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Changes in the channels and floodplains of Sudetic rivers in the Morava river basin after the flood in july 1997

Introduction

The flood of July 1997 was the most severe natural disaster occurring in the Czech Republic in the 20th century, surmounting with its size and geomorphological effects the heavy floods from the end of the 19th century. Although we learn from the historical records that the old floods caused great material losses, the data on changes in river channels and on floodplain surfaces are very rare, usually unspecific and rather presented in an indirect context. This is why the documentation of changes after the last large flood whose reasons are well known is of such a great importance. It should be born in mind that the situation in the valleys of Sudetic rivers largely changed since the last big floods from the end of the 19th century due to the anthropogenic transformation of the landscape and the methods of soil cultivation and use were changed too after the transfer of the German ethnic. It was also these changes that affected the extent of the flood, which must be taken into account. Satisfying is the fact that the documentation of the last flood in the Sudeten has been very systematic on the both sides of the mountain range.

Studying the changes of floodplains and river channels after the flood we were led by an effort to distinguish the landforms developed during the increasing and decreasing stages of the flood routing and to better learn its physiology in this way.

Geographical setting

The Morava R. springs on the southern slopes of the Králický Sněžník (Mts.) its larger left-side tributaries being the Krupá, Branná and Desná rivers. The Krupá R. initiate in the southern part of the Rychlebské hory (Mts.) its tributaries coming down from the slopes of the Králický Sněžník Mt. 1423 m; the Branná R. originate in the Hrubý Jeseník (Mts.) on the slopes of the Keprník Mt. 1422 m with some of its tributaries such as Černý potok (Brook) running down also from the southern part of the Rychlebské hory (Mts.). The Desná R. which came into existence as a confluence of two branches (Divoká Desná and Hučivá Desná) springs in the Hrubý Jeseník (Mts.), too – the Hučivá Desná R. on the south-eastern slope of the Keprník Mt. and the Divoká Desná on the slopes of the Praděd Mt. 1491 m. A feature common to all rivers is that they flow down from the mountain sides as torrential streams, their channels exceeding in their uppermost reaches an inclination of 50‰. Middle reaches of the rivers pass through the Sudeten Piedmont in the basin of the upper Morava R. with an upland relief and channel slopes 20 - 50‰. An important feature of the river pattern in the Sudeten Piedmont are basins which divide the valley pattern into sections dominated by either accumulation or erosion. The Morava River flows down from the Králický Sněžník Mt. into the Červený potok Basin by which it separates the erosional reach of the valley near Vlaské from the basin at Hanušovice, which is a part of the basin system of the Mohelnická brázda (Furrow). The upper torrential reach of the Krupá R. similarly opens into the step-like arranged Staroměstská kotlina (Basin); the Branná R. valley opens into the basin near Hanušovice as well. The Hučivá Desná and Divoká Desná rivers confluence at Kouty nad Desnou situated in the northern corner of the Šumperská kotlina (Basin) which is passed through by the Desná R. up to its opening into the Morava River. An important mountain tributary of the Desná R. from the left side is the Merta R. Valley sections between the basins are tight and the rivers (Morava near Vlaské, Branná below town Branná) develop free meanders with a floodplain width being up to 200 m. Natural sinuosity of the Branná R. channel below Jindřichov was 1:1.31 and the W value (valley width/channel width ratio) was ranging from 20-40. In the last reach before mouth into the Morava R. the Krupá R. has created V-shape valley.
Anthropogenic transformations of floodplains in the historical context

Valleys in the upper Morava River pattern used to play an important role at the colonization of the Sudeten Mts. in the 13th century. Valleys of Branná and Krupá were passed through by provincial paths leading to borderland mountain pass and saddles to Silesia and Kłodzko, records on the condition of roads give us some information about the appearance of rivers. The records indicate that spring and autumn floods were frequent in the valleys of Branná, Krupá and Desná; low river banks of Branná overgrown with vegetation facilitated good stream crossing by wading; on the other hand, the Morava River had a deep channel near Olšany and ten deep pools arose at Leština during the flood. Also, the flooded alluvial plain of Desná was swampy and often hardly passable from Šumperk to Sudkov. This is why a record from the First Military Mapping made in 1768 classified the upper Morava R. basin as passable with difficulty (Polách and Gába, 1998). The occurrence of alluvial placers and mine dump piles in the valleys give testimony to the extraction of gold and other minerals as early as at the time of Celtic settlement alike as in the Middle Ages and later, the power of water stream was used in a number of hammer-mills processing iron ores, in glassworks and flour mills with races. The thickness of alluvial loams deposited in the piedmont valleys in the Sudeten is low (ca. 0.5 - 1m) due to the late colonization and agricultural cultivation of deforested soil (cf. Teisseyre, 1985; Klimek, 2000).

The greatest changes occurred at the end of the 19th and at the beginning of the 20th centuries. After big floods and due to the construction of railways the river channels were realigned to a varied extent and protected with stone walls or just by channelization and plantation of riparian stands. Dikes were built in some river reaches. Railway embankments constructed in the valleys of Morava, Krupá, Branná and Desná from the 1870s considerably narrowed -together with parallel roads - the widths of the valley floor and waterway also in the basins. Artificial floodplain depressions arouse between the road and the railway embankments. The straightening of river channels can be documented by concrete examples in the valley of Branná and Krupá. There were originally 3 bends of meanders on a 1 km long reach of Branná at Potůčník. During the railway construction, two river meanders were separated, artificially blocked and the remaining riverbed was channelized and regulated. After the railway construction had been completed, the natural river sinuosity of 1:1.3 was reduced to 1:1.14. A similar case can be found also in a narrow valley of the Moravská Sázava River near Tatenice. In the Krupá R. valley near Staré Město, the Krupá river pattern in the Staroměstská kotlina (Basin) was reorganized due to the construction of railway. The channel of the Krupá R. was first connected to the left side tributary one by an artificial arch and then interconnected with meanders located down the river. Another tributary from the right side was channeled into an artificial trench draining the railway embankment. The regulations cut the Krupá River shorter and widened the backswamp with alluvial meadows. The typical floodplain communities of waterlogged meadows with dead ox bows were replaced by cultural meadows.

Means of soil cultivation and use in the Sudeten were gradually changing after the transfer of the German ethnic and after collectivization of agriculture. The change can be generally characterized by shrinking arable land and its gradual replacement with pastures, meadows and forest. Consequences of the change can show in runoff conditions, reduced soil erosion and subsequently also in the suspended load in river channels. In contrast, an extension of areas with meadows and pastures could have resulted in the effect of increased runoff into streams, channel erosion and increased bedload transport. The effect of runoff from extraordinary rainfall from extensive meadows on steep slope on erosion has been observed by Hrádek (2000).

The original appearance of floodplains prior to the technical measures can be relatively well analyzed according to topographic maps and aerial photographs. Changes in the valleys induced by anthropogenic transformations affected the hydraulics of river channels during the flood.

Changes in river channels and floodplains

Values of measured peak flood discharges of rivers (Q_{max}) in the upper Morava R. basin surpassed the 100-year flood discharge (Q_{100}) in July 1997 (Gába and Gába Jr., 1997, Hrádek, 1999). There are records available from measurements taken on the Morava River at the nearest gauging station in Moravičany on 8 July 1997 with peak discharges Q_{max} 625 m³/sec and Q_{100} 300 m³/sec. The
extremity of peak discharges was increasing from the lower reach to the upper reach; the peak discharge measured in Moravičany was assessed as a 700-year discharge ($Q_{700}$) and in Raškov – located upstream - even as a 800-year discharge ($Q_{800}$). Due to the fact that the energy thresholds had been exceeded, a metamorphosis occurred of floodplains and river channels. Water stream velocity during the culminating flood was estimated to 5-7 m/sec. High inclination of river channels in upper reaches made it possible for streaming water to move blocks of 2-3 m in size along the riverbed floor (Gába and Gába Jr., 1997). Due to the high discharge and water stream velocity the river channels exhibited extremely high values of near-bank and bed shear stresses with high channel erosion rates and corresponding amounts of carried and dragged bedload and suspension load.

Geomorphological documentation of the river valleys coming from the mountain region of the Králický Sněžník Mt. and Rychlebské hory Mts. and in the mountain massif of Keprník and Praděd in the Hrubý Jeseník Mts. after the flood in July 1997 (Gába and Gába, 1997, Vít. et al., 1998, Hrádek, 1999, 2000), a number of works entering on the Polish side of the Sudeten (Żurawek, , Czerwiński and Żurawek, 1999, Lach, 2001, Migoń et al., 2002) and the subsequent monitoring within the Academy of Sciences of the Czech Republic grant project in the years 1999-2002 disclosed a range of erosional and depositional fluvial landforms connected both with the lateral erosion of bankfull channels and with the inundation of floodplains and overbank flow, but also with the return of the flood water back into the channel. The list of fluvial landforms includes both the general lowering of the floodplain surface due to stripping on the one side or its accretion due to overbank deposition/diffusion on the other side, and the linear landforms origin created or by accumulation such as natural levée and crevasse splay, or by erosion such as various types of overbank channels which came into existence by branching of the thalweg and floodplain flows as crevasse channels and chutes, and eventually the lateral channel migration and braiding due to bedload transport at the end of the flood.

A decisive influence on the metamorphosis of floodplains during the record discharges was that of exceptionally high amounts of transported coarse bedloads, which was increasing the effect of shear stress in dependence on the width of the flooded valleys and hence on the degree of their anthropogenic transformation, particularly the channel realignment, narrowing of valley profiles due to embankments of roads, railway fills and bridges which also influenced the direction of the flood thalweg and origin of funnel - like effect and last but not least the blockage of river channels with wood debris. Dynamic effects of the flood were also affected by reaches of basins alternating with tight reaches of valleys.

The transport of coarse bedload started already in the upstream torrential reaches of valleys in mountain steepland. Channels with slopes greater than 50% lost the most of its gravel bed deposits by the water flow. Some widened places of valleys with the lower channel slope such as in the upper Morava R., Krupá R. and tributaries of Branná exhibited gravel bars deposition and braiding of streams. Headwater erosion in channels of stream arms gave rise to erosional crevasses with waterfalls, which were up to 2.5 m deep (Gába and Gába, 1997). Alluvial fans got deposited locally at the foot of mountain slopes on which braiding of channels occurred (e.g. on the Černý potok Brook – tributary of Branná).

The flood impacts showed in full in channels of narrow valleys in middle reaches with slopes ranging from 20-40%. The rivers did the greatest geomorphic work in the reaches in which they were meandering before the flood. The bedload source were river channels widened by lateral erosion, channel bed pavements (Březina, 1998) and gravels of valley bottom. The valley of Branná whose width is up to 200 m with the original river channel wide up to about 5 m exhibited local widening up to 50, the channel of Morava R. in Hanušovice widened up to 80 m, and in the valley of Desná in Loučná nad Desnou even up to 90 m. The widening resulted in the extinction of some meanders and in a further straightening of channels. In the reach of sinuosity measurement on the Branná R. near Potičněk (at Jindřichov), there was another meander that ceased to exist after the extreme widening of the channel and the after-flood value of sinuosity dropped from 1:1.14 after anthropogenic measures to 1:1.071. Shallow floodplain loams of about 0.5 m in depth were removed. The accompanying phenomenon of channel widening due to lateral erosion was a collaps of the undercut banks high up to 2.5 m and even valley sides. Stone retaining walls and beds of channel protection were destroyed during the channel widening. Towards the end of the flood in particular, the coarse gravel deposited either inside the widened and straightened channels in the form of point bars, or outside the channel as a natural levée on the floodplain surface in stripes of up to 15 m wide. Some floodplain sections such
as that of Branná got entirely covered with overbank gravel deposition. At the end of the flood braiding of channels occurred in the narrow valleys in the widened bedload channels and at the entrance of erosional valley reaches to basins on the flat gravel fan-like crevasse splays. In Hanušovice thickness of gravel accumulation reached up to 1 m and Morava R. displaced its channel in by 80 m to the edge of the basin. In the basin below Staré Mís to a flood arm separated from the arch of the artificially realigned channel of Krupá and through a crevasse channel penetrated into the backswamp depression where it deposited a fan-like crevasse splay with a number of braiding arms. A typical erosional form of narrow erosional valleys but also basin segments were the separated erosional overbank channels usually referred to as a chute (cf. e.g. Coxon et al., 1989) or crevasse channel (Teisseyre, 1991), some of them cutoff at the stage of flood wave increase and some of them at the stage of flood decrease. According to our experience, they come into existence in two ways:

1. By flood thalweg deflection after the cutting off of natural levee, often at the places of terrain depressions and usually at the place of original channels, roads, races, etc. during the floodplain inundation at the stage of flood increasing; the channels often end with a flat gravel accumulation of crevasse splay.

2. By headwater erosion at the stage when flood falls away and inundation return back into the active channel.

There were five flood channels of the first type, which split from the active channel and then turn back to it after a certain distance, recorded in a 9 km long valley reach of the Branná R. between Nové Losiny, Jindřichov and Hanušovice. An about 300 m long, 10 m wide and 1.6 m deep crevasse channel is monitored near Potučník, which has been preserved to these days in the backswamp space being artificially shortened by means of a trench connected to the active channel. The entrance into the flood channel is blocked from the active channel by a low gravel levee which prevents water flow from penetrating into the chute cutoff under normal conditions. Even in this case the channel passed into a flat fan-like accumulation. In consequence of the extraordinary bedload transport the erosional features were transferred also into the basin-like reaches of valleys with low gradient (<10‰). In the widened segment of the Desná R. valley near Filipová, there is a case of overbank channel branching. The chute developed after the inundation had penetrated into the terrain depression between the railway and road and during regression created a cutoff of the second type, incised through the alluvial loams up to the valley floor gravel. The channel is up to 20 m wide and separated by edge into a lower and higher levels with the lower one returning into the active channel of the Desná R. and the higher, about 1 m deep, joining another crevasse channel which singles out from the Desná R. downstream from the mouth of the first mentioned one. At the point of channel division, a low aggradation gravel bar originated which passes into a well preserved isle of floodplain even with its grassy surface. Connection of both flood channels having occurred in the hanging position. The lower situated crevasse channel is up to 2 m deep and 4-5 m wide, paved with coarse gravel; it gradually becomes shallower until passing into the gravel deposition of the fan-like crevasse splay on whose surface braiding of flood arms occurred. As to the branching of channels, it apparently did not occur at the same time. The returning arm developed in time of the flood attenuating as the youngest, separated and after this manner captured channel being older and opening into an even older crevasse channel of the increasing stage of the flood. The above mentioned central gravel bar developed as a natural levee of the returning chute. The locality on the Desná R. gave us a chance to analyze the stages of the flood and to look closer into its physiology. In the valley basin of the Morava R. near Bohdíkov, the flood thalweg arm got over a railway embankment developing a chute which was 20-30 m wide. The existence of corrosional scours in alluvial loams (cf. Hrádek, 1999) confirms a large amount of both carried and dragged bedload and its important role in the stripping of floodplains and erosion of channels in the basins also at places where the channel slope is low and moreover where a railway embankment has to be passed over. The funnel-like effect in railway embankment culverts and the headwater erosion gave rise to a fan-like system of up to 2 m high crevasses at this place. This locality also demonstrated a local accretion of fine sand slackwater deposits from the end of the flood, deposited on the imbricated gravel surface of chute bottom with typical transverse ripple marks. In the floodplain spaces locally enclosed between the road and railway embankments there is a layer of up to 0.5 m thick of these subhorizontally bedded slackwater deposits. In the southern portion of the Mohelnická brázda (Furrow) where the Morava River enters into the anastomosing regime of lowland,
the overbank bedload transport has not been documented. Erosional phenomena were detected to have occurred near Mohelnice in connection with the extraction of gravel for construction purposes, i.e. due to the anthropogenic impact. The headwater effect during the flooding of water filled gravel pits induced development of up to 2 m deep crevasses in the floodplain surface, opening into the gravel pits.

After - flood monitoring

Efforts aiming at the fastest possible rectification of losses and restoration of the valley in its original status came immediately after the flood and in the following years. The river channels were excavated, the banks paved with stone or concrete support walls. Places with the flood landforms preserved are rare and located outside the villages. It is at these places where the development of fluvial flood landforms is further monitored, particularly those of flood channels. Most overbank flood channels are not flown through with water, they are either dry or water-logged. An exception is the Krupá R. with about 1.3 km long active, originally flood overbank channel below Staré Město, in which flood arms braiding occurred in the crevasse splay gravel deposits. The gravel islands and channels got gradually grown over with vegetation in the following years and the braiding river system from the period after the flood ceased to exist. There is a system of one active channel that remained preserved, which branches after leaving of the crevasse channel cutoff in natural levée and transforms into an anastomosing and maybe even re-anastomosing channel with grassy islands of various sizes (max. 80x30 m). This channel with mild bends is shallow to a depth of turf (0.2 – 0.3 m), with the floor built of alluvial loams, at some places with the deposition of gravel bars. Bedload transport has been considerably reduced in the present time. The anastomosing channel then finally returns into the old meandering channel of the Krupá River. The walls of unflooded channels of other rivers formed by cohesive loams are subjected to gravitation processes which include both the falling of tiny particles at desiccation and slab-failures and rotational slips. The fallen material accumulates at the foot of the walls. The development will continue this way and the channels will get filled.

Conclusion

The flood from the beginning of July 1997 showed that the geomorphological effects of a great mountain flood in the channels and on the floodplains develop under the water level during a polymorphous phenomenon which takes places under the influence of local temporal and spatial conditions and whose results can be recorded and explained only after its termination. The conditions of flood generation were heavily influenced by man. The greatest metamorphosis of floodplains and river channels in the basin of the upper Morava R. occurred in the valley segments before the Hanušovice hydrographic junction and in upper portion of the basin system of the Mohelnická brázda (Furrow), whose part is also the Šumperská kotlina (Basin) and the valley basins near Raškov and Bohdíkov. With the enormous flood volume and bedload transport the erosional effects of the flood trasferred into the upper parts of the basins where the river channels exhibit lower inclinations. It is therefore obvious that the effect of channel slope on erosion is not conclusive during great floods but that an efficient tool of corrasion is the amount of bedload. The undercutting and widening of banks was contributed to by the near-bank shear stress in the bankfull channels, special vortex structure associated both with overbank flow and with water flow plunging back to the channel. Another evidence of erosional effectiveness of the flood is the occurrence of separated flood channels in the basin-like segments of valleys. This kind of erosional channels hourly occurring in narrower valleys and designated as crevasse channels or chutes is, apart from active channels abnormally widened by lateral erosion, the most typical fluvial form of the flood. A distinction was made between flood channel cutoffs generating under the overbank condition during the flood wave increasing, and channels created by the headwater erosion of inundation water returning back into the active channel in descendent stage of flood. Examples of the channel dividing and/or connecting analogous to the Desná River show that the sequence of their development can be assessed by their mutual position. The flood has contributed to the long-term and anthropogenically supported tendency of straightening the channels in tight valleys and transition of meandering streams to braiding ones. On the other hand, the monitoring of river channels in basins after the flood recorded a trend of the return to the river
anastomosis were braiding due to the bedload transport was a stage of transition immediately after the flood [cf. Teisseyre, 1985, Migoń et al., 2002]. The banks widened by lateral erosion develop mainly by the action of gravitational processes after the flood.

Bibliography


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