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GEOINFORMATIC ASSESSMENT OF EXTREME FLOOD CONSEQUENCES - CASE STUDY: FLOOD IN AUGUST 2002 IN CENTRAL EUROPE

J. Langhammer: *Geoinformatic assessment of extreme flood consequences – case study: flood in August 2002 in Central Europe.* – Geografie–Sborník ČGS, 111, 1, pp. 33–50 (2006). – The extreme flood events in the last decade in Central Europe served as a unique opportunity to study the impact of environmental changes on runoff process, to test the methods of their efficient assessment and to determine the applicability of the findings in effective flood protection measures. The paper presents the assessment of impact of environmental changes in landscape on the course and consequences of extreme floods. Assessment draws on selected indicators of environmental transformation related to rainfall-runoff processes, flood wave formation and transformation, and local retention capacity. The solution is based on geostatistical approach and applies to the Otava river basin located in the core zone of the extreme floods in August 2002 in Central Europe and representing area with high level of heterogeneity in terms of physicogeographic and social and economic aspects. The results of the presented research indicated evident links between physicogeographic characteristics of river basins, their anthropogenic transformation, and responses to extreme runoff situations. However the results hasn't proved the current intensity of river network shortening, riverbed transformation or floodplain and landscape modifications to be the main driving force of extremity of the flooding that occurred in August 2002 in Central Europe.

KEY WORDS: Floods – Riverbed modifications – Stream shortening – Floodplain – GIS – Rule-based classification.

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1. Introduction

After the extreme floods that hit the Central Europe during the last decadethere were broadly debated questions on how much the unexpected flood extremity was affected by long-term modification of the landscape, how the environmental changes affected the runoff process, flood wave progress and flood induced consequences and if there are efficient ways to reduce the flood risk via restoration of the natural environment (Konvička et al. 2002, Kender et al. 2004, Just 2003).

The above mentioned extreme flood served as a unique opportunity to analyze the past and current changes in the landscape and to test the methods of efficient assessment and modeling their relations to the runoff process and flood consequences and to transform the findings into improvements of flood protection measures.

The article is focused on the analysis of relations among flood consequences and selected indicators of landscape vulnerability in the area located in the core zone of the flood in August 2002 as the main result of research project released after the catastrophic flooding in 2002. The research was focused on following three fundamental tasks:

1. Assessment of intensity and spatial differetiation of historical and present anthropogenic impact on landscape in indicators related to the runoff process.
2. Analysis of consequences of the extreme flood in August 2002 in the core zone of the flood.
3. Analysis of relations among the indicators of landscape modification and observed flood consequences.

The analysis of human impact on runoff process mainly in relation to extreme events is one of the current topics in hydrologic research as it is related to the phenomenon important for effective protection of lives and properties against the natural hazards. The methods applicable for the analysis of this process are multiple and are dependent mainly on the objective of research, selected indicators and spatial scale (Anselmo, Galeati et al. 1996; De Roo, Odijk et al. 2001; Nachtnebel, Konečný 1987; Niehoff, Fritsch et al. 2002; Stover, Montgomery 2001). At the local scale the physically-based runoff models or process-based approaches are usually applied. The larger and complex basins require application of different tools – empirically-based or statistical models.

This article presents the geostatistical approach based on GIS analysis and geostatistical analysis techniques namely the rule-based classification, applied in the research project as an integrative technique to identify the spatial and statistical relations between the landscape vulnerability and observed flood effects. This approach allows bridging the gap between spatially accurate data sources and the needs of assessment of large-scale complex river basins aimed to finding solutions for reducing the flood risk in the landscape.

2. Material and Methods

2. 1 Research Area

The research area is represented by the Otava river basin located in the core zone of the extreme floods in August 2002. The Otava river basin with total area of 2986 km^2 is situated at the south-western part of the Czech republic at the border with Germany (Figure 1) and is marked by diverse physicogeographical features as well as varying intensity of anthropogenic pressure.

The southern part of the river basin is located in the upper area of the Bohemian Forest (Šumava) formed by leveled surfaces with altitude over 1 000 meters asl. This area has prevailing natural character with scarce settlements and a forestation ratio exceeding 80 percent. Intensity of human activities is continously growing downwards to the north western lowland part of the river basin.

The backbone of river system in the river basin is formed by the Otava, Blanice, and Volyňka rivers. These streams were since the middle age subject rectification and modifications of riverbed and floodplain due to the growing settlement, agriculture, timber floating and transport (Langhammer 2004).

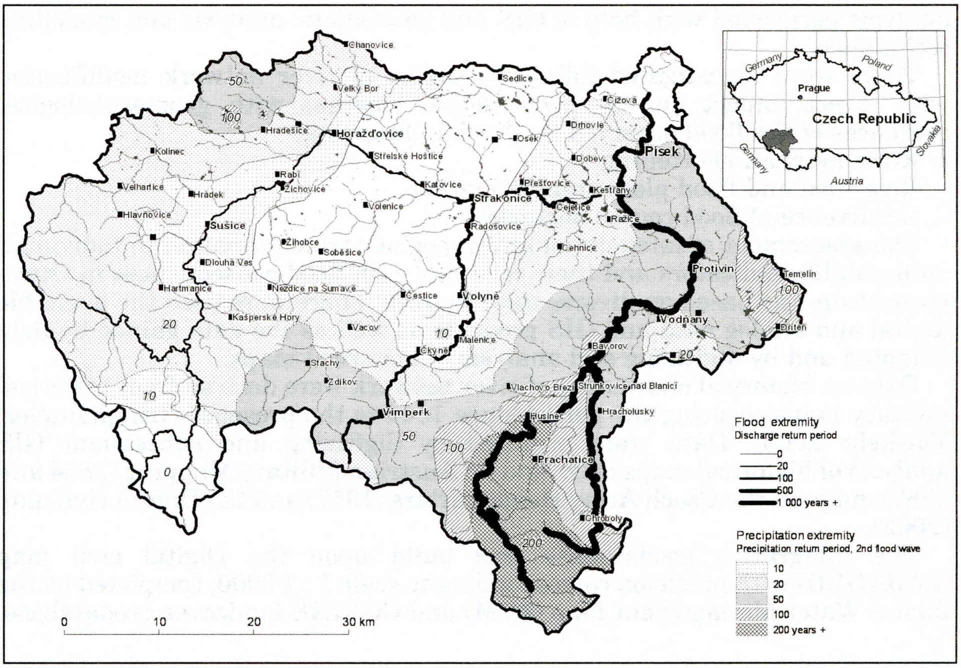


Fig. 1 – Otava river basin. The research area represents one of the core zones of the Central European extreme flood in August 2002. In the eastern part of the basin – the Blanice catchment were recorded precipitations over 300 mm during two consecutive events.

Because of its geography and the windward effect of northwestern slopes of Bohemian Forest, Otava river basin is a region with frequent occurrence of floods. Since 1888 we can observe 12 floods with return period exceeding 10-years flood whose origin is dominantly in summer frontal rainfalls (Vlasák 2004). As the Otava river is drained to the Vltava river dam cascade, the mitigation of peak flood in this region is critical for the effective flood protection of the down parts of the Vltava river basin including the city of Prague.

In August 2002, the Otava river basin was affected by two waves of extreme precipitation. The first wave hit the region on August 6–7, 2002 and the second on August 11–14, 2002. The overall precipitation volume in the basin was 0.737 km^3. The spatial distribution of the precipitation in the basin was highly asymmetric reaching the highest volumes in the mountainous parts of the river basin with maximum precipitation exceeding 340 mm for the both periods. The hydrological response of the river basin to the intensive rainfall was more extreme than the causal precipitation. The extremity of peak discharges observed during the second flood wave exceeded on Blanice river 1000-years return period while the recurrence of rainfall reached 100–250 years (ČHMÚ 2003).

2. 2 Methodology and data sources

The assessment of landscape vulnerability indicators and their relations with observed consequences of extreme flood in August 2002 in the Otava river basin was based on complex hydrological and physicogeographical analysis performed with help of GIS and geostatistic analysis and modelling techniques.

There were investigated following factors of river network modification with direct impact on the flood course together with geomorphological evidences of the flood observed by the field mapping:

- River network shortening
- River-bed and flood plain transformation
- Occurrence of flood course obstacles.

The assessment of intensity of anthropogenic transformation in individual vulnerability indicators and their relations with flood consequences in Otava river basin was based on diverse data sources. There were used the available digital and analog data and GIS products as well as the data gained by field mapping and by digitizing and analysis of historical maps.

Data on historical shortening of river network were derived from historical military maps covering the period since 1844 to the presence (Langhammer, Vajskebr 2005). Data were acquired by digitizing and subsequent GIS analysis of historical maps of 2nd and 3rd Austrian Military Mapping (1844 and 1887), maps of the Czech Army Headquarters (1957) and the Digital civil map (2002).

The integrative geodatabase was build upon the Digital civil map (ZABAGED) with precision corresponding to scale 1 : 1 0000, completed by the digital Water Management Map (ZVM) and CORINE landcover geodatabase.

2. 3 Mapping of flood consequences and of riverbed transformation

Data on geomorphologic evidences of the flood, information on current intensity and character of river network and floodplain modifications and identification of flood course obstacles were acquired by field mapping based on newly developed and tested methodology. The methodology was designed to allow treatment of large area, involvement of a higher number of mapping staff with keeping accuracy and consistency of results. Results of field mapping were digitized and integrated in the geodatabase to enable further processing and analysis.

Main principle of the new methodology of mapping of watercourses and floodplain modifications was to split the watercourses into segments marked by homogeneity in at least one of the observed parameters while allowing the variability of their length. In the course of field mapping, individual river segments are indicated on maps, identified by codes, and values were recorded in prepared forms. It was decided to develop a new methodology that could exactly fit the project needs instead of use some of the current methods of ecomorphological assessment (e.g. Rosgen 1996; Vlček, Šindlar 2002) due to their complexness and focus on parameters different from the project needs.

Watercourse anthropogenic modifications were evaluated in five key parameters – stream route, longitudinal profile modifications, river-bed modifications, floodplain modifications, and occurrence and nature of flood control measures (Table 1).

The indicators of anthropogenic modification intensity were assessed for the whole river segment while the character of individual changes was investigated separately for left and right banks. Individual segments were marked by system of uniform coding so that they could be linked to the corresponding geodatabase features (Langhammer 2005).

Table 1 – Main parameters of watercourse and floodplain modifications selected for the field mapping

Parameter	Conditions
Stream route	Straight / Sinuous / Meandering / Braided / Branched
Longitudinal profile modifications	No modifications / Low steps (water level difference <50 cm) / Medium steps (50 - 100 cm) / High steps (> 100 cm)
River-bed modifications	No modifications / Partially modified / Modified / Channelled into tubes
Floodplain modifications	Natural vegetation (meadows, wetland, forest etc.) / Agriculturally used areas / Anthropogenic area – discontinuous development, roads / Anthropogenic area – continuous development
Flood control measures	None / Flood control dykes / Polders, abandoned river arms (meanders) / Ponds and waterworks

Table 2 – Landforms assessed by field mapping as geomorphological evidences of the flood effects

Gravitational forms: Landslides, landslide areas **Fluvial forms:** *Accumulative forms:* Alluvial (dejection) cone Terrace Flood plains Older (Holocene) fluvial / flood accumulation Recent fluvial accumulation *Erosion forms:* Erosion furrow, source areas of erosion runoff Shifted river-bed, abandoned river-bed Significant damage to banks, bank caving Broken mounds Recent cuts of watercourses into flood plain sediments Rock steps in river-beds	**Anthropogenic forms:** Weirs Flood control obstacles Anthropogenically reinforced slopes Anthropogenic mounds, heaps Damaged or destroyed bridge Bridge, foot bridge Improperly located structures in floodplain **Other:** The maximum observed water level Dips (in valleys, on slopes) Drainless depression Isolated boulder

Mapping of geomorphologic evidences of the flood was performed on the basis of reduced legend of a geomorphologic map that contained phenomena related to flood effects plus features potentially affecting the course of flood. As in the previous case the mapping wasn't aimed at creating a complex geomorphologic map, but at collecting data on flood consequences and progress fitting the needs of project solution and required for further joint analysis. The mapping was focused on the landforms stated in the Table 2.

2. 4. Data analysis

The geostatistical analysis was based on data matrix generated from the GIS geodatabase. Original and derived spatial data of different topological characteristics were integrated into stream segments representing the

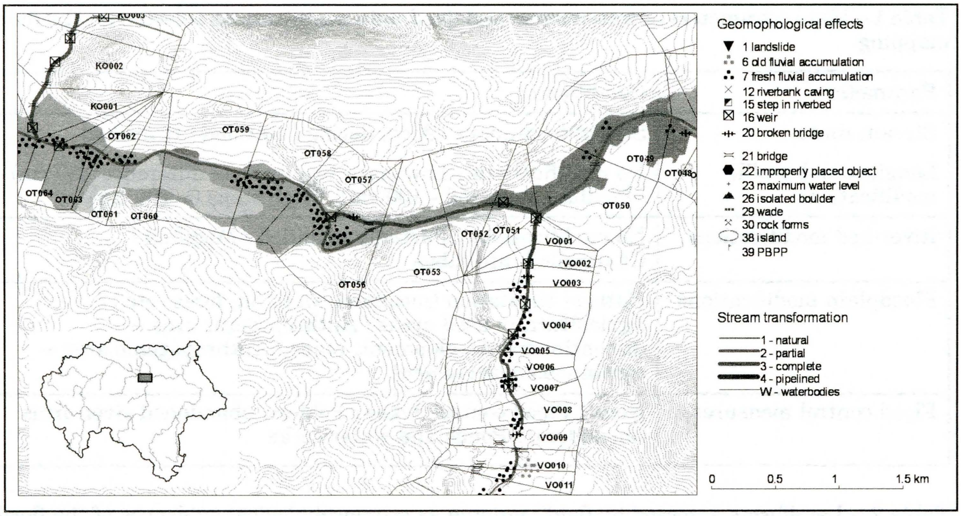


Fig. 2 – Integration of data sources into the elementary river segment using the GIS. Example shows the area of confluence of the Otava and Volyňka rivers.

elementary spatial unit for analysis (Figure 2). Each segment was extended by buffer zone of 500 m in which were integrated information from individual analytical layers – geomorphologic mapping, assessment of the river network shortening, analysis of land use changes and current state, relief digital model analysis etc. The geodatabase maintenance, data sharing, and analysis were performed on the ArcGIS platform. The special analysis and visualizations were made with the GIS MapInfo Professional / Vertical Mapper.

As the main analysis method, presented in this article was selected the rule-based classification. This technique based on database querying process allows analyzing the spatial coincidence of different types of flood effects and individual indicators of landscape transformation on the level of the basic spatial units – the river segments (Figure 1). The statistical analysis on data extracted from the GIS was performed in the XLStat statistical software and the results were imported back into the original geodatabase.

3. Results

3. 1 River network shortening

The most of watercourses in European cultural landscape was in the course of last centuries intensively rectified to improve transport conditions, to drain agricultural areas, to protect towns and cities from floods, or to leave a wider space for urbanization and industrialization of the landscape. Shortening of the river network have a significant negative impact in relation to the process of flooding. Stream rectification is inducing consequent increase of the slope of affected river segment and changes in riverbed geometry which is both resulting in speeding of the flow velocity, and in increasing of the destructive force of the flood wave in affected areas.

Analysis of historical shortening of the river network (Figure 3) in the Otava river basin proved that in average values this region shows similar

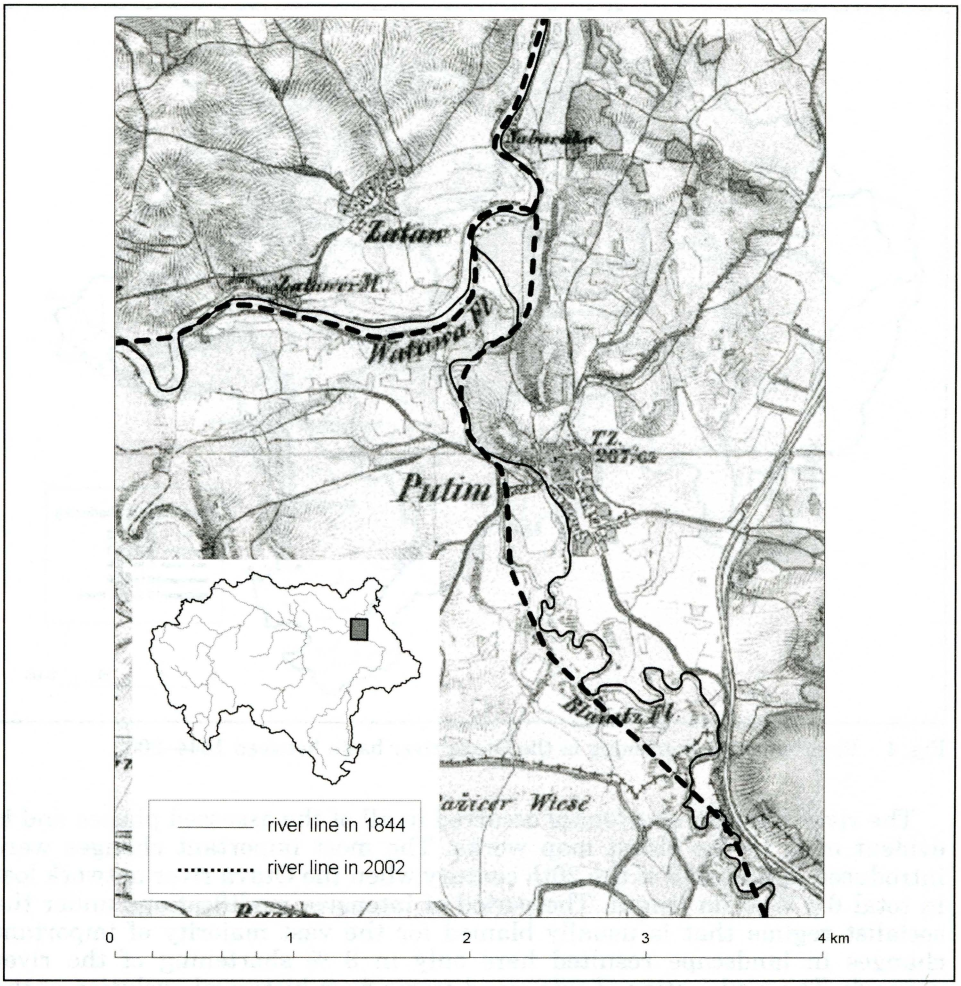


Fig. 3 – Overlay of waterlines of Digital civil map on the georefferenced digital image of the 2nd Military Map with digitized waterlines.

intensity of stream rectification as the most of streams in the Central Europe. Over the last 150 years, the length of the river network backbone has been cut from 611.6 km to current 555.9 km, i.e. by 9.1 percent.

The detailed assessment based on analysis of historical maps showed the fundamental spatial differentiation of this process in the Otava river basin. The maximum intensity of stream rectification in period 1844–2002 is reaching up to 40 % of the original river length in the Otava and Blanice down river courses located in the agricultural regions in lowland part of the river basin. To the contrary, the streams in headwater mountainous areas weren't significantly affected due to the terrain morphology and smaller pressure on land-use and the shortening rates here are generally not exceeding 4 %. Shortening of the Otava mid and downstream areas, where the rivers were subject to modifications already in the 18th century mainly due to the timber flowing in average accounts for 10% of the original length (Figure 4).

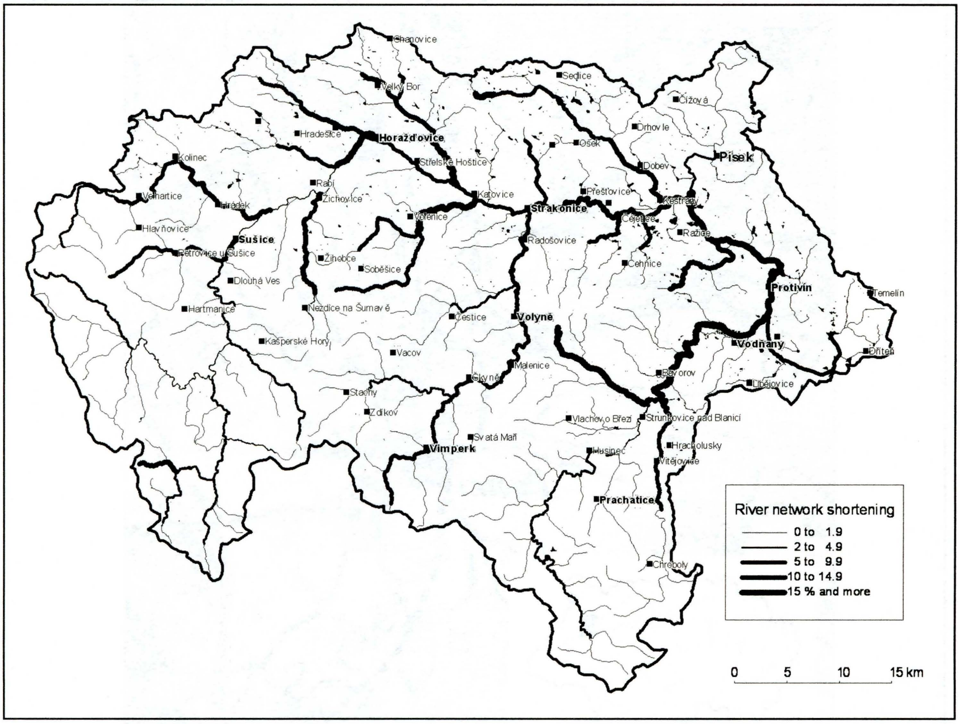


Fig. 4 – River network shortening in the Otava river basin between 1844–2002

The river network shortening occurred in all of the assessed phases and is evident even in the oldest map works. The most important changes were introduced in first half of the 20th century when the Otava river network lost in total 6.6 % of its length. The period of intensive modifications under the socialist regime that is usually blamed for the vast majority of important changes in landscape resulted here only in 3 % shortening of the river network. The explanation of this trend stems from historical evolution of the area. Due to the favorable conditions the Otava river basin was subject of intensive settlement, agriculture and other activities already since the middle age and thus the most important changes in river network were done in the history. So the stream rectifications made in 1970´s and 1980´s affected predominantly the small streams draining agricultural fields that were not subject of the assessment and thus are not appearing in the results.

The experience from field mapping of flood effects after the extreme floods in July 1997 and August 2002 shows that water course rectification is usually accompanied by acceleration of erosive and accumulative processes. The performed rule-based classification proved this relation although the overall statistical correlations between the watercourse shortening rate and intensity of the 2002 flood consequences are weak.

The rule-based classification was based on occurrence of at least one of the above-mentioned flood consequences (accumulation, river bank erosion, landslide, destruction of structures in floodplain) in the assessed river segment in coincidence with stream shortening rate for the period 1844-2000 exceeding specified threshold (Table 3).

Table 3 – Results of rule-based classification of stream rectification intensity impact on flood consequences.

	Shortening > 2 %	Shortening > 5 %	Shortening > 10 %
Total number of river elements	725	725	725
Shortening □ consequences	42,9 %	30,1 %	9,4 %
Shortening □ no consequences	52,7 %	32,8 %	14,8 %
No shortening □ consequences	2,8 %	15,6 %	36,3 %
No shortening □ no consequences	1,7 %	21,5 %	39,6 %
Share of shortened segments	95.6 %	62.9 %	24.1 %
Share of segments with flood consequences	45.7 %	45.7 %	45.7 %
Share of the shortened segments on the segments with consequences	94.0 %	65.9 %	20.5 %
Share of the consequences in shortened segments	44.9 %	47.8 %	38.9 %

The results of classification showed that relations between stream segment rectification and flood consequences depended on the threshold value of river network shortening used as an input criterion. The most numerous occurrences of flood consequences in modified segments were detected at the minimum shortening level. With the threshold set to 5 % which indicates the moderate shortening values the number of segments affected by flood effects is at 66 %. If the threshold is shifted to 10 %, which means in the Otava river basin an above average value, the share of segments with flood consequences drops to 20 %.

3. 2 Riverbed and floodplain transformation

Analysis of current intensity of the hydrographic network and flood plains anthropogenic modifications was based on field mapping of the state of backbone of the Otava river network and the consequences of the flood in August 2002 in total length of 610 km. From the results of mapping stored in GIS were extracted four main parameters of riverbed and floodplain transformation – stream route modifications, longitudinal profile, river bed modification and floodplain transformation.

The anthropogenic alterations currently affects 42,8 percent of the total length out of which 26,3 percent represent partial and 16,4 percent complete modifications (Figure 5).

The transformation intensity is however spatially highly diffentiated. The largest extent of changes is detected in downstream areas with intensive agricultural activities and dense population. The absolutely highest rate was found in the downstream of the Blanice river basin where almost 100 % of major watercourses length is classified as partially or completely modified. Extensive modifications involve also streams at mid and downstream courses of Otava, Volyňka, Ostružná and other rivers. To the contrary, the rivers in the headstream areas in mountainous parts remain practically untouched by anthropogenic activities.

From the view of flood progress control a highly important factor is the spatial structure of anthropogenic modifications. Long and compact modified sections speed up the flow and are leading to concentration of bank erosion, accumulation of material and intensive damage upon hitting unmodified zones, mainly in meanders and bends. The highest attention should be paid to pipelined segments that despite their short length pose considerable risks

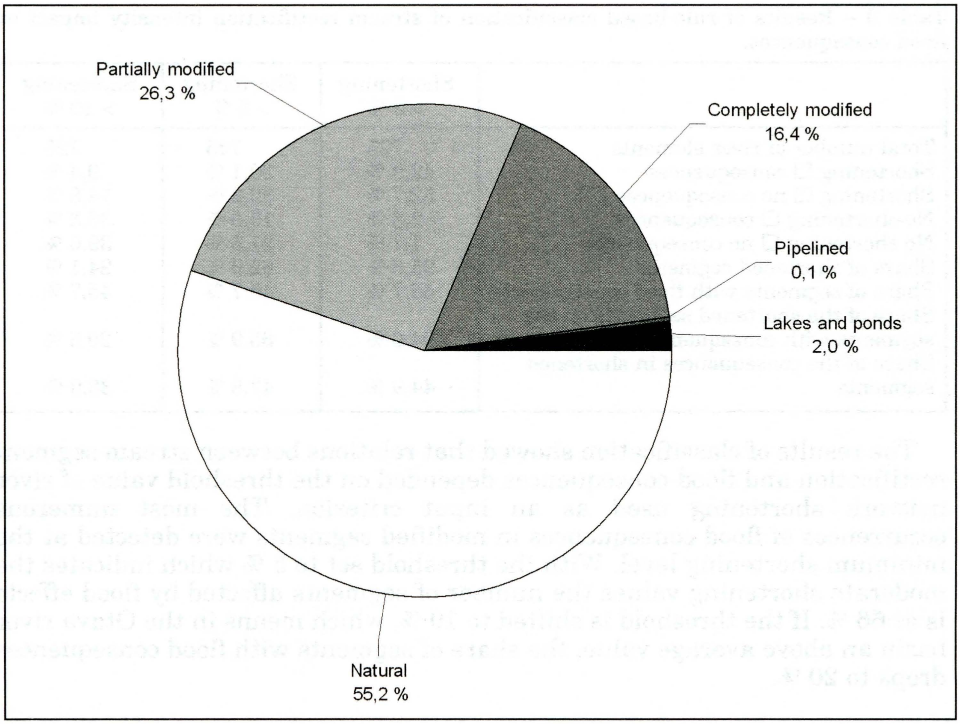


Fig. 5 – Anthropogenic transformation of riverbed – total shares of main categories of riverbed modification intensity at Otava river basin. Data from mapping of anthropogenic transformation of streams and floodplains in Otava river basin (Vilímek, Langhammer et al. 2004).

of damage due to their easy blockage by the material transported by the flood. This leads to creation of temporary water storages and subsequent break of the provisional dam resulting in local flash flood wave with destructive effect. Such problems were identified i.e. at the Losenice river at the slopes of Bohemian Forest where this process lead to serious damages on buildings and infrastructure during the flood in August 2002.

Another important factor affecting the runoff process during the flood is the land-use structure of flood plains. Importance of this factor is critical at situations when the water level exceeds the limits of the river bed or flood protection dykes and the area of the floodplain is involved in the runoff process. During the flood in August 2002 this occurred mainly in the lowland parts of the river basin during the second flood wave when the water level exceeded the flood plain bottom often even by several meters (Figure 6).

In conditions of such extreme events the structure of land cover of the flood plain can importantly affect the progress of the flood, the efficiency of flood wave transformation and the extent of damages. The analysis of land-use structure in the floodplain of the Otava river network pointed to the inadequate use of this area in regard to the flood protection needs – as much as 63 % of the total flooded area is of agricultural use, while 44 % of the total floodplain area is occupied by arable land. Meadows and pastures, forming the natural environment of the floodplain represent only 16 %, forests 11 %, wetlands and water bodies 1.4 % of the floodplain area. The intensity of

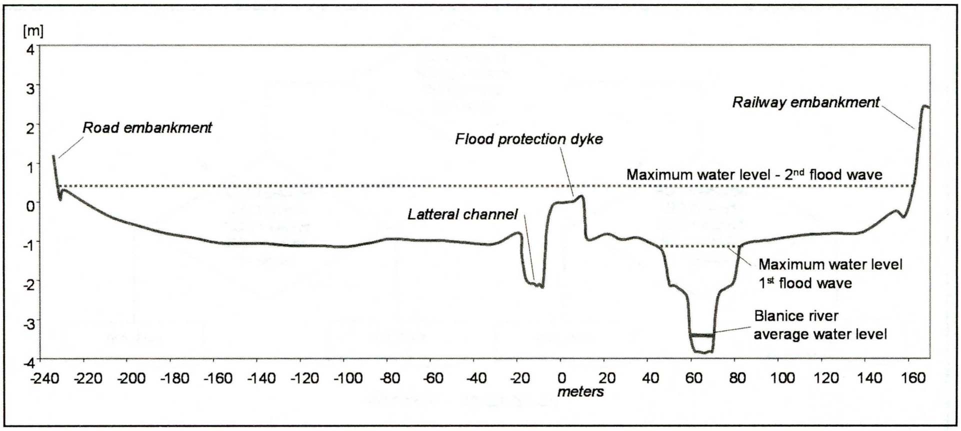


Fig. 6 – Cross section of the floodplain of the Blanice river by Protivín with marked water levels of 1st and 2nd flood wave in August 2002. Data from field mapping of consequences of flood in 2002 in Otava river basin (Langhammer 2006).

floodplain land-use differs significantly among individual subcatchments. Extreme values are reached at the Blanice and Otava downstream areas, where the shares of all anthropogenically modified surfaces in floodplains (agriculture, settlement, industry, transport) are exceeding even 90 % of the total floodplain area.

The rule-based classification was based on application of individual thresholds for each parameter of stream modification intensity and the comparison of resulting value with the occurrence of the flood consequences in coincident river segment (Figure 7).

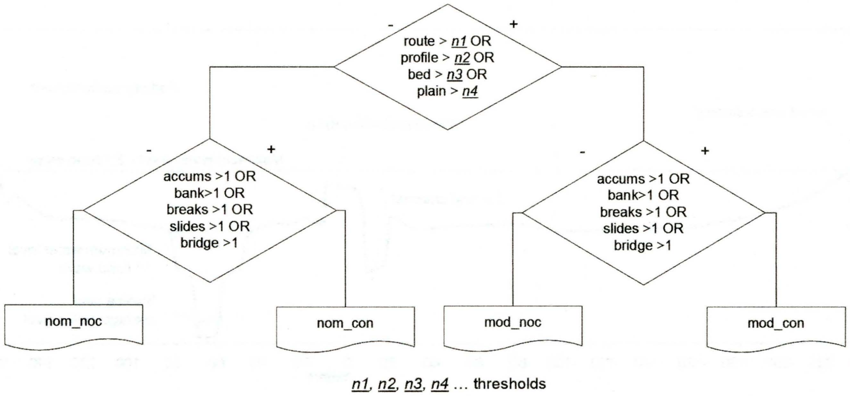
With respect to relations between watercourse modifications and flood consequences, it was of a vital significance to find that over 92 % of identified flood consequences were located in segments partially modified by anthropogenic activities according to at least one parameter.

The analysis indicated the strongest relation in the case of stream route and floodplain modifications – over 85 % of identified flood consequences were located in straight or sinuous segments, almost 60 % of detected flood consequences were located in segments affected by agriculture or settlement.

Relations between river-bed modification intensity and the flood consequences found in coincident and consequent segments are of inverse trend (Table 4). The flood consequences observed by the field mapping were identified in 49 % of river segments affected by partial or moderate modifications (level 2 and superior) but only in 11 % of entirely modified or pipelined segments (level 3 and superior). This results are in some aspects contradictory to the theories (i.e. Just, 2003) assuming that the higher modification intensity of the stream results in larger extent of flood induced effects.

3. 3 Flood course obstacles

For the extent of flood damages related to the extreme events is one of the key factors the occurrence of obstacles impeding water flow in the flood plain. Structures and objects located in the flood plains like inadequately designed bridges, weirs or improperly located objects in flood plains staying in normal



Explanation to abbreviations:

classification criteria

route, profile, bed, plain

intensity of watercourse modification in parameters:
stream route, longitudinal profile, riverbed transformation, floodplain modification

accums, bank, breaks, slides, bridge

number of following flood effects in river element:
fresh fluvial accumulations, bank cavings, dam breaks, landslides, damaged bridges

resulting classes of relationship between stream modification and flood effects

nom_noc no modification - no consequences
nom_con no modification - consequences
mod_noc modification - no consequences
mod_con modification - consequences

Fig. 7 – Decision tree for classification of relations between riverbed transformation and flood consequences

Table 4 – Results of rule-based classification of stream and floodplain modification impact on observed flood consequences

	Stream routing >1	Longitudinal profile >1	Riverbed modification >1	Floodplain modification >1	Overall modification > 1	Overall modification >2
Total	829	829	829	829	829	829
Modification → consequences	311	83	180	217	336	306
Modification → no consequences	347	89	199	244	399	368
No modification → consequences	54	282	185	148	29	59
No modification → no consequences	117	375	265	220	65	96
Share of modified segments	79.4 %	20.7 %	45.7 %	55.6 %	88.7 %	81.3 %
Share of segments with flood consequences	44.0 %	44.0 %	44.0 %	44.0 %	44.0 %	44.0 %
Share of the modified segments on the segments with consequences	85.2 %	22.7 %	49.3 %	59.5 %	92.1 %	83.8 %
Share of the consequences in modified segments	47.3 %	48.3 %	47.5 %	47.1 %	45.7 %	45.4 %

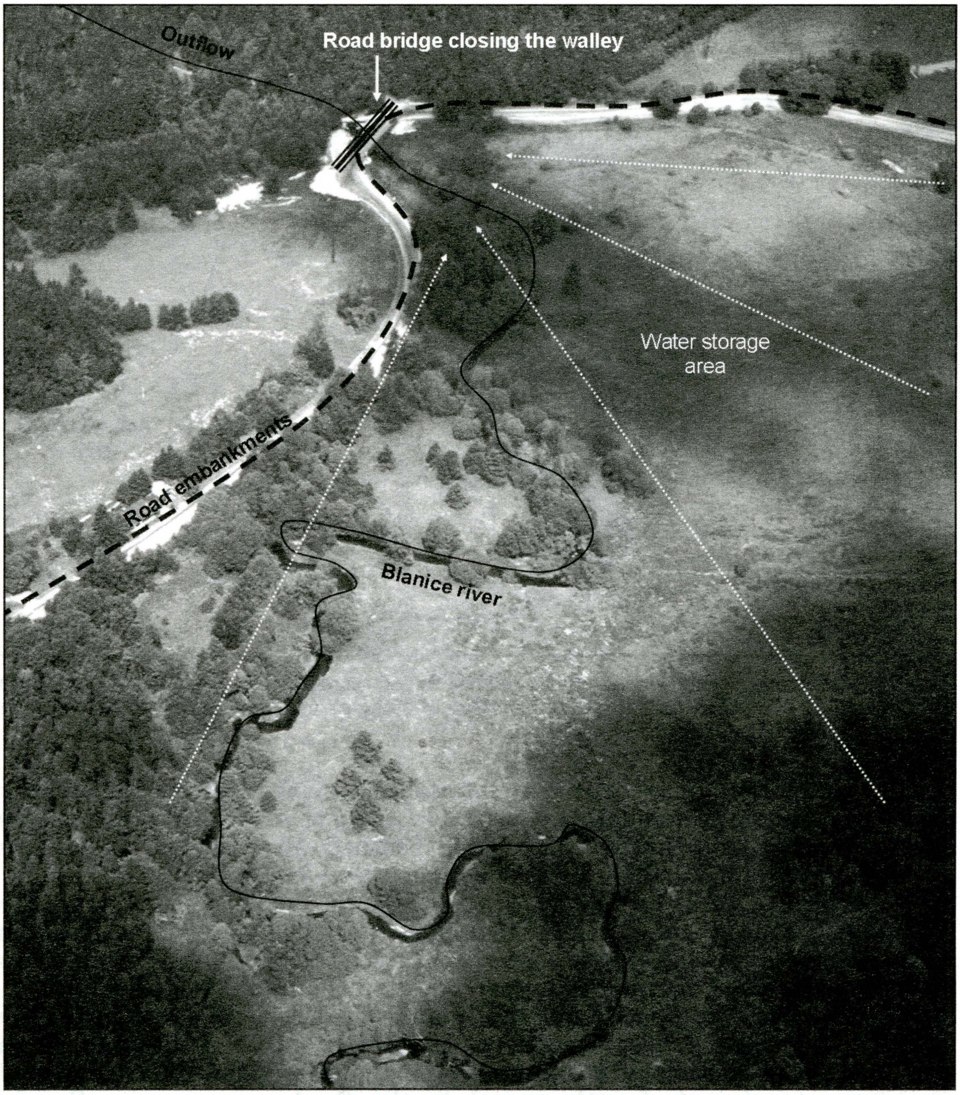


Fig. 8 – Inadequately Located Bridge on the Upstream Blanice River Impeding Flow During Floods (Photo Langhammer 2003)

conditions outside of the inundation zone during extreme flooding may become important flow obstacles. With help of material carried by the flood they cause temporary blockages, which after their breaking can trigger the local flash flood. Such processes accelerate accumulative and erosive processes and the destroyed structures become source of material carried by the flood wave and may amplify problems further down the stream.

This process is illustrated by the event caused by the road bridge on the upstream Blanice river during the 2002 flood (Figure 8). The small and relatively unimportant local road bridge is located at the end of shallow but large valley. Because of its inadequate design capacity it was during the first

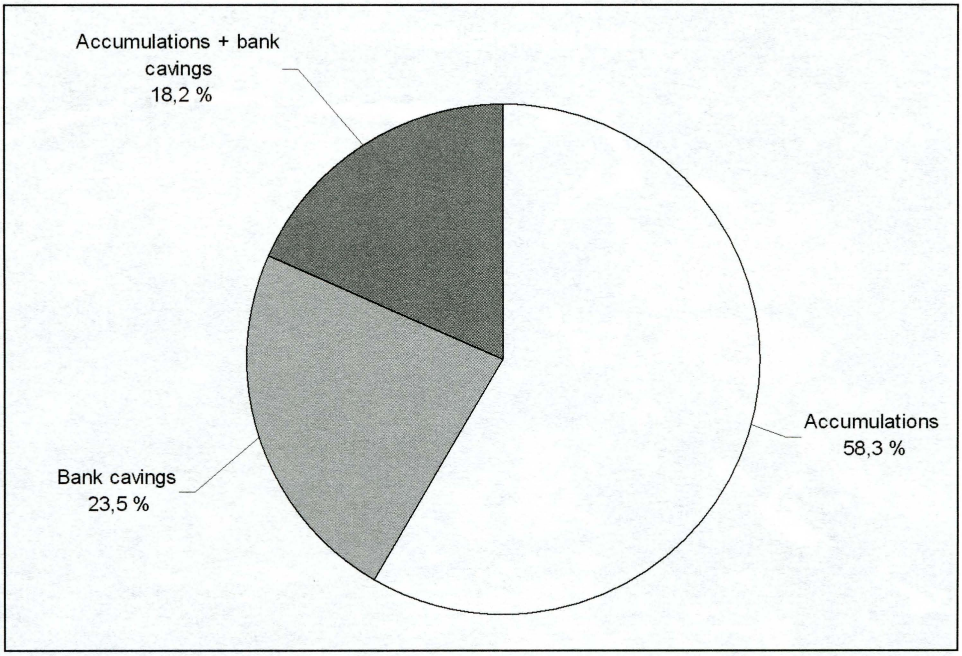


Fig. 9 – Structure of flood consequences related to the occurrence of steps and weirs. Data from mapping of anthropogenic transformation of streams and floodplains in Otava river basin (Vilímek, Langhammer et al. 2004).

flood wave blocked by transported material and turned the upstream valley in temporary lake accumulating enormous volume of water. After the collapse of the bridge the triggered flash flood reached after several kilometers Husinec river dam endangering seriously its safety and stability.

The classification of relations between occurrence of flood course obstacles and observed flood consequences was based on following structures which were selected as potential flow obstacles in river-beds and flood plains: steps in river-beds, weirs, bridges, improperly located objects in floodplain.

The detection of these potential flood course obstacles was performed in the actual and preceding stream segments because of nature of their impact on the flood course. Assessment results proved the importance of occurrence of structures in river bed with regard to the flood consequences. Special importance has the consecutive occurrence of steps in subsequent segments – when evaluating the impact of steps on occurrence of fluvial accumulations and bank cavings in coincident segment only 8 % of river segments were corresponding to this criterion. If the detection of presence of the step or weir is extended also to the preceding river segment, the share of segments with respective flood consequences increases to 13 %.

The flood consequences related to the weirs are differetiated according the nature of prevailing geomorphologic process (Figure 9). The most frequent are fluvial accumulations (58 %) followed by bank cavings (23.5 %), simultaneous occurrence of both accumulations and bank cavings is recorded in 18 % of segments.

4. Discussion

The classification of the impact of watercourse shortening, river-bed and flood plains anthropogenic modification and flow obstacles on observed flood consequences proves surprisingly weaker relations in the areas of high intensity of anthropogenic modification of river-beds and flood plains. This applies mainly to the downstream areas of the Blanice and Otava, the two main watercourses of the river basin. Here is recorded maximum intensity of watercourse, riverbed and flood plains modifications, but relations between the state of anthropogenic transformation and flood consequences aren't clearly proved.

This may be caused by unprecedented extremity of the flood in August 2002. In downstream areas, the flood wave filled the whole area of the flood plains with water levels exceeding by several meters the level of floodplain. Therefore the impact of anthropogenic modifications of watercourses was weakened. To the contrary, in upstream and midstream areas, where flood wave waters mostly did not leaved the river-beds or spilt into a narrow floodplain area, the impact of anthropogenic interventions on flood consequences increased. These findings are in line with current results of research in the field in various geographical conditions (Naef, Scherrer et al. 2002; Niehoff et al. 2002; Robinson, Cognard-Plancq et al. 2003; Sear, Newson 2003).

5. Conclusions

The results of presented research indicated the links between anthropogenic transformation of the streams and the response of river basin to the extreme flooding.

The research proved that the relations between individual indicators of landscape vulnerability and observed flood consequences may differ according the geography, intensity of the overall anthropogenic impact on river basin, basin scale, extremity of the causal precipitation and mainly extremity of resulting runoff response of the river basin.

River network shortening and river-bed modifications have important influence on the progress of the flood, flood wave shape, velocity and on possibilities of its effective control and transformation. However during extreme flood events when whole flood plains are involved in the runoff process their effect down significantly. In case of the flood in August 2002 in the core zone of the flood the effect of these factors was remarkable during the first flood wave. During the second flood wave which came some days later and because of preceding saturation of the river basin resulted in runoff response that in some catchments exceeded 1000 years return period, the role of these landscape and river network modifications was marginal. On the contrary, very important impacts have the modifications of flood plains and mainly the occurrence of the potential obstacles to the flood course. The analysis proved the effect of improperly located objects in the floodplain, insufficiently designed structures or bridges impeding the water flow during the extreme flooding on the extent of flood consequences.

Geostatistical analysis of relations between landscape modifications and consequences of the flood in August 2002 in the Otava river basin proved that these relations are remarkable even at the regional level but that they cannot be considered as the main driving force of unprecedented extremity of the assessed flood and its consequences. These findings are applicable in the process of improvement of flood protection design and management. The restoration of streams and landscape thus can be considered as important complement to the structural measures but there is always necessary to take into account the limits of these measures on flood mitigation and their varying effect under different flood extremity levels.

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Shrnutí

GEOINFORMATICKÉ VYHODNOCENÍ SOUVISLOSTÍ EXTRÉMNÍCH POVODNÍ – PŘÍPADOVÁ STUDIE: POVODNĚ V SRPNU 2002 VE STŘEDNÍ EVROPĚ

Předložené výsledky výzkumu ukazují vztahy mezi antropogenními změnami vodních toků a reakcí povodí řek na velké povodně. Výzkum potvrdil, že vztahy mezi jednotlivými ukazateli zranitelnosti krajiny a pozorovanými následky povodní se mohou lišit podle zeměpisných poměrů, intenzity celkového vlivu člověka na povodí řeky, velikosti povodí, extrémního charakteru dotyčné přeháňky a zejména podle extrémní odtokové reakce povodí řeky.

Zkrácení říční sítě a úpravy říčního koryta mají velký vliv na postup záplav, tvar povodňové vlny, rychlost a možnosti jejího účinného řízení a změny. Avšak při extrémních povodňových situacích, když jsou do odtokového procesu zapojeny celé říční nivy, se jejich účinek se výrazně snižuje. V případě povodní v srpnu 202 byl v hlavní povodňové zóně účinek těchto činitelů významný v první povodňové vlně. Během druhé povodňové vlny, která přišla o několik dní později a vlivem předchozí saturace povodí řeky došlo v některých povodích k více než tisícileté vodě, byla úloha těchto změn krajiny a říční sítě pouze okrajová. Naopak velký vliv mají změny říčních niv a zejména výskyt možných překážek postupu povodní. Analýza prokázala vliv nevhodně umístěných objektů v říční nivě a špatně navržených budov či mostů zabraňujících průtoku vody při extrémních povodních na rozsah povodňových škod.

Geostatistická analýza vztahů mezi změnami v krajině a následky povodně ze srpna 2002 v povodí řeky Otavy ukázala, že tyto vztahy jsou pozoruhodné i na regionální úrovni, ale nemohou být považovány za hlavní hybnou sílu bezprecedentního rozsahu záplav a jejich následků. Tyto poznatky lze využít při zlepšování projektů a správy protipovodňových opatření. Obnova vodních toků a krajiny může být tedy považována za důležitý prvek strukturálních opatření, ale je vždy třeba brát do úvahy limity těchto opatření na zmírnění záplav a jejich proměnlivý účinek při různé síle povodní.

Obr. 1 – Povodí řeky Otavy. Zkoumaná oblast je jednou z hlavních zón extrémních povodní ve střední Evropě v srpnu 2002. Ve východní části povodí podél řeky Blanice byly zaznamenány ve dvou po sobě následujících vlnách srážky přesahujících 300 mm. Vysvětlivky vpravo dole: síla povodně (xletá voda), rekordní srážky (xleté extrémy, druhá povodňová vlna).

Obr. 2 – Zanesení údajů do základního úseku řeky za pomoci GIS. Příklad ukazuje oblast soutoku řek Otavy a Volyňky. Geomorfologické následky: sesuv, staré říční naplaveniny, čerstvé říční naplaveniny, vymletí říčního břehu, stupeň v říčním korytě, jez, rozbitý most, most, nevhodně umístěný object, maximální stav vody, osamělý balvan, brod, sklaní útvary, ostrov.

Obr. 3 – Přenesení vodních toků z digitální civilní mapy na georeferenční digitální zobrazení 2. vojenské mapy s digitalizovanými vodními toky. Plně – linie řeky v roce 1844, tečkovaně – linie řeky v roce 2002.

Obr. 4 – Zkrácení říční sítě v povodí Otavy v období 1844–2002.

Obr. 5 – Antropogenní změny říčního koryta – celkový podíl hlavních kategorií intenzity změn říčního koryta v povodí Otavy. Údaje z mapování antropogenních změn vodních toků a říčních niv v povodí Otavy (Vilímek, Langhammer et al. 2004). Shora ve směru hodinových ručiček: částečně změněno, úplně změněno, vedeno v trubkách, jezera a rybníky, přírodní

Obr. 6 – Příčný řez říční nivou Blanice u Protivína s vyznačením úrovně první a druhé povodňové vlny v srpnu 2002. Údaje z terénního mapování následků povodně z roku 2002 v povodí Otavy (Langhammer 2006). Zleva nad tečkovanou čárou: silniční násep – ochranný povodňový val – maximální stav vody (druhá povodňová vlna) – železniční násep. Zleva pod tečkovanou čárou: postranní kanál – maximální stav vody (první povodňová vlna) – průměrný stav vody v Blanici.

Obr. 7 – Graf ke stanovení vztahů mezi změny říčního koryta a následky povodní. Horní kosočtverec: směr, profil, dno, niva. Levý i pravý kosočtverec: naplaveniny, břeh, průlom, sesuvy, most, nl – prahy. Vysvětlení zkratek: klasifikační hlediska: směr, profil,dno, niva. Iintenzita změn vodního toku v parametrech: směr proudu, podélný profil, změna řečiště, změna říční nivy. Naplaveniny, břeh, průlomy, sesuvy, most; počet následujících povodňových následků v řece; čerstvé říční naplaveniny, vymleté břehy, průlomy hrází, sesuvy půdy, poškozené mosty. Výsledné třídy vztahů mezi změnami řeky a následky povodně: žádné změny – žádné následky, žádné změny – následky, změny – žádné následky, změny – následky.

Obr. 8 – Nesprávně umístěný most na horním toku Blanice zabraňující průtoku vody při povodních (foto Langhammer 2003) Shora ve směru hodinových ručiček: odtok, silniční most uzavírající údolí, oblast akumulace vody, řeka Blanice, silniční násep.

Obr. 9 – Struktura následků povodní ve vztahu s výskytem stupňů a jezů . Údaje z mapování antropogenních změn vodních toků a říčních údolí v povodí Otavy (Vilímek, Langhammer et al. 2004). Shora ve směru hodinových ručiček: naplaveniny a vymleté břehy, naplaveniny, vymleté břehy.

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