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Geomorphological Consequences of the 2002 Flood in the Otava River Drainage Basin

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Abstract

Geomorphological consequences of the 2002 flood were mapped in the Otava river drainage basin. Field mapping was focused on relief changes in river beds and floodplains and on flood geomorphological indications in adjacent slopes. Geomorphological consequences of the flood according to anthropogenic impacts into floodplains were assessed.

Key words: flood sediments, erosion, floodplains, Otava river

1. Introduction

The geomorphological research of the 2002 flood impacts in the Otava river drainage basin was realized as an analysis of changes in river beds and floodplains of the Otava river basin. As a part of the Czech Science Foundation grant project 205/03/Z046 the research had the following objectives:

1) to map geomorphological consequences of floods in floodplains,
2) to identify relations between anthropogenic impacts in floodplains and flood geomorphological consequences.

2. Methodology

The geomorphological research was realized in the following order:

1) Field research initialization and geomorphological map legend suggestion. The legend was prepared using the 1997 Moravia floods documentation (Hrádek 2000, 2002) analysis, the geomorphological research of the 2002 flood in the Blanice river drainage basin (Červinka, in print), and geomorphological mapping of the Volyňka river valley (Křížek, 2003; Křížek – Engel, 2004).
2) Geomorphological mapping of flood impacts in inundation areas of the Otava river and its main tributaries (Blanice river, Volyňka river, Vydra river, Křemelná river, Losenice river, Ostružná river, Spůlka river, Peklov river, Zlatý potok stream, Brložský potok stream, Roklanský potok stream, Kolčavka river, Březový potok

stream, Novosedelský potok stream, Nezdický potok stream, Bořanovický potok stream, Slatinný potok stream, Volšovka river, and Řepický potok stream). Mapping was also focused on landforms at adjacent slopes genetically related to forms appearing in floodplains. For the mapping purposes, the 1:10 000 and 1:25 000 topographic maps were used. The fieldwork was realized by a mapping team of 20 trained observers according to uniform legend created by M. Křížek.

3) Field data digitalisation and their processing in GIS. Digital topological-vectorial file ZM ČR 1:10 000 – ZABAGED (ČÚZAK, 2003) became one of the main components of the GIS environment where field data were reviewed and transformed into a geomorphological map.
4) Geomorphological analysis of field data. The identification of structural conditions and correlation in floodplain delimitation was made using air survey photographs, bonitation maps BPEJ (1:5000) and geological maps, scale 1:25 000 and 1: 50 000 (ÚÚG 1979–1996).

3. Geomorphological Characteristics of the Otava River Drainage Basin

The Otava river drainage basin is situated in the geomorphological systems of the Šumavská hornatina Mountains (the Šumava Mountains and the Šumavské podhůří Foothills geomorphological subsystems), the Středočeská pahorkatina Hilly land (the Benešovská pahorkatina Hilly land, the Táborská pahorkatina Hilly land and the Blatenská pahorkatina Hilly land geomorphological subsystems) and the Jihočeské pánve Basins (the Českobudějovická pánev Basin geomorphological subsystem). The headstream areas of the river and its right-hand tributaries at the height 1000–1300 m above the sea level are situated in large relics of levelled Šumava plains or in regions of dissected highlands (the Železnorudská hornatina Mountains and the Boubínská hornatina Mountains) and flat highlands (the Želnavská hornatina Mountains). The midstream course cuts into the erosional and denudated relief of the Šumavské podhůří Foothills while the downstream area of the Otava river drainage basin is located in the Českobudějovická pánev Basin, Blatenská pahorkatina Hilly land, Táborská pahorkatina Hilly land and Benešovská pahorkatina Hilly land.

The flat or slightly undulated relief of the headstream area is a relic of old levelled surface maintained in areas unaffected by retrogressive watercourse-driven erosion (Demek, 1965). River valleys in this area are wide and shallow, and drainage divides are flat and low. This part of the river system originated in Upper Cretaceous or Tertiary Periods (Chábera et al. 1985). Northwards from the relics of levelled surface, the relief of the studied area is affected by retrogressive erosion caused due to the Šumava region uplift in the Neogene and Pleistocene periods. Due to erosin during the Pleistocene, smaller watercourses were channelled to the Otava river (Kettner 1923). Foothill areas in the Otava river drainage basin have been affected by selective erosion resulting in elevated forms with levee cores rising above the surrounding relief (Kodym, 1961).

4. Results

4.1. Geomorphological Mapping

The following landforms were mapped in the Otava river drainage basin floodplains.

Mass movement landforms

Landslides, landslide areas. In the study area, only small (in order of tens m^2) and shallow landslides were recorded in six locations:

1) in the river basin of the Mlýnský potok stream near Březany;
2) in the Křemelná river basin beyond Čeňkova pila;
3) in the river basin of the Roklanský potok stream on the left slope delimited by Javoří pila and Rybárna localities;
4) in the river basin of the Zlatý potok stream near Chroboly;
5) in the Otava river basin near Kestřany;
6) on the Spůlka river at the U Vítovců area.

Landslide areas, i.e. larger areas (in order of hundreds m^2) affected by landslides were identified only in the Ostružná river basin by the town of Kolinec and in the source area of the Volyňka river. Occurrence of gravity forms in the monitored area was only sporadic. This fact results from stable geological conditions and represents one of the key geomorphological differences in comparison with the 1997 flooding in flysch areas in Moravia.

Fluvial accumulative forms

Floodplains. In geological terms, floodplains are made of the youngest Holocene or recent sediments and are subject to significant sedimentation and erosional processes. Water outflows into floodplains and subsequent sedimentation of flood sediments led to filling of uneven forms and shallow depressions of the floodplain surface by fine sediments. Floodplains have developed along all of the mapped watercourses (Fig. 1), but their width varies due to geological conditions and anthropological interventions causing their partial or complete disappearance. Floodplains have been narrowed due to construction of roads and associated facilities (embankments and bridges), which in terms of floods poses significant risks in the areas where such structures are built across floodplains. One example of such a state was detected in the Volyňka valley where it concerned a railway embankment in the town of Strakonice and roads in the towns of Čkyně and Bohumilice. Due to unsuitably located bridge in Bohumilice, the Volyňka river bed was even moved to another place. Large-scale destruction of railway embankments was found in the Blanice valley. The embankment located in the Otava river floodplains between the towns of Dolní Poříčí and Katovice resulted in the accumulation of floodwaters above the embankment as well as on the banks beyond. However, the railway embankment itself didn't suffer any visible damage by water.

In floodplain areas, two types of flood accumulations were identified:

1) Older (Holocene) fluvial accumulation classified in terms of the accumulated material character as loamy, gravel-stony, and combined. Thickness values vary from several cm to 2 m.

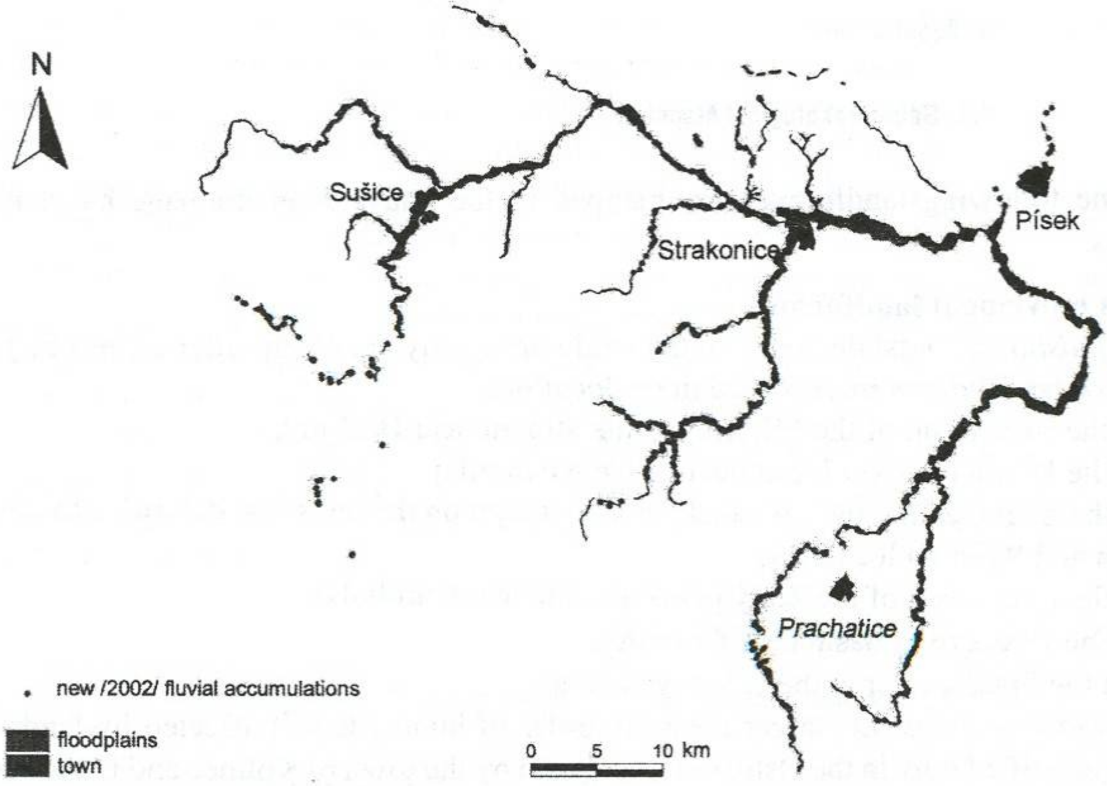

Fig. 1 New fluvial (2002) accumulations in the Otava river drainage basin

2) Fluvial accumulations (Fig. 1) originated during the flood of 2002. In many locations, particularly in river beds, only residues of accumulations were recorded (due to their anthropogenic removal early after the floods). These are also classified into loamy, gravel-stony, and combined categories.

The spread of individual accumulation types depends on changes in the carrying capacity of water. While gravel-stony material were accumulated mostly close to main flood streamlines, sand materials prevailed in overflow areas where the carrying capacity was lower. The same principles apply in the longitudinal direction – rough layers of flood sediments are found close to places where watercourses leave their river beds while sand materials are mostly located further away from river beds. The overall distribution of accumulated materials is significantly influenced by anthropogenic interventions into river beds or floodplains. Such technical modifications completely or partially change original natural zones of sedimentation.

Alluvial (dejection) cones. Such forms are found in the whole Otava river drainage basin around watercourses of various sizes. However, they didn't accelerate the flood situation. Their dimensions reach tens of metres. During the 2002 flooding, no new cones were formed in the studied area around valley mouths or ravines.

Fluvial terrace. Such forms were detected outside floodplains, i.e. outside flooded areas. Fluvial terraces developed in the Otava river midstream and downstream areas delimited by the town of Střelské Hoštice and the confluence with the Blanice river where they occur in two levels. In floodplains, low steps characterising the youngest development phase of valleys around the studied watercourses were identified. Such steps are located also in upstream areas 1–1.5 m above valley bottoms (e.g. the Volyňka river upstream area above Lipka).

Fluvial erosion forms

Shifted and abandoned river beds. Such linear geomorphological forms were created in areas where watercourse acted with the greatest erosive force, i.e. areas of increased flow velocities conditioned often by anthropological interventions. Circumstances allowing for river bed shifting were also created due to river beds silting or banks weakening (Photo 1). Such forms were abundant in the Blanice river upstream areas, the Volyňka river upstream and midstream and, in the Otava river upstream. The length of new river beds varies from 200 m to 600 m and arose either by accumulation in the river bed and consequent splitting of watercourse or by destruction of the bank in river bends.

Photo 1 Abandoned river bed of the Volyňka river (near Malenice). Shifted river bed of the Volyňka river was formed in consequence of the cracking of its right bank, which was weaked by mining of river sands (Photo by Z. Engel, 2003)

Significant damage to banks, bank caving. Such phenomena were found along all of the studied watercourses (Fig. 2) and represent one of the most frequent fluvial erosion forms. Their occurrence is intensified in areas highly affected by anthropogenic activities (e.g. weirs, anthropogenically modified river bed routes). On small watercourses, their occurrence is limited, e.g. in the northern part of the Otava river drainage basin.

Broken bank reinforcement. Due to a low number of flood-control bank reinforcements, such a phenomenon was found only in six locations – on the Otava river under the town of Horažďovice, in Katovice, beyond the confluence with the Blanice river, on the Blanice river around the mouth of the Zlatý potok stream, and on the Volyňka river

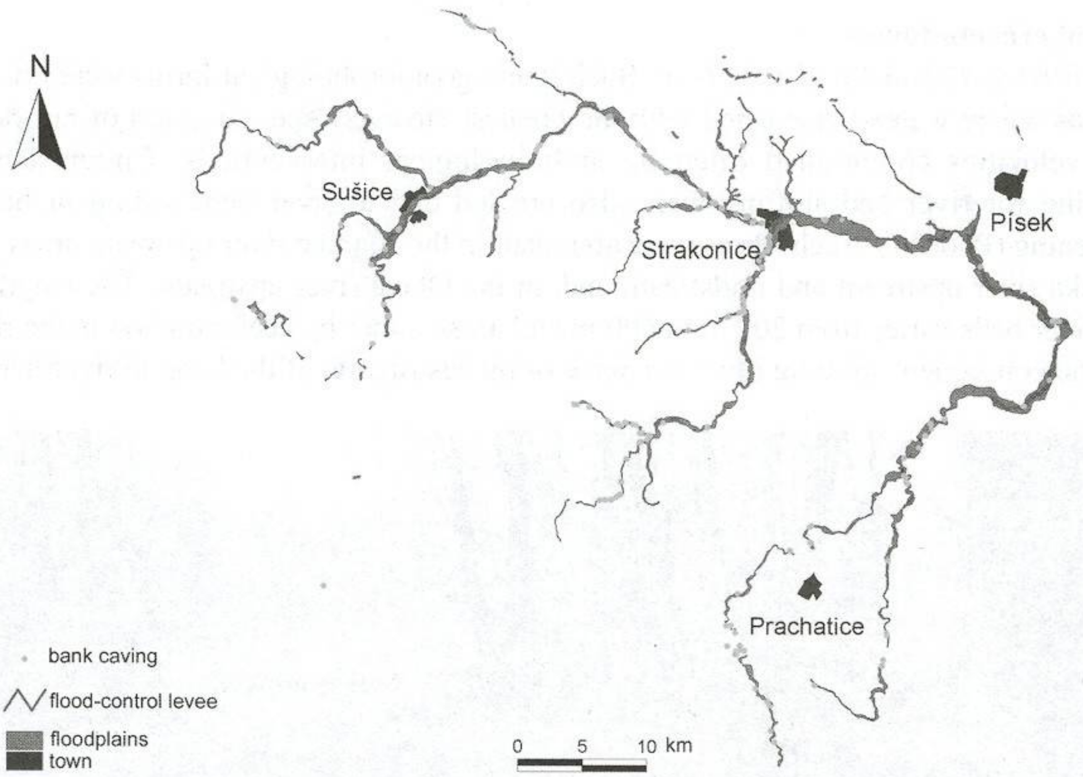

Fig. 2 Bank cavings and flood-control levees in the Otava river drainage basin. Flood-control levees are situated above all in lower parts of rivers and brooks and in towns and villages. The highest concentration of bank cavings is in neighbourhood of bigger technical adjustment of streams (weirs, canalized river)

Photo 2 Broken flood-control levee in the Volyňka river near Volyně. During the flooding the main stream headed straight to houses (Photo by Z. Engel, 2003)

above and under the town of Volyně (Photo 2). Besides, there were many minor water outbreaks around weirs of width varying from several meters to tens of meters. Bursting of a pond levee on the Brložský potok stream led to a domino effect of levee bursting on ponds located further along the stream due to an anthropogenically accelerated flood wave. Levee bursting was also common on the Volyňka river midstream and on the Bavorovský potok stream. In terms of potential risks, mounds and levees pose a considerable threat derived from their potential destruction and acceleration of erosion processes.

Erosion furrow. All erosion furrows found in the studied area were located in ravines (i.e. erosion furrow in lose rocks) created before the 2002 floods. Erosion furrows deeper than 1.5 m were taken into account. Erosion furrows were abundant in downstream areas of watercourses due to higher thickness of weathering covers, thinner vegetation cover, or negative anthropological impacts.

Source areas of erosion runoff. Material is mostly transported due to surface runoff from agricultural land to ditches and depressions at slope bases.

Anthropogenic landforms

Weirs. Weirs are located on all of the studied watercourses (Fig. 3; Photo 3) with higher concentration in midstream and downstream areas. Weirs were classified in terms of their height (up to 0.5 m; 0.5–1m; above 1 m), which enabled to assess the impact

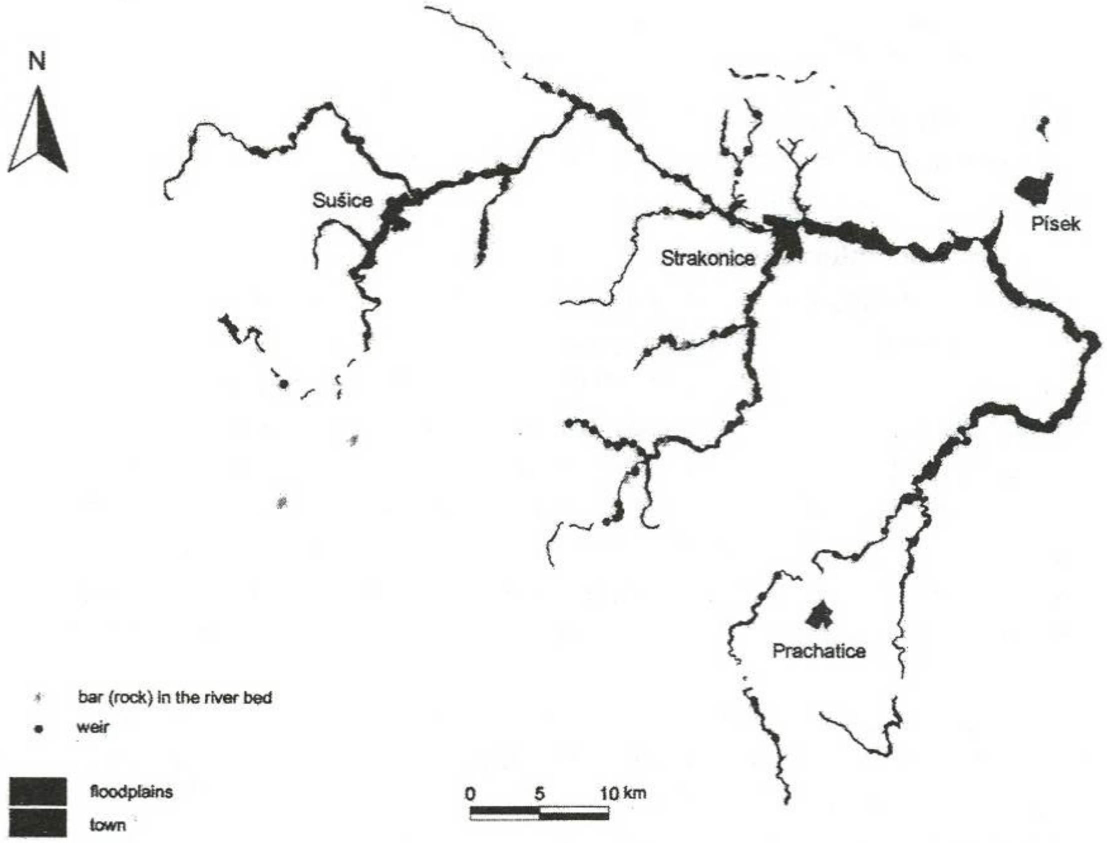

Fig. 3 Location of weirs and bars in the Otava river drainage basin. Rock bars in the river beds (natural steps or levels in the river beds) are situated above all in the upper parts of streams and singularly in the middle parts of streams. These forms as against weirs did not influence a course of flooding

Photo 3 Surroundings of weirs are dangerous and more prone to overspill due to water flow. This location of weir near Volyně is good example of total ignorance of natural principle of water circulation in case high flow rate of water. This weir is situated in fornt of orthogonal bight of river. Gravel-stony accumulations on the snap are a proof of the lapse of the purpose of this weir and the threat of neighbourhood localities by deflected main stream of the Volyňka river (Photo by M. Křížek, 2003)

of anthropogenic interventions in watercourse longitudinal profiles on erosive and accumulative activities of watercourses. Results of field mapping imply that the most significant erosive and accumulative landforms of fluvial activities are concentrated around weirs. The higher the weir, the more damaging consequences, e.g. weirs in Strakonice, Radošovice, Strunkovice nad Volyňkou, Volyně, Nišovice, Vimperk, Horní Poříčí etc. damaged the surrounding areas by causing large accumulations, cracks, breakages of flood control mounds, and destruction of bridges and footbridges. Their negative effects were often intensified by unsuitable location in curving channel where watercourses are more prone to overspill due to water flow characteristics (unbalanced pressure on banks, centred streamline in river beds, sudden slowdown of the flow, etc.).

Flood-control levees. Such forms are mostly located close to settlements and in areas affected by the most intense anthropogenic activities in floodplains, i.e. in the Otava river midstream and downstream areas (Sušice, Dobršín, Čepice, Velké Hydčice, Horažďovice, Střelské Hoštice, Dolní Poříčí, Katovice, and Strakonice), on the Volyňka river (Strakonice, Radošovice, Přední Zborovice, Volyně, and Čkyně), and in the Blanice river downstream area (Fig. 2). The highest artificial levees are built above Radošovice (height – 4 m, width – 6 m), above Přední Zborovice (height – 3 m, width – 4 m), and in Sušice (height – 3 m). However, levees proved to be effective only in Radošovice, while others were broken (Volyně) or overflowed (Čkyně, Přední Zborovice, and Strakonice).

Anthropogenic mounds, heaps. Such anthropogenic forms are mostly concentrated around towns and villages in association with transport structures cutting through floodplains. They are mostly found in the Volyňka river midstream and downstream areas and in the Otava river midstream area. During floods, heaps of anthropogenically accumulated material increase velocity of water flow. Such an effect was produced by a railway embankment through the Otava river floodplains delimited by Dolní Poříčí and Katovice (see above). This particular railway embankment is 6m high and 6 m wide. Floodwaters concentrated above the embankment, which resulted in vast accumulation above the embankment as well as on the banks beyond. The railway embankment itself didn't suffer any visible damage by water.

Damaged or destroyed bridges. Damaged or destroyed bridges were found on all of the studied watercourses. The highest concentration was recorded in the Blanice river upstream area, on Zlatý potok stream, on the Volyňka river and its tributaries – the Peklov river and Spůlka river. This is related to rainfall distribution and characteristics of valleys. In some cases, consequences of unsuitable bridge location were intensified by further negative anthropogenic impacts in riverbeds.

Other landforms

Dellen. Dellen were mapped only when directly connected to landforms in floodplains, mostly through dejection cones. Dellen didn't have any direct impact on the 2002 flood development.

Drainless depressions. Depressions in inundation areas or places on low-slope hills inundated by surface water or upwelling groundwater are found in midstream and downstream areas of the Otava river and Volyňka river, and the Mlýnský potok stream.

4.2. Relations Between Anthropogenic Impacts in Floodplains and Flood Geomorphological Consequences

Results of geomorphological mapping in the Otava river drainage basin clearly indicate a certain level of dependence between floodplains use, i.e. their anthropogenic transformation, and damage caused by floods. Damage caused in upstream areas or on small watercourses left in natural or almost natural conditions was minimum because water could overflow to surrounding areas and flow velocities, the most decisive factor in terms of erosion, were also lower in natural zones. On the contrary, erosion was intensified in anthropogenically transformed areas (narrowed, blocked by levees) or fully built-up floodplains not allowing for any overflow due to higher velocities of water, which resulted in bank damages and bursting of flood control mounds and levees (Photo 4). Subsequently, vast amounts of water accumulated in floodplains were prevented from flowing back to river beds by levees and other barriers. Anthropogenic mounds lacking sufficient number of culverts, built in floodplains in consequence of roads and railways construction, had negative effects on the flood development in

Photo 4 Damaged flood-control levees and anthropogenic reinforced bank in the Volyňka river in Vimperk. It is a result of anthropogenic restriction of the river bed capacity (Photo by M. Křížek, 2003)

floodplains (intensified erosion and accumulation). The same applies to bridges and embankments located close to areas where direction of river beds changes. In such places, water flows at a lower pace and sediments accumulate on bridge structures blocking the flow together with surrounding embankments and other barriers. After reaching a critical point, water spills over and temporary levees burst accelerating a flood wave accompanied by damaging erosion (shifting of river beds and bridges, destruction of buildings, e.g. bridges across the Volyňka river in Bohumilice and across the Peklov river in Nihošovice).

The negative geomorphological consequences are caused also by weirs, inappropriatelly located in bends of river channels, i.e. areas where direction of river beds changes. Significant erosional and accumulational processes resulting in catastrophic consequences were always concentrated around such weirs, e.g. Volyně weir (Photo 3).

Anthropogenic transformation of floodplains, particularly inappropriately located weirs, bridges and levees, has direct effects on distribution, scale and character of erosion and accumulation activities of watercourses. First of all, these constructions accelerate water flow and intensify its erosive effects, which is reflected by larger overflows (reaching further to edges of floodplains) and bigger (deeper) cracks in banks or flood control levees (e.g. the right-hand bank of the Otava above Strakonice). Additionally, near the erosionally destructed banks, vast amounts of sand, grave-stony or combined beds were accumulated (e.g. the Blanice river in Bavorov).

5. Discussion and Conclusions

When building flood control barriers, it should be taken into account that water flows in floodplains will be changed. This could lead to endangering surrounding areas that would be less affected by floods under natural conditions (the flood barrier in Radošovice on the Volyňka river to the detriment of a meadow on the opposite bank) or wouldn't be directly affected by flood risks (the flood barrier in floodplains of the Volyňka river in Strakonice to the detriment of residential dwellings and gardens in Strakonice). Natural retention areas like deserted meanders (the Volyňka river above Přední Zborovice) or floodplain forests (Bažantnice on the Otava river above Strakonice) should be used to a maximum extent.

In the periods of abnormally high water levels, weirs become centres of intensive erosive and accumulative fluvial processes. Building new weirs, smaller ones should be given preference over high weirs. Their locations should be carefully selected with respect to surrounding area condition and mainly the characteristics of watercourses and floodplains (weirs shouldn't be built in bights or meanders and the nearest surrounding areas).

During the 2002 flooding, changes of river beds and floodplains were produced on all monitored watercourses, first of all in midstream and downstream areas. In terms of the overall geomorphological damage in the Otava river drainage basin, headstream and upstream areas represent a secondary zone because they were affected only to a small extent. Watercourse sections surroundings of which were affected by erosive or accumulative effects of floodwaters show a different level of flood-related transformations in relation to the overall water volume (i.e. getting further away from the stream) flowing through the flow profile (the river valley) and the characteristics (discharge, velocity, pulse) of flow (i.e. in relation to local conditions modifying rise and decline of the water level).

Differences in discharge values, determining the rate of transport, erosion and accumulation, were influenced in partial areas of the Otava river drainage basin by the precipitation distribution. While the overall flood-related geomorphological transformations was relatively low in the river basins of the Otava river left-hand tributaries, the Otava river right-hand tributaries produced the highest changes in the whole river drainage basin (Volyňka river and Blanice river). Differences in geomorphological effects were less distinctive when assessed in relation to the size of watercourses. The bigger the size, the higher was the scale and thickness of flood sediments and the deeper were erosion-related deformations of riverbanks. The broadest areas affected by erosive and accumulative processes were located around the largest watercourses.

Flood-related changes of stream beds and floodplains were closely connected with the morphology of valley bottoms and the characteristics of cross profiles of individual river valleys. Differences in geomorphological consequences determined by the characteristics, course and velocities of floodwaters were visible in partial river basins of individual watercourses, often in very short sections of valley bottoms. This process was significantly affected by anthropogenic transformation of river beds, floodplains, or whole cross profiles of valleys. The most considerable relief transformations generated by the floods occurred in the areas around high weirs, flood levees, artificially straightened channels, and other technically modified parts of river beds.

6. Summary

After the flood of 2002, the largest geomorphological changes in floodplains were detected in areas subject to anthropogenic interventions. However, such modifications appeared only locally and didn't coincide with flood-related landforms originating in the period prior to anthropogenic changes introduced for hydrodevelopment purposes. The natural course and areas subject to flood-related geomorphological processes are thus disrupted (compare Ložek 2003) and, in comparison with the natural condition, broader areas of current floodplains are less affected. Results of the geomorphological analysis imply that flood geomorphological risks can be reduced by applying such measures that respect natural morphology of valley bottoms and ongoing geomorphological processes, i.e. measures aimed at preservation of natural conditions of river beds and floodplains. This conclusion supports results of flood research activities in various parts of the Czech Republic (e.g. Hrádek 2002, Cílek 2003). Remedial measures applied to damaged river beds shouldn't comprise only amendment of flood consequences and mechanical reconstruction, but also elimination of causes of individual negative flood consequences. Outside developed urban areas, watercourses and their close surroundings should be preserved in natural conditions.

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GEOMORFOLOGICKÉ PROJEVY POVODNĚ 2002 V POVODÍ OTAVY

Résumé

Geomorfologický výzkum projevů povodně 2002 v povodí Otavy byl koncipován jako analýza změn v říčních korytech a údolních nivách povodí Otavy integrovaná součást projektu Hodnocení vlivu změn přírodního prostředí na vznik a vývoj povodní byl zaměřen na následující cíle:

A) Zmapování geomorfologických projevů povodně v údolních nivách.
B) Určení kauzálních vztahů mezi reliéfem, antropogenními zásahy do údolní nivy a geomorfologickými následky povodně.

Účelový geomorfologický výzkum byl realizován v následujících etapách:

1) Příprava terénního výzkumu a návrh legendy geomorfologické mapy.
2) Terénní mapování geomorfologických projevů povodně v inundačních oblastech Otavy a jejích hlavních přítoků do listů Základní mapy ČR v měřítku 1:10 000 a 1:25 000.
3) Digitalizace terénních dat a jejich implementace do prostředí GIS, jehož základní složkou byl digitální topologickovektorový soubor ZM ČR 1:10 000 – ZABAGED.
4) Geomorfologická analýza terénních dat. Vektorizované topografické podklady byly analyzovány pomocí náhledů leteckých měřických snímků (LMS) a digitálních ortofotomap (ČÚZAK, 2002). Za účelem zjištění strukturních podmínek a korelace vymezení údolních niv byly využity bonitační mapy BPEJ (1:5 000) a geologické mapy v měřítku (1:25 000 a 1:50 000) ze Souboru geologických účelových map (ÚÚG 1979–1996).

Při terénním výzkumu geomorfologických projevů povodní byl kladen důraz na tvary, které vznikají fluviálními procesy a které mají vliv na odtokový režim, případně jsou v přímé vazbě s údolní nivou a procesy v ní probíhající. Mapovány byly gravitační, fluviální a antropogenní tvary.

Z účelového geomorfologického mapování proběhlého na povodí Otavy jednoznačně vyplývá zřejmá závislost mezi využitím údolních niv, resp. její antropogenní transformací a škodami, které způsobily povodně. Horní toky nebo malé toky, které byly ponechány v přírodním nebo přírodě blízkém stavu jsou škody minimální, neboť tok měl možnost rozlivu do okolních prostor, taktéž rychlost proudící vody jako limitujícího faktoru pro vznik erozních tvarů byla v přirozených úsecích zpravidla menší. Naopak v antropogenně pozměněných (přehrazených, zúžených) nebo zcela zastavěných údolních nivách, kde vodní tok neměl možnost rozlivu, docházelo k zesíleným projevům erozní činnosti v důsledku zvýšené rychlosti proudící vody.

Největší změny v morfologii říčního koryta či údolní nivy byly po srpnové povodni 2002 zjištěny v bezprostřední návaznosti na úseky koryta či nivy antropogenně ovlivněné. Tyto změny mají navíc většinou pouze lokální rozsah a z územního hlediska se nekryjí s „povodňovými" transformacemi reliéfu, ke kterým docházelo v období před realizací vodohospodářských úprav. Přirozený průběh a oblast působení geomorfologických procesů spojených s povodněmi je tak narušen (srov. Ložek 2003) a širší oblasti současné údolní nivy jsou v porovnání s přírodním stavem zasaženy méně. Výsledky geomorfologické analýzy napovídají, že snížení povodňových geomorfologických rizik lze dosáhnout aplikací takových opatření, která respektují přirozenou morfologii údolního dna a geomorfologických procesů v ní probíhajících, tedy směřují k přírodě blízkému stavu říčních koryt a niv.

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