Czech Hydrometeorological Institute) and on evaluations of discharge rates (after the Czech Hydrometeorological Institute). Also experience from evaluation of flood events in 1997 in Moravia (Havlík et al. 1998) and in 2002 in Czech Republic (Vilímek et al. 2003; Langhammer 2005) was used.

Basin description

According to geomorphological classification, the Olešenský potok Brook basin belongs to the Hornosázavská pahorkatina Hilly Land (Jurigová ed. 1986) that is further divided into its eastern and western parts. The eastern part is formed by a depression between Havlíčkův Brod and Jihlava and the western part has the character of a hilly land. (The Olešenský potok Brook basin is situated in the western part). This hilly land has relatively rugged topography which is due to erosion activities of the Sázava River and of its right-bank tributaries. Then the relief quickly rises up from Sázava to a relatively flat summit part, while more northwards it slopes more gently (Demek et al. 1965). Steeper southern slopes are formed by Sázava's erosional cutting and due to this development, its right-bank tributaries (including the Olešenský potok Brook) got deepened. They are also characterized by steep slopes on their middle and lower course descending to a flat floodplain. This corresponds to Upper Quaternary deepening of the stream corresponding to the Sázava River valley development. Intervalley ridges are significantly flatter.

The Olešenský potok Brook rises in Třebětín at 555 m a. s. l. and after 13.2 km it mouths from the right side to the Sázava River in Ledeč nad Sázavou (348 m a. s. l). Its drainage area is 34.5 km^2. No gauging station has been operating on this catchment. Mean discharge at the mouth (0.23 m$^3 \cdot$ s^{-1}) was therefore estimated by methods of hydrological analogy (Czech Hydrometeorological Institute). The mean altitude of the drainage area is 498 m; the mean gradient of the course 1.6% and the mean inclination of slopes in the catchment is 9.8%.

From the geological viewpoint, the studied territory is formed by biotitic paragneisses with quartzite and crystalline limestone intercalations. Soils are here (according to their granularity) light to mean, sandy loams to loamy sands, with percentage of clay particles below 20% (Tomášek 2003). From the flood regime viewpoint, their characteristics are relatively favourable. This fact was verified especially in localities, where enormously intensive erosion was ascertained by field research, i.e. westwards from Zdeslavice. Short left-bank tributaries of the Olešenský potok Brook were mainly studied. High differences in erosion activity were found in relatively short distances.

The land use in the major part of the territory is agricultural (fields, pastures), the rest is covered by forests. Mildly inclined slopes in the upper parts and watershed plateau are covered with fields; steep slopes adjacent to the valley bottom are mostly covered with forests. The valley bottom is formed by flood plain and it is permanently waterlogged due to high level of water table. Land use of the floodplain corresponds to this situation – permanent meadow communities are found there. Buildings are only scarce.

Meteorological situation description

Weather conditions over the Czech Republic were characterized, on June 10, 2004, by a front boundary remaining above our country practically without motion and separating warmer air in the south and south-east from the cold air mass in the north and north-east (Šercl et al. 2004). The frontal system over Central Europe was oriented in northwest – southeast direction. Temperature difference between both air masses on the level of 850 hPa reached 9 °C. Near the ground it was possible to analyse a shallow trough of lower pressure; on the level of 500 hPa, a belt of high pressure spreading over western and Central Europe was dominant.

Air with significant potential instability was coming to our country from the northwest, convective available potential energy (CAPE) from the ALADIN model of June 10, 2004, 00 UTC, reached in Central Bohemia in the afternoon up to 2100 J/kg, so that strong thunderstorms were likely to come.

Because of the described meteorological situation, the Czech Hydrometeorological Institute issued on June 10, 2004 at 15:30 CEST, a warning for the whole territory of the Czech Republic concerning the following dangerous phenomena: intensive thunderstorms, hailstorm, torrential rain, river surge, local flooding.

Already in the morning thunderstorms progressed over the Karlovy Vary Region and southwestern Bohemia further to the southeast. At about 14:30, a belt of thunderstorms formed in the north-south direction stretching from Liberec to České Budějovice and it was progressing further to the east and southeast. At about 15:30, thunderstorms in this belt, on the windward side of the northern margin of the Středočeská pahorkatina Hilly Land (near Říčany), grew more intensive and both their vertical extent and rainfall intensity were increasing. During the following hours, convective cells repeatedly formed in the region south-eastwards from Říčany and were progressing along the same trajectory from the northwest to the southeast. They were progressing from Říčany via Uhlířské Janovice and Světlá nad Sázavou and near Havlíčkův Brod they diminished. In the area affected by the flood, rain stopped falling not sooner than at about 8 p.m.

Intensity of rainfall

No precipitation-gage stations are being run in the Olešenský potok Brook catchment. The following daily precipitation totals were measured in these nearest stations: Bohdaneč 89.6 mm; Zbýšov-Dobrovítov 65.2 mm and Ledeč nad Sázavou 6.2 mm (Šercl et al. 2004). Data provided by meteorological radar were used for evaluation of the areal pattern of rain and of its intensity. There were ten-minute rainfall intensities available provided by the radar and their sum for the period from 14:00 to 20:00 CEST, also derived from the meteorological radar observations. Operatively ascertained 24-hour sums from precipitation-gage stations in the neighbourhood helped to adjust the given rainfall sum for 6 hours, because practically the whole 24-hour sum was reached during the mentioned six hours.

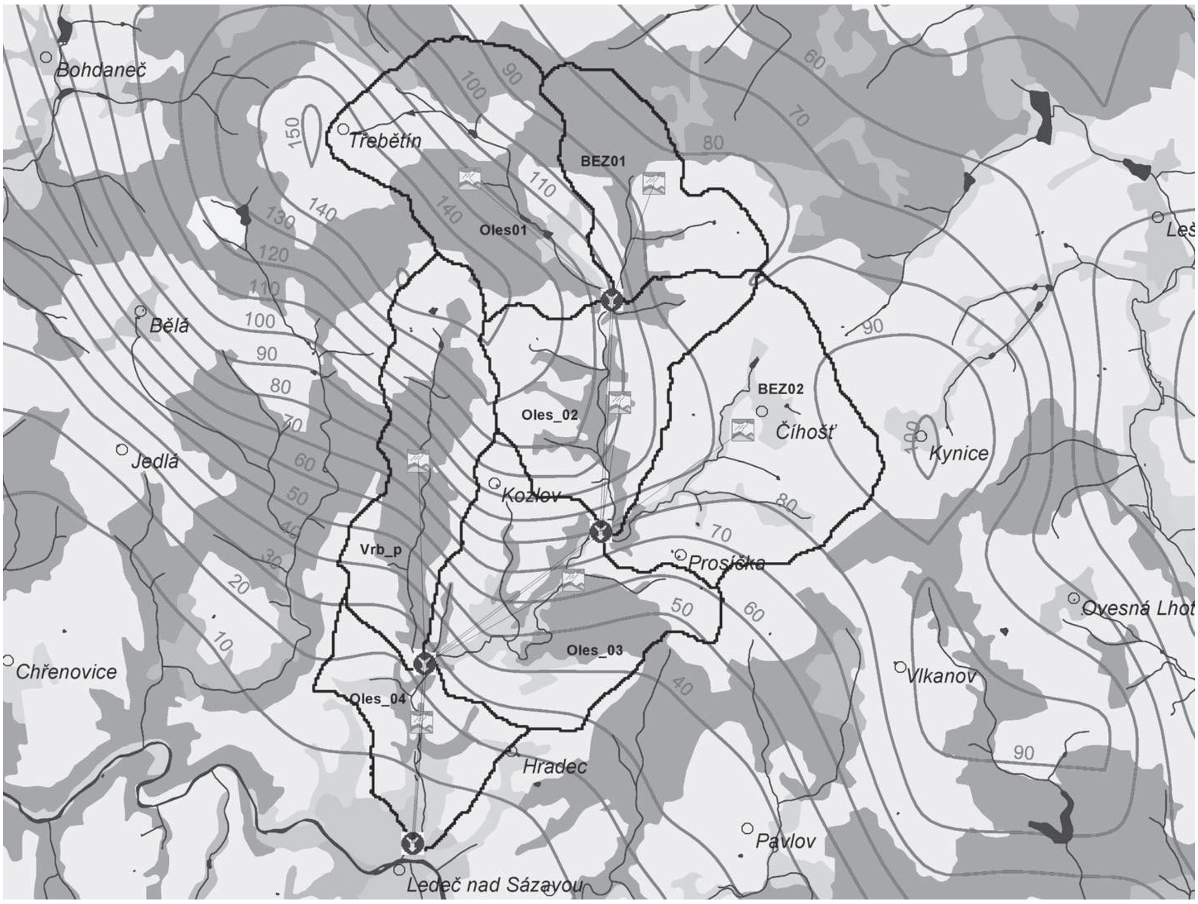

Fig. 1. Map of the Olešenský potok Brook drainage area with areal distribution of rainfall totals in the time period 14:00 – 20:00 CEST on June 10, 2004 (corrected radar on ground observation).

In Fig. 1, isohyets show the total sum of rainfall during the period from 14:00 to 20:00 CEST derived on the basis of meteorological radar observations and adjusted by field observations. It must be once more stressed that it is a mere estimation, because really measured rainfall is available only for the territory outside the Olešenský potok Brook drainage area. But also an estimation done in such a way enables to deduce that average rainfall in the basin was probably higher than 80 mm and the highest rainfall totals were recorded in the upper course (near Třebětín), where more than 100 mm fell; on the contrary in the lower course of the Olešenský potok Brook, rainfall sums quickly decreased in the direction to Ledeč nad Sázavou.

The highest average ten-minute intensities in the basin were recorded for the time period between 16:30 and 18:30 CEST with the peak between 16:50 and 17:00 (Fig. 2). During the mentioned two hours, more than 60 mm of precipitation fell over the whole catchment, which is probably more than the 100-year recurrence period. Intensities were still higher in the upper course, where 100-year recurrence period was largely exceeded, and that also with regard to 24-hour rainfall sums.

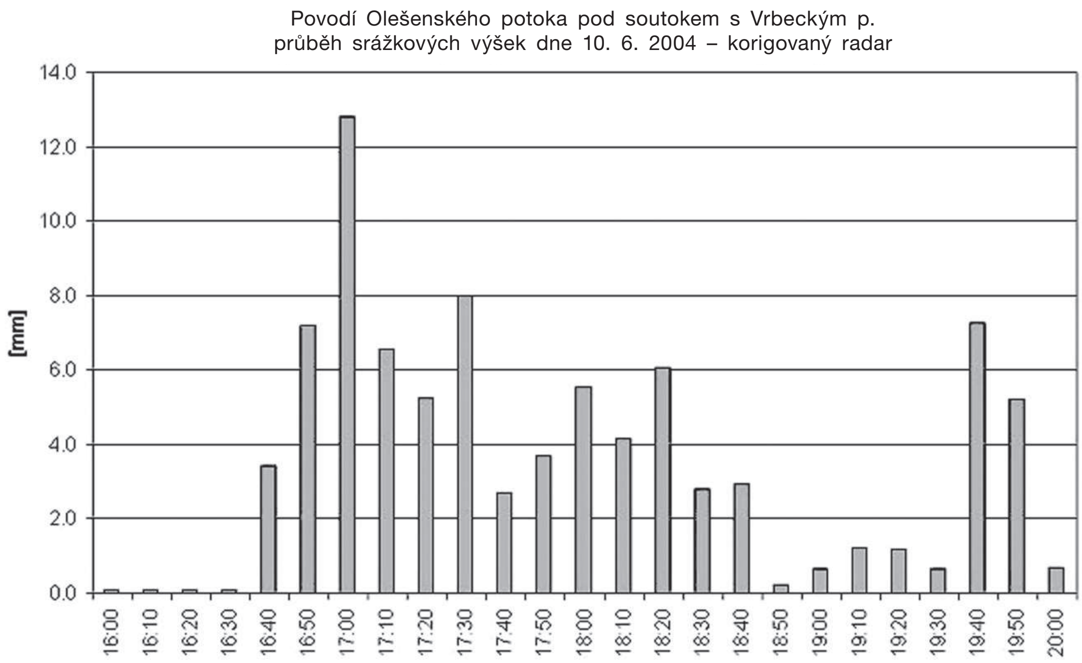

Fig. 2. Probable hyetograph of ten-minute intensities of rainfall in the Olešenský potok Brook drainage area downstream the confluence with the Vrbecký potok Brook.

Discharge evaluation

According to a local inhabitant affected by this flood (locality downstream the confluence of the Olešenský potok and the Vrbecký potok Brooks), the flood came suddenly after 7 p.m. and it was characterized by a very rapid increase (literally "during a couple of minutes water rose by more than one metre"). This could be due to the impact of smaller ponds in the upper course that probably got filled very quickly and water began to spill over their dikes that were consequently partly destroyed. This could correspond also to the alleged statement that thereafter the flood wave decreased in the place of observation but after a while it began to rise again due to formation of a flood wave on the rest of the drainage area (Šercl et al. 2004).

The Olešenský potok Brook basin is not hydrologically monitored, therefore the probable time course of the flood had to be derived with the help of rainfall – runoff model and peak discharge had to be calculated from the measured benchmarks with the help of hydraulic model.

To estimate the time course of the flood, HEC-HMS software with rainfall-runoff model HEC-1 was used. Parameters of the model (for instance time of concentration for unit hydrograph) were estimated from physical-geographical characteristics of the catchment on the basis of digital elevation model. To determine runoff losses, the method of CN curves was used, for which the necessary data are also available in GIS.

The scheme of the drainage area for evaluation in the rainfall-runoff model HEC-1 is in Fig. 1 formed by 7 elements of drainage type and 3 elements of river

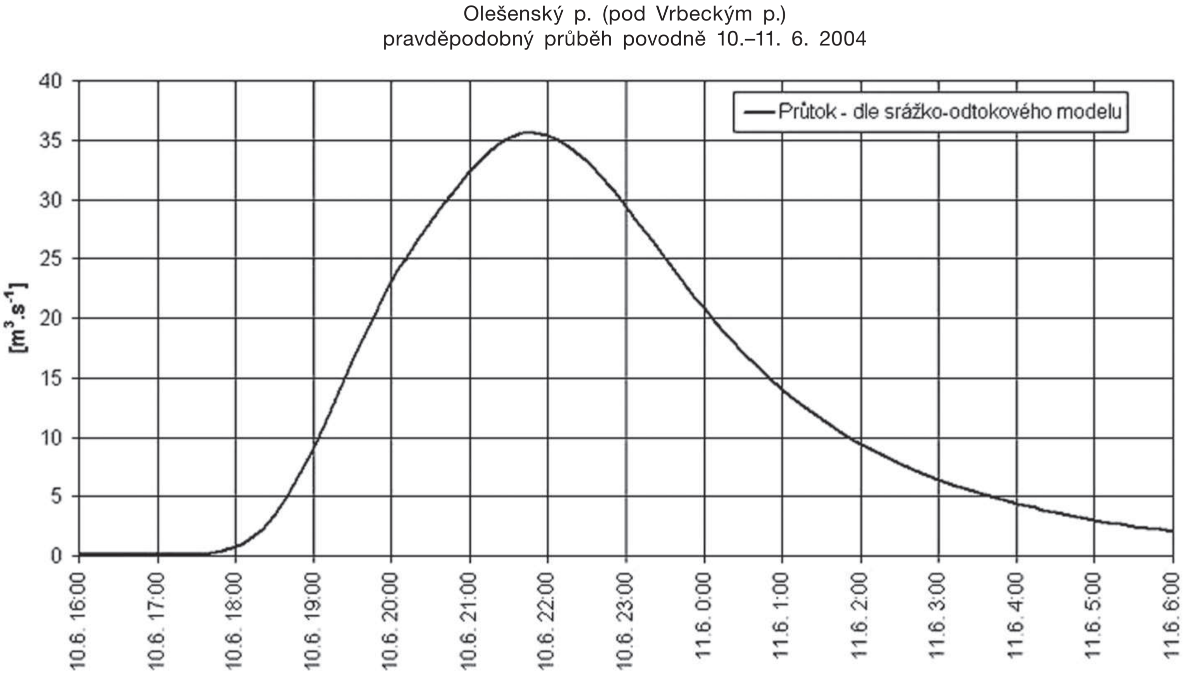

Fig. 3. Theoretical hydrograph of the flood wave along the Olešenský potok Brook in the profile downstream the confluence with the Vrbecký potok Brook according to calculations of the rainfall – runoff model.

reach type. All parameters of the model were not subsequently changed, the velocity of flood wave in river reaches was estimated as 1.5 m · s^{-1}

Fig. 3 presents the hydrograph of the flood course in the locality downstream the confluence of the Olešenský potok and the Vrbecký potok Brooks derived from the rainfall– runoff model. The graph shows that in the given place peak flow could occur between 21:00 and 22:00 CEST. According to information from Ledeč nad Sázavou (about 3 km downstream) the flood was probably a little faster than it is given by the model calculation. It peaked there already at about 21:00. The hydrograph depicted in Fig. 3 presents the theoretical course of the flood not including the above-mentioned possible impact of water reservoirs or other impacts, as for instance a possible blockage of the stream profile followed by its rupture, etc.

For hydraulic analysis of peak discharge, HEC-RAS software was used. In total four cross sections and flood benchmarks were geodetically measured along an about 270 m long reach downstream the confluence of the Olešenský potok and the Vrbecký potok Brooks. The width of the bed profile is about 4 m and its depth 1.25 m; the bottom is from coarse gravel; the brook is lined on banks by full-grown trees and on the left bank partly overgrown by bushes. In the area of a trout hatchery reservoir, a waste canal from hatchery reservoirs runs parallel to the bed and then joins it.

The left bank is in the measured reach at first steep and water cannot spread here, lower downstream it progressively opens and is overgrown by bushes and young trees. On the right bank, the stream begins to leave the bed already at about 10 $m^3 \cdot s^{-1}$ and it spreads to the hatchery reservoirs area and to the adjacent meadow (where it gets spread already at lower flows).

To obtain more realistic results, further 9 profiles were added to the measured ones, and that in places where there were changes in roughness (tree lines with bushes) and bottom inclination, or in places of some obstacles (fenced plot, building). According to registered foot-prints, water circulation in the trout hatchery area was not taken into consideration. All was measured in relative heights. Roughness coefficients in the bed and grassed inundations were considered as 0.045–0.050; in places with bushes or trees as 0.1 and more.

According to the hydraulic evaluation, the magnitude of the peak discharge was determined downstream the confluence of the Olešenský potok and the Vrbecký potok Brooks as 36 $m^3 \cdot s^{-1}$ which corresponds to the estimation according to the rainfall-runoff model. According to available data, the time of recurrence of this peak flow largely exceeds the period of 100-year recurrence. The highest specific runoffs (approximately 2 $m^3 \cdot s^{-1}$. km^{-2}) did not reach extreme levels when taking into consideration the extent of the flooded area.

Evaluation of factors influencing causes and the course of the flood

This chapter sums up factors (with regard to the given type of stream) that could theoretically increase flood risk along the Olešenský potok Brook. At the same time, it is evaluated to which extent these types of factors occur in the given locality and whether they could influence the destructive course of the flood in June 2004.

A greater part of the Olešenský potok Brook has the character of a stream meandering in a narrow floodplain without any regulation of the stream course. Its natural character is thus relatively maintained. As it was found for instance along the Blanice River after 2002 floods, just the relatively significant shortening of its stream length had a negative influence of the flood situation development (Langhammer 2003, Langhammer and Vajskebr 2006). In the upper and middle course, in reaches where the natural character of the valley was maintained, flood did not cause practically any damages, with the exception of localities with enormous erosion and accumulations, but this cannot be considered as damaging in the strict sense of the word, because it is a quite natural part of the valley development. It has therefore no sense to consider here remediation or removal of deposited material, if it does not directly menace inhabitants, communications or buildings.

No sudden large-area deforestation, which could have speeded up water runoff from the drainage, was done in the basin during the last years. On the contrary, an intensive runoff was registered also from forested areas. None of the above-mentioned factors (stream regulation, deforestation) occur in the given basin and therefore it could not affect the origin and the course of the flash flood.

As great differences in erosion intensity and consequent accumulation at the mouth of lateral ravines to the Olešenský potok Brook floodplain were found, geological and soil conditions were studied with the aim to establish to which degree the runoff could have been influenced by a lower permeability of the soil cover. It

Photo 1 During the flood dejection cones were locally formed by the material washed away from lateral ravines containing clay clods.

was found that in collecting areas of these recently re-deepened ravines there are light to medium soils from the granularity viewpoint, i.e. relatively well permeable soils. Neither this factor was decisive in formation of this flood situation. The only factors that could have locally speeded up the runoff from the catchment are the clayey positions taking place in the middle course of the Olešenský potok Brook. They are a part of the weathered mantle (Photo 1) and they are impermeable.

Eastwards from the Leština village, on the left bank of the Olešenský potok Brook, a small slide was identified during field research but it could not have dammed the valley and present any possible menace if such a naturally formed dam would have broken. Nevertheless its formation is again conditioned by the position of clayey weathered materials.

The stability of a dam near Hlohov was disturbed which led to a single spillover to the catchment, but the whole pond was not emptied; – see also Chapter Discharge evaluation (Damaged were also dikes of old ponds along the road between Vrbka and Kozlov.)

A factor that could locally influence the quantity and velocity of concentration of water from slopes in the valley network is the sort of grown crops in fields, here maize fields. In any case, field research could clearly document an abnormally high

Photo 2 Intensive erosion at the margin of the floodplain (up to the depth of 1 m).

rate of erosion (Photo 2 and 3), which caused again an enormous sedimentation in the floodplain (Photos 1 and 4). This was true for instance for the area eastwards from Hlohov (on a left-bank tributary of the Olešenský potok Brook). These sediments were deposited in the nearest places of flow velocity reduction, i.e. in places where erosion gullies join the floodplain.

Field research at the drainage area

Field research at the drainage area was done immediately after the flood when foot-prints in relief and vegetation were still well identifiable (precise). It enabled making an idea about the intensity of rainfall-runoff processes. We observed mainly the surface level of the flood area, the intensity of erosion and accumulation processes, type of sediments and traces of area washing away. Important is also areal evaluation of occurrence of abnormal erosion and sedimentation in relation to the rainfall estimation, slope inclination, bedrock and soil conditions. Evaluation of both rainfall and discharge proves that rainfall intensity in a short time period was abnormal. This can be confirmed also by field research after the flood, when manifestations of area washing away were found in fields and in forests.

Photo 3 Erosion of the maize fields (along the road Tunochody-Hlohov villages).

In several places, deep erosion furrows (up to 1 m) were found in a relatively small collecting area (north-westwards from Zdeslavice), partly covered by meadows or forests (Photo 2). There are no fields. In this part of the Olešenský potok Brook catchment, flood progressed quite differently along its left-bank tributaries. Abnormally deep erosional furrows formed during the flood alternated with older ravines without any more pronounced manifestations of erosion. In a short reach of a comparable inclination of slopes, there were large differences in the intensity of erosion. It can be explained by local changes in rainfall intensity within the area affected by thunderstorms. In the floodplain, sharp-edged material from slope deluvium was often found, which proves again a strong deep erosion both in soil cover and in upper parts of the weathered mantle where stone debris are partly rounded. Only deeper parts of weathering mantle contain sharp-edges debris.

The documented flood plain stratigraphy (locality about 1 km downstream Hlohov) shows that comparable flood had to occur here in the geological past. This type of young sediments (floodplain) is formed periodically during repeated floods. In the mentioned locality it was possible to observe, under about 20 cm of alluvial soil, mother substrate under the form of brook alluvia (coarse-grained, partly rounded gravel sands). Comparably characterized sediments could be identified on the surface of the floodplain as a product of recent floods.

Photo 4 Abnormally intensive accumulation of soil and weathered material runoff from maize fields. Sediments have completely covered the floodplain.

Geomorphological development of a valley during floods includes also bursting of streams from their banks when water forms new beds in the floodplain. It occurs mainly in places where the river, due to intensive lateral erosion, bursts banks or when the stream is locally dammed by floating material (as logs or branches). Such behaviour of the Olešenský potok Brook could be documented for instance north-eastwards from Leština, which proves again extreme discharge during the floods.

Conclusions and recommendations

The flood along the Olešenský potok Brook on June 10, 2004 was an extreme flash flood with period of recurrence as well as the period of recurrence of causal rainfall exceeding 100-year period (Šercl et al. 2004). These are quantified estimations, because no direct rainfall or hydrometric monitoring is run in the studied catchment.

This is evident not only from the assessment of the Czech Hydrometeorological Institute, but also from local manifestations of water erosion, of area washing away, etc. Other causes, as for instance inappropriately chosen crops (maize), have only a secondary impact and they caused for instance a transfer of sediments from fields.

Area washing away occurred not only in fields but also in forest areas (!). An immediate risk of a sudden move of these fine-grained sediments to the lower part of the catchment does not exist (without further extreme rainfall), nevertheless from the long-term perspective it is a material that will be transported to the confluence with the Sázava River.

The flood was so important that it filled the floodplain in all reaches of the valley. Locally also older coarser-grained positions were found in the floodplain profile during the field monitoring, that means that an even more intensive transport might have occurred here in the past.

The course of the flood in the landscape with undeveloped floodplain was in general without problems. Local manifestations of erosion and accumulations are a part of relief development, i.e. natural processes modelling valleys in the Quaternary period. Problems appeared only in places where the floodplain is built-up or crossed by a communication. In both cases, these are obstacles to a free water flowing.

Because slopes with maize fields are easily affected by soil erosion during intensive rainfall, this vegetation cover is entirely unsuitable. Not only because of flood prevention, but because of protection of the soil itself. Similar problems with erosion in maize fields were recorded for instance by field research in the Haraska watershed (Šefrna and Vilímek 2003). It is nevertheless necessary to realize that the vegetation impact is more important during smaller floods than during larger ones (Janeček 1997).

The extent of damages in Ledeč nad Sázavou is given by combination of three factors: by an enormously high discharge due to the rainfall episode which was not exceptional and there is no reason to presume it was the last one, by the building-up of the flood plain upstream the confluence with the Sázava River and by an artificial narrowing of the flow flood profile (in the place of the bridge to Aquacomp Company). Low bridges combined with drift material cause local accumulation and consequent higher water level.

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Résumé

Vyhodnocení příčin povodně na Olešenském potoce

Ve dnech 10. a 11. června 2004 došlo k rozvodnění Olešenského potoka následkem extrémních srážek přívalového charakteru. Jednalo se o lokální povodeň z kategorie tzv. přívalových povodní. Příčinou mimořádně intenzivních srážek byla bouřková činnost. Bouřky se dne 10. června 2004 odpoledne a navečer vyskytovaly ve své nejsilnější podobě v pásu širokém asi 15 km a dlouhém 75 km, a to od Kostelce nad Černými Lesy směrem k JV až po Havlíčkův Brod. Zde již značně zeslábly. Povodeň způsobila velké materiální škody zejména v Ledči nad Sázavou, kde se Olešenský potok vlévá zprava do Sázavy. Ztráty na životech hlášeny nebyly. Předmětem článku je vyhodnocení příčin povodně, tedy posouzení do jaké míry byla povodeň způsobena čistě přírodními příčinami, či zda se mohly projevit i vlivy hospodaření člověka v krajině, úpravy koryta toku apod.

Předložená práce se opírá o terénní průzkum uskutečněný bezprostředně po povodni, o hodnocení povodí Olešenského potoka z hlediska geologických, geomorfologických a pedologických poměrů, které byly provedeny na základě archivních materiálů (zejm. mapových), a dále o popis meteorologické situace (zdroj ČHMÚ) a o vyhodnocení průtoků (zdroj ČHMÚ). Využito bylo rovněž zkušeností z vyhodnocování povodňových událostí z roku 1997 na Moravě (Havlík et al., 1998) a z roku 2002 v Čechách (Vilímek et al., 2003).