GEOGRAFIE

SBORNÍK
ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI

ČESKÁ GEOGRAFICKÁ SPOLEČNOST
1894

2006/3
ROČNÍK 111

GEOGRAFIE
SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI
GEOGRAPHY
JOURNAL OF CZECH GEOGRAPHIC SOCIETY

OBSAH – CONTENTS

HLAVNÍ ČLÁNKY – ARTICLES

GEOGRAFIE – SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI
ROK 2006 • ČÍSLO 3 • ROČNÍK 111

JAKUB LANGHAMMER, VÍT VILÍMEK

PRESENT APPROACHES TO EVALUATION OF ANTHROPOGENOUS CHANGES IN LANDSCAPE AS A FACTOR OF FLOOD RISK

J. Langhammer, V. Vilímek: *Present approaches to evaluation of anthropogenous changes in landscape as a factor of flood risk.* – Geografie–Sborník ČGS, 111, 3, pp. 233–246 (2006). – Flood risks can be evaluated from two points of view, the economic and the process one. The economic approach parts from consequences of the causal event when the risk is defined as the function of probability of occurrence of a certain phenomenon and of potential damage. The process approach evaluates the risk via main processes and factors involved in the risk development. The risk is then defined on the basis of three factors – hazard, exposure, vulnerability (Barredo et al. 2005, Crichton 1999, Kron 2003). Anthropogenous changes in the landscape represent, according to the process approach to risks, one of the vulnerability factors. Vulnerability of environment in relation to values exposed to the hazard represents their susceptibility to damage occurrence and is decisive for the extent of damage. Large changes in intensity, character and structure of land-use occurring in the cultural landscape during these last centuries, affect changes in outflow conditions of the catchment and can thus influence the course of floods. Vulnerability is a risk element which can be, differently from the other risk components, at least partly influenced and controlled. While natural processes representing a source of hazard cannot be influenced and accumulation of property in flood areas can be only hardly reduced, it is possible to purposefully reduce vulnerability both of natural environment and of social links in a way to minimize consequences of natural elements activities, to increase the efficiency of flood control measures and to limit damages to a strict minimum corresponding to the extremity of the phenomenon.
KEY WORDS: natural hazards – floods – risk – land-use – anthropogenic changes.

The presented research was funded by the Research Plan MSM 0021620831 "Geographical Systems and Risk Processes in Context of Global Changes and European Integration" of the Czech Ministry of Education and Research Project VaV-SM/2/57/05 "Long-term changes of river ecosystems in floodplains affected by extreme floods" of the Ministry of Environment of the Czech Republic which is fully appreciated by the authors.

1. Introduction

An increased settlement density and growing financial and technical requirements of buildings make it necessary for the society to ensure the most effective protection possible against both direct and indirect consequences of natural disasters. At the same time however, people influence natural environment to such a degree that they largely contribute to deterioration of the given situation. However, also quite natural changes occur simultaneously in the physical-geographical sphere (as for instance valley and erosional network development) which have nothing in common with human impact as they manifested already in the palaeogeographical history of the Earth and they will occur also in future. Some of these processes go on very slowly and in long perspective, others, on the contrary, in a catastrophic way. Exactly differentiation of intensity of the impact of human society on the course of natural processes may help to ensure protection against natural disasters.

Floods as one of many types of natural hazards have their causes and consequences and they are also bound to some other types of natural disasters. They belong to the category of hydrometeorological events, but they are bound to other types of natural hazards as well (e.g. Kukal 1982, Vilímek 2003). This subject matter is also dealt with in general publications on natural hazards (e.g. Bolt et al. 1975, Alexander 1993).

With regard to requirements of management of risks, we are in a situation, when governmental bodies ask scientific workplaces not only to identify the hazards but also to quantify the risks. It is crucial for a successful quantification to determine the degree of risk (of the process intensity), the probability of occurrence in the given locality (region) and the most precise time possible when risk processes set in. Different kinds of natural hazards offer different possibilities how to solve these tasks in dependence on our more or less detailed knowledge of respective components of physical-geographical sphere. For instance earthquakes occur often without previous symptoms, volcanic activities are mostly intensifying gradually as well as flood risk, on the other side flash floods manifest a much quicker development of critical state.

Because of the complexity of physical-geographical sphere, the degree of interconnection between individual components and a still limited degree of knowledge of some natural processes, it is sometimes very difficult and even impossible to quantify the natural hazard with the necessary precision. And consequently it is difficult for governmental bodies to determine adequate preventive measures (including the decision to evacuate population). In case of a too late reaction or an insufficient degree of prevention, there are human and material losses and when, on the contrary, the risk is overestimated, future mistrust of population is probable and financial costs are qualified as superfluous. And floods are not an exception.

2. Risks and approaches to their assessment

Mutual relationship of natural hazards and risks was summarily dealt with for instance in the paper by Vilímek (2003), and that mainly in respect of floods and other kinds of natural hazards. Flood hazard is defined for instance by Alexander (1993) as "threat to life or property posed by rising or spilling water". The term risk is often used in different connections and contexts. It is used not only with regard to natural processes, but also in social, economic, security or environmental spheres and its understanding, delimitation and usage are generally different in each of these spheres. But as it is necessary to have a clear definition for analysing, assessing and controlling risks, several methodological approaches have progressively developed to enable to define, assess and consequently also to control the risks.

Main current approaches to risk understanding are represented by two views – an economic and a process one. The economic approach evaluates the risks from the perspective of consequences of the causal event when the risk is defined as function of probability of occurrence of a certain phenomenon and of a possible damage. The process approach assesses the risk through the main processes and factors involved in the risk emergence. The process approach is a significant contribution to assessment and modelling of the risk and a basis of many evaluation approaches used in natural sciences as well as in practical applications. The risk is defined by three factors – hazard, exposure, vulnerability (Barredo et al. 2005, Crichton 1999, Kron 2003):

$$R = O \times E \times Z \tag{1}$$

where R is risk, O – hazard, E – exposure and Z – vulnerability. These three components act in synergy and interaction, but they differ by their origin, character and manifestations.

The component of hazard in the process conception is represented by the proper stochastic natural process causing threats to natural or social system. In the case of flood risk there are causal processes causing the flood itself – atmospheric precipitations, snow melting, or processes causing dam ruptures.

The component of exposure represents potential for damage emergence, as it includes property in the areas exposed to natural process threat. In case of floods there are for instance residential and commercial structures, industrial areas, movable property, communications, agricultural facilities, etc., which are endangered.

Vulnerability can be defined as predisposition to damage occurrence (HZS 2006). In the system of natural risks it represents a binding element determining the course of a natural hazard, the character of its consequences and the resulting extent of damage. It can be evaluated in relation to the both remaining factors of the risk – exposure and hazard. These two vulnerability aspects being different – the first one represents vulnerability of socio-economic structures and links, the second one vulnerability of the natural environment.

Mutual relationship of the given three risk components can be expressed by a triangle, where individual components are represented by its sides and the resulting degree of risk by the area of the triangle (Fig. 1). The risk emerges only when all its components are greater than zero. If we eliminate any of the risk components, the risk disappears.

The process concept of risk understanding is an important contribution to management of and protection against the risk of natural disasters. It enables to better understand and assess the significance of individual factors for the intensity of the risk that differ for individual situations, geographical areas and time periods and, according to the character of the risk, to choose corresponding methods for its mitigation or elimination.

3. Anthropogenous changes in landscape as a factor of vulnerability

Anthropogenous changes in landscape are, according to the process approach to risks, one of the factors of vulnerability. The scheme in Figure 2 shows the position of floods in context of relationship cause-consequence, and that both natural and anthropogenous. The principle of development of systems with non-linear dynamism, in literature as a rule called "chaos theory", "complexity theory" or "self-organized criticality" (Viles 2005), must

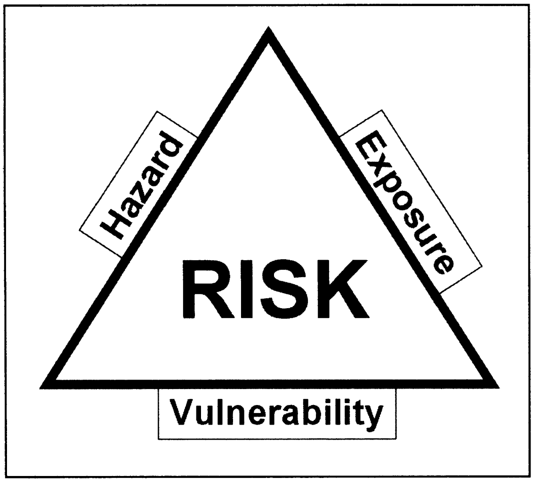

Fig. 1 – Main components of flood risk

be for better understanding of erosional-accumulational processes during floods flows used also when studying geomorphological manifestations of floods (flood geomorphology). The part of anthropogenous factors in emergence and course of floods can be consequently determined.

Individual manifestations of human activities in landscape – changes in land-use, deforestation, large-scale drainage, stream straightening and regulation, modifications in floodplain, etc., as factors of vulnerability – influence both the predisposition of the system to damages as well as the character and course of the natural hazard process itself. The impact of these changes is nevertheless bound to the other components of the risk process, i.e. exposure, hazard and other factors of vulnerability.

Vulnerability of the environment in relation to values exposed to the hazard is represented by their sensibility to damage occurrence and is decisive for the extent of damage. While the total damage potential representing the maximal possible damage due to the causal process is given by the structure, value and location of property in flood area, the resulting extent of damage differs in relation to the vulnerability of the system exposed to the hazard. In case of floods the vulnerability of socio-economic structures is reflected to the factor of exposure, for instance in the following aspects:

- Increasing dependence of the society on sophisticated technologies and communication systems. Dependence of all control systems on electric power supplies for computer, information and communication systems, on telecommunication networks and transport connections causes, in case of their collapse, chaos and greater damages than in less developed systems.
- Insufficient communication and coordination. In crisis situation, vital for rescue system is the ability to deliver the right information to the right place at the right time and in the right form. During floods in August 2002 in Czechia for instance, shortcomings in communication between providers of data on hydrological situation and the central crisis headquarters in Prague led to a false interpretation of the information about the extreme character of the flood and consequently to unnecessarily high damages caused by the ill state of preparation.
- Insufficient preparedness and incapacity to respond in time and in the right way. Due to little experience with floods, many inhabitants do not know in case of flood events what to do before the flood comes, how to respond in the right way and some of them even refuse to cooperate with the rescue system. Underestimating of the risk causes unnecessary damages and secondary costs, for instance during evacuation operations.

Vulnerability of the natural environment influences the character and intensity of processes representing the proper source of hazard. Therefore

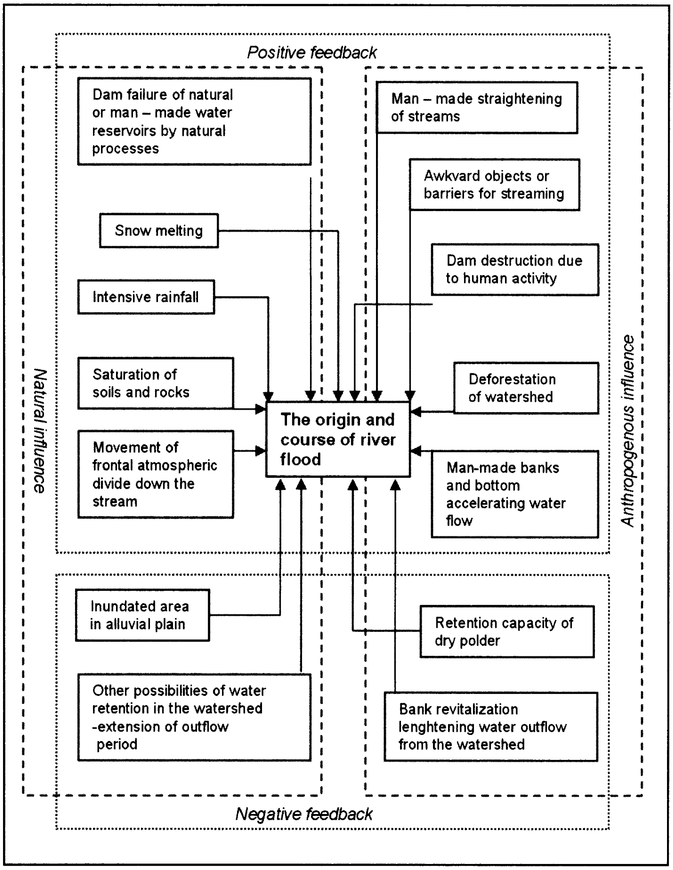

Fig. 2 – Scheme of interactions of natural and anthropogenous processes in emergence and development of river floods

vulnerability influences the hazard component and may change the course and extreme character of a catastrophic process. As to flood risk, vulnerability factors are for instance the following:
– climatic changes causing an increase of the extreme character of atmospheric processes and of changes in their time and space distribution
– changes in landscape influencing the energetic balance of the landscape, its water-bearing capacity and runoff character
– modifications of streams and floodplains causing a lower water-bearing capacity of the floodplain and changes in streaming in riverbed.

4. Geographical methods of assessment of anthropogenous changes in landscape

Anthropogenous changes in landscape represent an important factor influencing the flood risk. Large changes in land-use intensity, character and structure occurring during the last centuries in cultural landscape have caused changes in runoff conditions of river basins and can thus influence also the course of floods. Among the main factors causing changes in rainfall-runoff process, mainly during extreme events, are the following:
– changes in land-use, structure and quality of landscape cover
– large-scale drainage of the landscape
– shortening of river network
– modifications of stream beds
– floodplain use structure
– presence of obstacles to water circulation in floodplain.

These manifestations of anthropogenous impacts in landscape have, during flood situations, different impact on individual runoff process components and they influence differently the development of the flood, its progression, transformation of flood wave or consequences of flood in the landscape. Influencing of runoff process differs in individual types of landscape modifications for different reached levels of flood extremity, in dependence on the size of the affected territory as well as according to the location in principal function areas of flood development in the area of flood wave formation, flood routing and flood spilling.

4.1 Changes in land-use and land cover structur

Changes in functional land-use are connected mainly with assessment of the level of natural character of individual landscape cover types. The influence of functional land-use on the runoff process is crucial and sudden and large land-use changes may have a crucial impact during extreme events.

When evaluating the impact of the present land-use and of its changes on the runoff process, important, besides the proper functional land-use, is also the space structure of the landscape and the quality of its vegetation cover.

Among land-use changes occurring simultaneously with the development of civilization, the most important for the runoff process are the following:
- deforestation of the landscape
- intensive farming
- landscape urbanization
- industrialization.

4.1.1 Deforestation of the landscape

Physical presence of natural landscape elements – forests and meadows – in a basin is considered as a key element influencing the character of the rainfall-runoff process. Forests positively influence retention of water in the basin, transformation of flood wave or its spreading into a longer time period and the related lowering of culmination flow and timing of concurrence of runoff waves from partial catchments (see Maidment 1993). Transformation function of forests differs according to the species composition of the forest, its age, growth and health state and the character of forestry; an important part is played also by geographical characteristics – character of relief, hydrographic network, total forest coverage and spatial distribution of causal rainfall. The greatest influence on the flood course has deforestation of the landscape in the area of flood wave development, i.e. mostly in mountain areas and generally in headwater areas where vegetation interception plays a major part in the rainfall-runoff process.

The runoff process is negatively influenced mostly by deforestation and forest dieback as they weaken the retention capacity and at the same time contribute to degradation and removal of the upper soil layer. Anthropogenous interventions into agricultural landscape, as consolidation of land, unsuitable cultivation methods and soil compression by heavy vehicles, contribute to an accelerated runoff from the basin (Munich Re 1997).

A very important factor of runoff formation during floods is also the forestry character. Building of hard forest communications used by heavy vehicles contributes, mainly in slopy terrains, to an intensive concentration of surface runoff; during heavy rainfall a secondary hydric network is thus formed and water is carried away from the forested area much quicklier than in less intensively used areas.

4.1.2 Intensive farming

Intensive agricultural production as a result of growing total consumption of our society is connected mainly with the second half of the 20th century, nevertheless deep interventions into landscape connected with farming have been accompanying human society for long years.

The impact of transformation of original natural landscape elements – meadows, pastures and forests into intensively farmed areas – on the runoff process is well described in literature. From the viewpoint of extreme rainfall-runoff events, it manifests mainly by a loss of retention capacity of soil and of agricultural territory as a whole. Differences in retention capacity of agricultural land, forests or natural meadows are in orders and during floods they influence the changed capacity of the landscape to transform the runoff wave.

In addition, intensive farming is often accompanied by a large-scale drainage of the territory which, mainly under the form of open drainage systems, influence the acceleration of runoff from the landscape, insufficient usage of soil retention capacity and changes in timing of runoff waves.

4.2 Large-scale drainage of the landscape

Systematic drainage of landscape affects mainly areas with intensive agricultural production where drainage systems are built in view to use the maximum of the territory for crop growing and to maximize the profits from farming.

As far as runoff process is concerned, we differentiate two main forms of drainage, both having a different effect.

The open drainage systems (open drains) have a clearly negative impact on the landscape, as they concentrate the surface runoff and accelerate water runoff from the landscape without using its retention potential. This causes a very steep gradient of the runoff wave, increase of culmination flows on lower reaches, changes in runoff wave timing and a lower transformational effect of the landscape on flood runoff.

On the contrary *the closed drainage systems* (closed drains) have a positive impact on the runoff as they increase water infiltration into soil, thus reduce surface runoff and at the same time form above drains a greater retention space than undrained soil could have formed. It results into a more effective transformation of flood wave, reduction of culmination flow and spacing of flood wave in time. Culmination of runoff from drainage systems occur as a rule later than culmination in recipient, but at the same time it precedes culmination from surface and subsurface runoff from not drained areas. Their mechanism is limited by infiltration capacity of soil and when exceeded, the drainage ceases to have any impact on the runoff.

The positive effect of closed drains is logically the highest during small floods and in initial stages of large floods when a more effective transformation of surface runoff reduces at least partly the culmination flow. During extreme floods when the project capacity of the drainage system is exceeded, the system is menaced by flooding and destruction accompanied by a significant erosion and material damages. The overall impact of drains on runoff during floods is, according to recent findings, sensibly lower than generally expected. Hladný et al.. (1998) indicate than during floods in Moravia in 1997 drainage runoff influenced, according to analysis, culmination only by 2–5 %.

4.2.1 Urbanization and industrialization

Urbanization and industrialization of landscape represent the most intensive form of transformation of original natural structures accompanied by the most radical influencing of the surface runoff process. Urbanized areas have, due to hard surfaces, a practically null retention capacity and, in addition, because of stream and waste systems canalization, they maximally accelerate surface water runoff.

Industrialized areas and mainly areas of surface mining of minerals, bring radical interventions into the hydrographic network. In industrial landscape stream beds are relocated, canalized or even piped, water is transferred from one catchment to another, water resources are intensively drawn and accumulated to different purposes. Denuded areas, where vegetation and original hydrographic network do not exist anymore, entirely lack the capacity to retain water in landscape and, consequently, the flood control is limited to technical protection only. During extreme events, when limits of protection elements are exceeded, there occur enormous damages on property and infrastructure.

4.2.2 Changes in landscape structure

Very important for surface runoff is also the space structure of landscape cover. During the 20th century, large-scale consolidation of agricultural land was going on in the majority of industrialized countries wishing to reach a higher economic efficiency, higher yields and profits.

This process caused disintegration of the mosaic structure of landscape and its transformation into large complexes of fields with crop monocultures. As to the surface runoff, this change has brought a general acceleration of runoff from the landscape because of removal of obstacles and natural retardation belts, initially separating individual plots. At the same time, more room has been given to water erosion and changes in flood waves timing.

4.2.3 Changes in quality of vegetation cover

When considering changes in landscape we must take into consideration also changes in qualitative characteristics of vegetation, mainly of forests. Because of weakening of forests by industrial emission, forests in many places are susceptible to pest attacks and to calamities when forests in large areas are dying out. Although this does not bring changes in functional usage or space structure of landscape cover, the change in vegetation quality affects in a long-time perspective parameters of the basic hydrologic balance of the affected territory.

The impact of changes in functional usage of the territory, in landscape cover structure and in vegetation quality on the runoff process is limited by the overall retention capacity of the landscape. After exceeding the soil infiltration capacity and retention capacities of the territory, the land-use element ceases to play a more important part in the runoff process. The limit, above which this change occurs, depends on physical-geographical conditions of the territory and on the character and intensity of its use, but as a rule it does not exceed the recurrence period of 5 to 10 year rainfall (fig. 3).

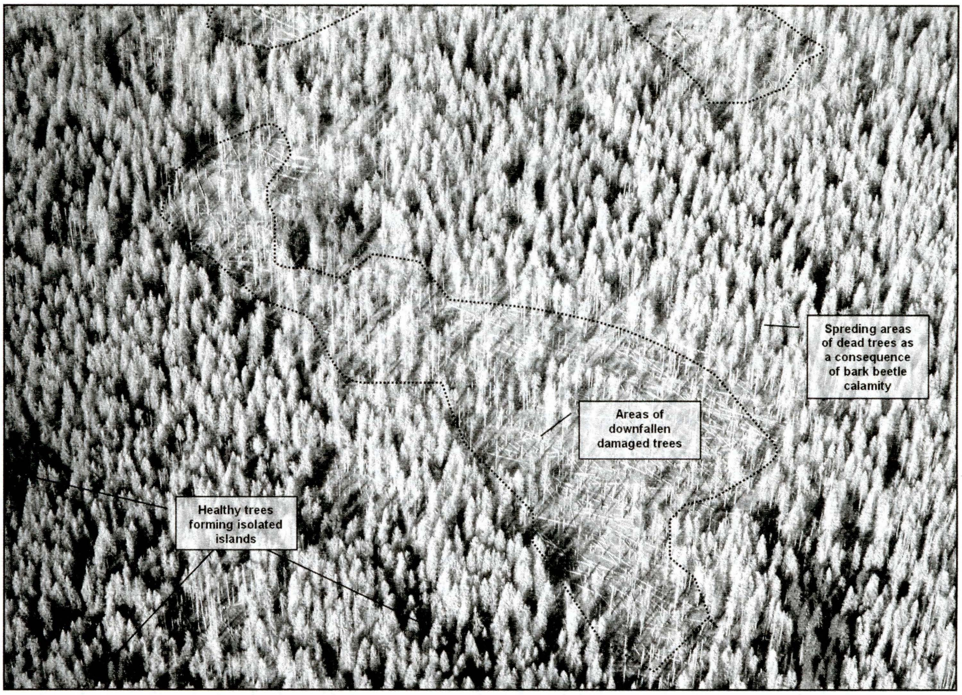

Fig. 3 – Dead forest in the Vydra River headwater area. Loss of natural hydrological function of forest in headwater area may significantly influence the runoff formation process. Photo J. Langhammer (2002).

4.3 River network shortening

Due to intensive land-use during the last 300 years, we assist in cultural landscape to a different intensity of river network shortening. Water streams have been straightened mainly to be used for transport of materials, to drain agricultural areas, to protect town and villages against floods or due to general urbanization and industrialization of the landscape.

Shortening of river network significantly influences water runoff from the landscape, especially during flood events. A shortening of stream length reduces the volume of river network and thus increases the part of the runoff wave volume that has to be deposited without the proper riverbed. A shortening of the stream further leads to an accelerated progression of the flood wave along the flood plain which reduces the possibilities to use its retention potential for transformation of the flood. An increased velocity of flood wave is accompanied by its increased steepness and higher water levels during culmination. At the same time, an accelerated progression of flood wave across the landscape also sensibly shortens the time necessary for preparation of flood control measures, evacuation of population and securing of property against damage.

4.4 Stream bed regulation

Besides shortening of the total length of a water stream also the level of regulation of the riverbed is important for the character of the flood.

Anthropogenous impacts can be differentiated on the level of changes in the riverbed and in changes in the longitudinal profile.

Due to intensive anthropogenous activities, the major part of water stream beds in cultural landscape are nowadays modified to a different degree, the most frequently by deepening of the bed in view to increase its capacity and to safely transport a higher flow through the given territory. Banks and bottom are usually solidified by different building processes going from stone pavements to prefabricated concrete profiles. The extreme form is stream piping, i.e. transfer of a free bed to closed pipes through which water is led generally through industrial zones, town centres and under communications.

Consolidation of banks and bottom by artificial materials leads to a reduction of hydraulic roughness of the bed in its lengthwise profile and thus to a higher velocity of water circulation in the course. During floods it results into a much steeper flood wave, higher water levels during culmination and an increase of its destructive power connected with higher erosional activities.

Especially critical for the character and level of damages caused by a flood is mainly an alteration of *natural and regulated reaches*. Straightened and regulated reaches increase the velocity of the flood wave and bring the water through the landscape more quickly. If a regulated reach is followed by a natural one where the roughness of the bed is naturally higher and the course is not straightened, the flood wave causes higher damages both in river bed and in regulation structures and in property in the flood plain.

An extreme increase of the risk represents during flood the *piped reaches of streams*. Because of a quantity of material transported by the flood, the upper sluice of pipes is quickly flooded, an artificial dam is formed which results to increased erosional and accumulational activities and as a rule also in destruction of the whole structure.

Regulation of streams in the longitudinal profile means presence of riverbed drops, weirs or dams in the riverbed. These structures modify conditions of water circulation in the stream, mainly its velocity, and significantly influence erosional and accumulational activities of the stream. Under normal hydrological conditions, weirs and drops in the bed are important for diversification of circulation in the stream, for slowing down of the runoff from regulated or straightened streams and for amelioration of oxygen conditions in streams as well as for water fauna and flora. During floods however, weirs are an obstacle to streaming and consequently localities of concentrated occurrence of erosional and accumulational manifestations of the flood. Consequences of a flood are multiplied by unsuitably located weir, as in a river bend or at the end of long intensively regulated reaches; on the contrary, near well-sized weirs and especially near the so-called movable weirs, damages are not so extensive.

4.5 Regulation and the character of use of a floodplain

Decisive for the capacity of a landscape to transform the flood wave is the state and character of the flood plain. The flood plain is the lowest situated part of the valley bottom in which water leaves the bed during floods. In this areas natural landscape elements should prevail, especially meadows, pastures and to a lesser degree also forests. These types of landscape cover stand also several day lasting inundation and above all they are able to retain water spilled over in the floodplain and transform the flood wave, i.e. to distribute its course over

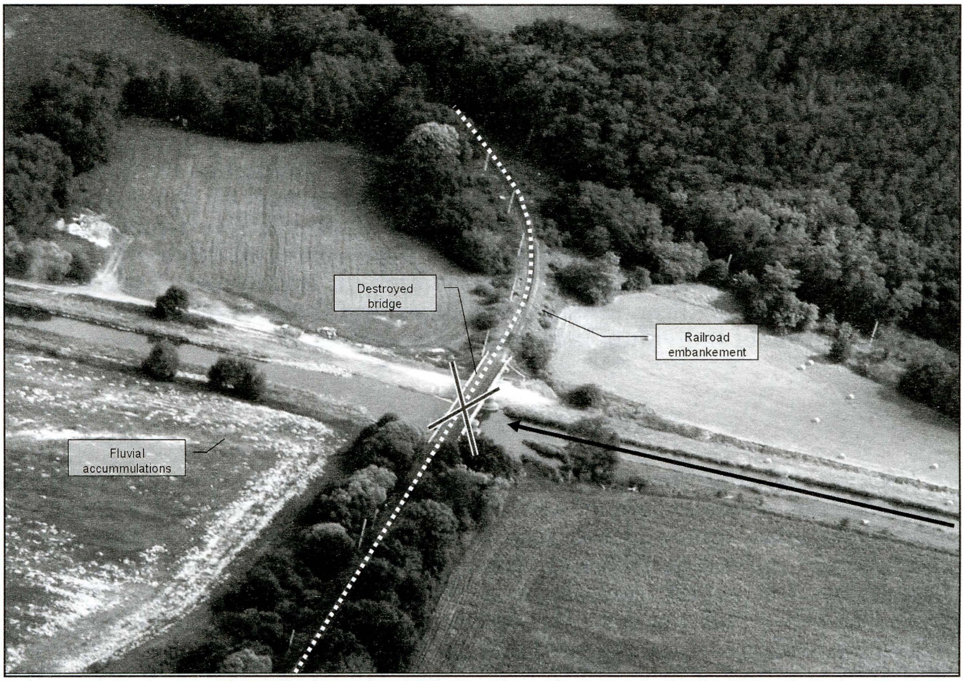

Fig. 4 – Railway bridge and embanment crossing the floodoplain of Blanice river presenting obstacle to the flood course during the flood in August 2002. Photo J. Langhammer (2002).

a longer time period and to reduce thus the culmination water level and flow. In case of its unappropriate use, transformation and retention capacities of a floodplain quickly decrease. This is mainly caused by agricultural areas, when especially arable land does not enable effective water retention in the floodplain and, in addition, it supplies material which is consequently deposited in lower reaches of the course (see Konvička 2002). Presence of agricultural areas and mainly settlements and industrial structures in floodplain causes in addition, because of possible high economic losses, demand for a more intensive modification of stream bed, mainly for an increase of its capacity, consolidation of banks or building of dams, which reduces again transformation and retention capacities of the floodplain and thus also the possibility to really and cheaply lower the flood culmination.

Obstacles to streaming are decisive for the extent of damage during floods, especially during extreme flood events when the whole floodplain is filled by water. They are unsuitably located and sized structures in floodplain as bridges, communication bodies, regulation structures on the stream or ill located buildings. Under normal hydrological conditions and during minor floods, these objects do not cause problems. During extreme events however, as sudden floods and regional floods, the impounded levels are exceeded and these objects constitute obstacles for streaming. The material transported by the flood for instance blocks up arches of bridge structures or culverts under communications; a temporary dam gets formed and then bursts. Thus not only the object itself is destroyed, but it generates a sudden flood wave which in lower reaches of the stream causes much higher damage that it would correspond to the character of the flood (fig. 4).

Theoretical knowledge from literature and practical findings obtained when analysing the extreme flood event in August 2002 in the Otava and Blanice River catchment confirmed that historical changes in landscape use structure, shortening of water streams or the level of current modification of their beds have a crucial impact on the runoff process during flood events. The significance of anthropogenous modifications of the landscape consists mainly in their impact on the water runoff from the landscape, on the shape of the discharge wave and in a reduced possibility of its effective transformation. Possibilities of positive influencing of the flood course by interventions into the landscape structure are nevertheless limited, mainly with regard to the physical geographical conditions of the basin and the character and intensity of modification of individual landscape components.

5. Discussion and conclusions

Because of the rapidity of society development, mainly intensive urbanization, development of technologies, social changes and intensity of anthropogenous interventions into landscape, vulnerability represents an increasingly important factor in assessment of risks connected with natural processes. Vulnerability represents a risk element which can be, differently from the other risk components, at least partly influenced and controlled. While natural processes representing an hazard factor cannot be influenced and accumulation of property in flood areas can be reduced only partly, it is possible to target efforts to reduce vulnerability both of natural environment and social links in a way to minimize consequences of natural elements activities, to increase effectiveness of flood control measures and to reduce damages to the lowest possible level corresponding to the extent of the phenomenon.

When compared to the components of hazard and exposure, the degree of vulnerability of environment cannot be quantified so easily, as it consists from a series of indicators for which standard data, assessment indicators and standards are not available. Shortage of precise information on vulnerability concerns both social systems and natural sphere, more precisely its anthropogenous impacts. To analyse anthropogenous changes in landscape as an indicator of vulnerability within flood risk, it is possible to use methods based on geographical analysis of environment and of its elements, on analysis of historical data, including information technologies (Langhammer 2003; Langhammer, Vajskebr 2003).

The results of research into the impact of natural environment changes on flood risk carried on in the context of assessment of extreme flood events in 1997 and 2002 show clear links between physical-geographical characteristics of the basin and river network, the level of their anthropogenous transformation and their behaviour during extreme runoff events. However, they have not confirmed the hypothesis that the current level of modification of water streambeds, floodplain and landscape is the main cause of the extreme character of large floods registered in Bohemia in 2002 or in Moravia in 1997.

As main causes of anthropogenous changes in the landscape acting as a negative factor during floods, we can give changes in land-use, structure and quality of landscape cover, large-scale drainage of the landscape, shortening of river network, modification of river beds and changes in the character of the floodplain use.

These factors have a different impact on individual components of runoff process during floods and they influence negatively the general course and consequences of floods. Intensive changes in landscape, floodplain and in river bed modification result in an accelerated runoff from the landscape, in an accelerated flow in the stream bed, in a much steeper flood wave, in changes in timing of flood waves from individual parts of the catchment, in a decrease of transformation and retention capacity of the landscape and floodplain and in resulting increase of culminations water levels and flows.

The above manifestations of changes in landscape differ by their effect at different levels of extreme floods, in addition, the individual factors acts differently at different space level of assessment.

References:

ALEXANDER, D. (1993): Natural Disasters. Routledge, London, New York, 632 p.

BARREDO, J. L., LAVALLE, C., de ROO, A. (2005): European flood risk mapping, EC DG JRC – Weather driven natural hazards, IES, Ispra, Italy, 6 p.

BOLT, B. A. et al. (1975): Geological Hazards. Springer Verlag, Berlin, Heidelberg, 328 p.

CRICHTON, D. (1999): The Risk Triangle, in Natural Disaster Management. In: Ingleton, J. (ed.): Tudor Rose, London.

HLADNÝ, J. et al. (1998): Vyhodnocení povodňové situace v červenci 1997. (Assessment of flood situation in July 1997.) Final report. ČHMÚ Praha, 70 p.

HZS (2006): Krizové a havarijní plánování (Crisis and breakdown planning). Hasičský záchranný sbor, Praha, http://www.hzspraha.cz.

KRON, W. (2003): Flood Disasters: causes – losses – prevention from an international reinsure`s viewpoint, in Precautionary Flood Protection in Europe, pp 1–16.

KUKAL, Z. (1982): Přírodní katastrofy (Natural catastrophes). Horizont, Praha, 252 p.

LANGHAMMER, J. (2003): Anthropogenic Transformation of River Network in the Otava River Basin. Acta Universitatis Carolinae–Geographica, XXXVIII, No. 2, pp. 139–156.

LANGHAMMER, J., VAJSKEBR, V. (2003): Historical Shortening of River Network in the Otava River Basin. Acta Universitatis Carolinae–Geographica, XXXVIII, No. 2, pp. 109–124.

MAIDMENT, D. R. ed. (1993): Handbook of Hydrology. Mc-Graw-Hill, New York.

TRIZNA, M. (1998): Identifikácie a hodnotenie povodňovej hrozby a povodňového rizika (Identification and assessment of flood hazard and risk). PrF UK, Bratislava.

VILES, H. A. (2005): Can stone decay be chaotic? Geological Society of America, Special Paper 390, pp. 11–16.

VILÍMEK, V. (2003): Floods in the context of natural hazards and risks. Acta Universitatis Carolinae–Geographica, XXXVIII, No. 2, pp. 5–18.

Shrnutí

SOUČASNÉ PŘÍSTUPY K HODNOCENÍ ANTROPOGENNÍCH ZMĚN V KRAJINĚ JAKO FAKTORU POVODŇOVÉHO RIZIKA

Článek se metodicky zabývá systémovým pohledem na hodnocení rizika ve vztahu k antropogenním změnám v krajině. Analyzovány jsou hlavní přístupy k hodnocení rizika – ekonomický přístup, hodnotící riziko jako funkci pravděpodobnosti výskytu a potenciální ztráty a procesní přístup, hodnotící rizko jako funkci tří složek – ohrožení, expozice a zranitelnosti.

Komplexní efekt antropogenních změn v krajině je hodnocen v kontextu procesního modelu povodňového rizika. Jednotlivé typy antropgenních zásahů do krajiny zde představují faktor zranitelnosti, která zpětně ovlivňuje obě základní složky rizika – ohrožení a expozici. Jednotlivé typy antropogenních zásahů do krajiny, které jsou klíčové z hlediska ovlivnění odtokového procesu jsou analyzovány s ohledem na možné ovlivnění průběhu a následků povodní.

Pro možnost praktické aplikace uvedených principů jsou prezentovány geografické metody, umožňující vyhodnocení aktuálního stavu antropogenních zásahů do krajiny a říční sítě, jejich časoprostorvé dynamiky a možností jejich kvantifikace pro účely vyhodnocení vlivu na průběh a následků povodně. Hlavní metody kvanitifikace a modelování povodňového rizika a jejich limity jsou hodnoceny s ohledem na prostorové měřítko hodnocení.

Antropogenní změny v krajině představují podle procesního přístupu faktor zranitelnosti, který se v souvislosti se socioekonomickým rozvojem společnosti velice dynamicky mění. Zranitelnost prostředí ve vztahu k hodnotám, vystaveným ohrožení, představuje jejich náchylnost ke vzniku škody a rozhoduje o rozsahu škod. Rozsáhlé změny v intenzitě, charakteru a struktuře využití území, ke kterým v kulturní krajině v posledních staletích dochází, působí na změny odtokových poměrů povodí a mohou tak ovlivňovat průběh povodní.

Význam zranitelnosti v kontextu povodňového rizika je proměnlivý v důsledku působení řady činitelů. Mezi klíčové patří extremita jevu, prostorové měřítko hodnoceného území, geografické charakteristiky území a v neposlední řadě celková intenzita a prostorová struktura antropogenních zásahů do povodí a toků.

Vliv antropogenních zásahů do toků, údolní nivy a povodí na průběh a následky povodní je často předmětem diskusí, kdy na jedné straně dochází k jeho bagatelizaci, na straně druhé k nadhodnocování. Je nesporné, že antropogenní zásahy do prostředí povodí vyvolávají odezvu v podobě ovlivnění srážkoodtokového procesu, ovlivnění průběhu povodňové vlny, jejích charakteristik, ovlivnění rozsahu a doby trvání rozlivu. Tato odezva je však odlišná v závislosti na výše uvedených činitelích, zejména na extremitě povodně. Vliv určitých typů modifikací krajiny a údolní nivy jako je např. napřímení a úpravy koryt toků, odvodnění zemědělskýc ploch a změny landuse, je nejvyšší u povodní s nízkou extremitou. Naproti tomu účinek jiných úprav toků a nivy, zejména výskytu překážek proudění, je naopak nejvyšší u extrémních událostí, kdy je do odtoku zapojen celý prostor údolní nivy. Tato zjištění korespondují s výsledky terénního mapování následků povodní, prováděných na územích, zasažených extrémními povodněmi v letech 1997 a 2002.

Zranitelnost v rámci systému přírodních rizik zároveň představuje prvek, který je možné na rozdíl od ostatních komponent rizika cíleně ovlivňovat a řídit. Zatímco přírodní procesy, které představují zdroj ohrožení nelze ovlivnit a akumulaci majetku v záplavových zónách lze snižovat jen obtížně, na snížení zranitelnosti je možné aktivně působit. Zranitelnost je možné ovlivňovat formou konkrétních úprav a zásahů, na úrovni legislativy, formou ekonomických nástrojů či nástrojů územního plánování tak, aby docházelo k minimalizaci následků působení přírodních živlů a omezení rozsahu škod pouze na nezbytnou úroveň, odpovídající extremitě jevu.

Obr. 1 – Hlavní komponenty povodňového rizika. Zleva: ohrožení, riziko, expozice, zranitelnost.

Obr. 2 – Schéma interakcí mezi přírodními a antropogenními procesy v rámci povodňového rizika

Obr. 3 – Mrtvý les v pramenné oblasti povodí Vydry. Ztráta hydrologické funkce lesa může významně ovlivnit odtokový proces. Zleva: zbývající zdravé stromy představující izolované ostrovy, padlé odumřelé stromy, rozšiřující se oblast odumírajících stromů jako důsledek kůrovcové kalamity.

Obr. 4 – Železniční most a násep trati protínající údolní nivu Blanice představující překážku proudění při povodni v srpnu 2002. Zleva: fluviální akumulace, stržený most, násep trati.

(Authors are with Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology, Albertov 6, 128 43 Praha 2, Czechia; e-mail: langhamr@natur.cuni.cz, vilimek@natur.cuni.cz.)

Arrived to the editorial board on August 28, 2006

GEOGRAFIE – SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI
ROK 2006 • ČÍSLO 3 • ROČNÍK 111

JANA CHALUŠOVÁ, JOSEF HLADNÝ, RADEK ČEKAL

REGIONAL DELIMITATION OF THE ELBE RIVER BASIN BASED ON FLOOD SEASONALITY ANALYSIS

J. Chalušová, J. Hladný, R. Čekal: *Regional delimitation of the Elbe River basin based on flood seasonality analysis.* – Geografie–Sborník ČGS, 111, 3, pp. 247–259 (2006). – The study presents approaches that can be used for assessing flood seasonality in the Czech part of the Elbe River basin. For each of the selected gauging stations, a graphic-numerical method based on flood cumulative frequency curves was applied for identification of intervals, during which the probability of seasonal flood occurrence was high. The results were used for classification of the individual catchments into seven regions specific in terms of the flood seasonality.
KEY WORDS: floods – seasonality – region delimitation.

The presented research was funded by the Research Plan MSM 0021620831 "Geographical Systems and Risk Processes in Context of Global Changes and European Integration" of the Czech Ministry of Education and Research Project VaV-SM/2/57/05 "Long-term changes of river ecosystems in floodplains affected by extreme floods" of the Ministry of Environment of the Czech Republic which is fully appreciated by the authors.

1. Introduction

The knowledge of region delimitations according to seasonality occurrence of maximum flows has a particular importance for flood protection and identification of the flood risks in specific catchments, identification of flood mechanisms, development of frequency analysis for derivation of design floods, water management in reservoirs, and for improving general knowledge of flood regime in the landscape. Regional analysis is also frequently used for improvement of estimates of occurrence probability of extreme flood flows in localities where the flood observations are short compared to the estimated return periods of floods or in ungauged localities where the information from the similar observed catchments is used (Black, Werritty 1997; Burn 1997).

For the purpose of this study, the region is understood as aggregation of small catchments with a similar character of flow regime. The delimitation of the regions is based on approximate similarity of the characteristics inside individual regions and on differences in characteristics among the regions. The objective of this approach is to identify a group of catchments, which are sufficiently similar for ensuring the transfer of information on extreme flows across all localities grouped in the same region. Concerning the extreme flows, such defined entities should be at least quasi-homogenous.

As a measure of similarity of the different catchments, a characteristic of flood occurrence seasonality was chosen. Individual outputs of the seasonal analysis permit us to divide the relevant area of river basin, into the regions

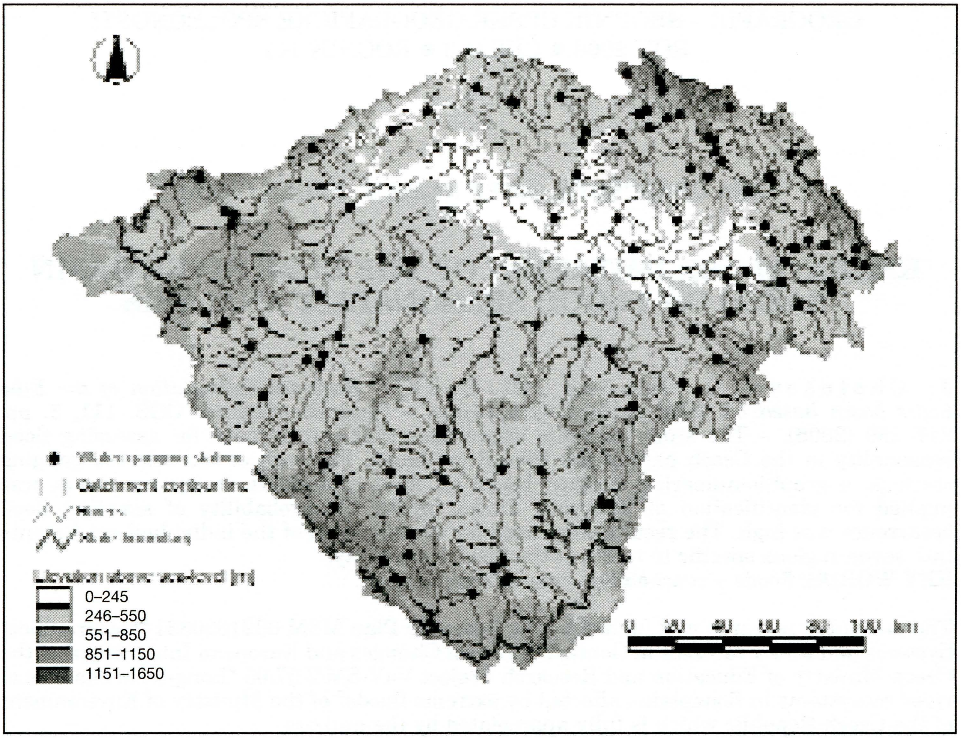

Fig. 1 – Selected stations in Czech Elbe River basin

with natural conditions predetermining the increased frequency of flood occurrence in the specific season of the year.

The research held previously on the observed area shows the differences as well as the similarities of selected catchments (Brádka 1967; Hladný 1971, 2001; Buchtele 1972; Kakos 1983, 1985; Vavruška 1989; Kašpárek 1999). In contrast to the previous studies, this study is not focused on an analysis of seasonal flood characteristics in selected catchments but it identifies hydrologically similar regions on the basis of similarity of seasonal characteristics of extreme flows occurrence. The methods that were used for analysis of seasonal flood occurrence include a polar diagram method, method of directional statistics and method of curves of cumulative frequency of flood occurrence.

The methods were applied for those gauging stations in the Czech part of Elbe River basin, whose flow regime is relatively natural.

2. Collection and selection of data

2.1 Selection of representative gauging stations

The database created for the purpose of this study contains the streamflow data observed by the selected gauging stations. The further criterion besides the natural streamflow regime was sufficient data quality. For this reason the gauging stations with significantly modified flow regime were not included into the database as well as the stations with incomplete or interrupted operating period.

The quality and quantity of available data differ across the regions of Czechia. In the area of the Elbe River basin, 441 gauging stations of state monitoring network were available. In the period from 1975 to 2000, the uninterrupted series of flow data were available in 158 of them. With respect of the above selection criteria and with the aim to cover the entire area, 110 gauging stations were chosen. They include mainly stations on upper stretches on the streams. Catchment areas of these stations are relatively small (Fig. 1).

2.2 Selection of hydrological data

The use of maximum flows in individual months for the purpose of the region delimitation showed that such data could be insufficient because this approach does not take into account possible occurrence of two or more floods in the same month. For example, the two floods in July 1997 would be interpreted like a single event.

The study of the seasonal flood occurrence was therefore based on mean daily flow series available from the database of the Czech Hydrometeorological Institute (CHMI). Flow series of daily maxima, which would be more suitable for description of the flow regime, were not available. For each of the selected 110 gauging stations, the data from the period 1975–2000 were used.

2.3 Selection of physic-geographical data

For the catchments corresponding to the selected gauging stations, a database of the following parameters was prepared:

- catchment area
- mean catchment slope
- mean catchment altitude
- percentage of forested area
- thalweg length
- index of catchment shape
- slope orientation.

For catchment areas and thalweg lengths, data from CHMI were used. Mean catchment altitudes, mean catchment slopes and slope orientations were calculated in a Geographical Information System (GIS) by using a Digital Elevation Model with grid cell dimension of 100 m x 100 m.

2.4 Selection of meteorological data

The study applied meteorological data from rain gauging and climate stations of CHMI, involving snow cover height related to 15th March of the individual years (for estimation of snow storage before spring melting period) and annual precipitation series. All stations operating in the given reference period in the Elbe River basin on the Czech territory were used.

The mean precipitation totals over the catchments were calculated in GIS by using a method of orographic interpolation of precipitation (Šercl and Lett 2002), which was applied for precipitation data in the individual stations. The resulting system of grid cells (1 km x 1 km) represents derived continual precipitation field for every year. Mean precipitation for the reference period 1975–2000 was calculated by averaging of precipitation fields in individual years.

This method was also applied for calculation of the mean height of the snow cover in March.

3. Methods for analysis of seasonal flood occurrence

The approach chosen to describe the spatial differences in seasonal flood occurrence in the Czech part of the Elbe River basin (covering an area of 51,394 km^2) uses daily data and permits more accurate identification of the season period when probability of flood occurrence is high. The seasonal analysis was applied all gauging stations, whose data illustrate flow regime of the selected catchments.

Peaks over threshold (POT) method was used for analysis of flood flows which exceed the chosen threshold Q_B.

The method is defined by the expression (Todorovic and Zelenhasic 1970), where:

$$\xi_v = \begin{cases} 0 & ; Q_i \leq Q_B \\ Q_i - Q_B & ; Q_i > Q_B \end{cases} \tag{1}$$

Q_B is the threshold flow,
Q_v is a flow in time $\tau(v)$, and
ζ is the flow above the threshold in time $\tau(v)$.

For effective interpretation of seasonal information in the database, the chosen statistical method must be as accurate as possible. The paper shows results of a comparison of three mentioned methods that are applied for visualisation of seasonal distribution of flood occurrence. Each of the methods uses series of floods that exceed given threshold. The value of 1 year discharge was used as appropriate limit for this purpose.

3.1 Method of polar diagrams

The method of polar diagrams is based on graphical analysis of a rose diagram, whose radial vectors with angle unit of 30° represent individual months of a year and are used for illustrating monthly occurrence frequencies or values of considered variable.

The rose diagrams were prepared for each of the gauging stations and the selected reference period. The lines that connect the individual values on the vectors form a polygon, which shows the seasonal distribution of the analysed variable and is typical for the specific station. If the frequencies of the occurrence could be uniform during the year, the shape of the diagram would form a regular dodecagon. However, the real distribution of a natural phenomenon is mostly typical by its irregularity. The values on the polar coordinates are more or less deviated for some periods of a year. Some periods are typical by the occurrence of extremes or remarkable deviation of the mean, while other periods show low probability of the flood occurrence (Fig. 2).

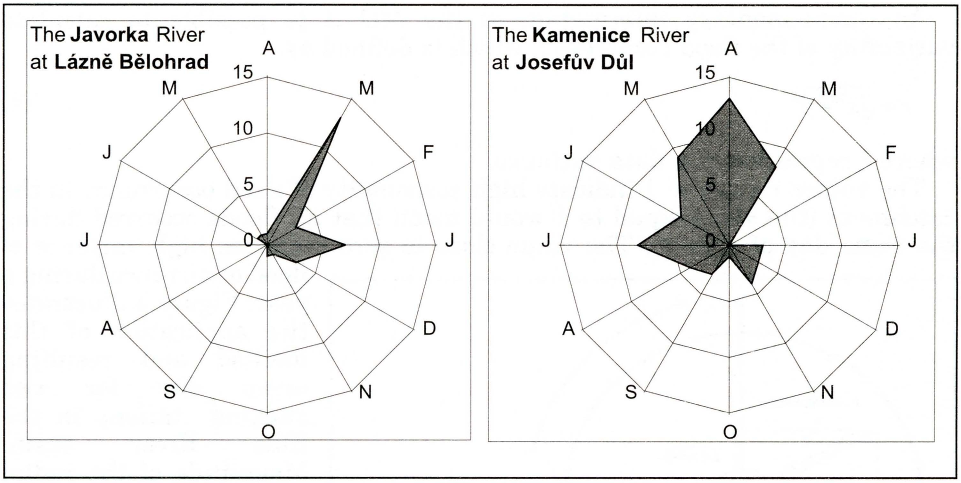

Fig. 2 – The method of polar diagrams used for analysis of flood occurrence at gauging stations Lázně Bělohrad on the Javorka River and Josefův Důl on the Kamenice River in the period 1975–2000.

The polar diagram method has good information capability and they can easily be constructed. Low accuracy of derivation of maximum flow mean occurrence is its disadvantage.

3.2 Method of directional statistics

In this method, the dates of occurrence of the flood events are converted by using a polar coordinate system into relevant positions (angles) on a unite circle. In accordance with the mathematical convention, the beginning of the year (January 1st) is placed onto the most eastern point of the circle and individual seasons of the year form quadrants in anticlockwise direction (Mardia 1972; Bayliss, Jones 1993; Fisher 1993). The Julian date of the flood occurrence i is converted into

$$\phi_i = JD_i\left(\frac{2\pi}{365}\right) \tag{2}$$

where ϕ_i is an angle value (in radians) of the date of the occurrence of the flood event i.

JD is Julian date.

Each date of flood occurrence can be interpreted as a vector (Fig. 3) given by angle ϕ_i and magnitude m, which represents the peak flow of the corresponding flood (m = 1 for maximum flood in selected gauging station). For series of n floods, we can calculate coordinates $\bar{x}$ and $\bar{y}$ of mean date of flood occurrence MD (Mean Day) in the selected gauging station as follows:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n}\cos(\phi_i) \qquad \bar{y} = \frac{1}{n}\sum_{i=1}^{n}\sin(\phi_i) \tag{3}$$

where $\bar{x}$ and $\bar{y}$ represent x and y coordinates of the mean date of flood occurrence in given catchment.

As complementary information to the *MD* it is possible to calculate variability of the flood occurrence, which is defined as:

$$r = \sqrt{\bar{x}^2 + \bar{y}^2} \tag{4}$$

where r represents the data variance.

The values r close to 1 indicate high seasonality of flood occurrence in the catchment (the value equal to 1 would mean that all floods occurred during the same day of a year). The value close to zero indicates high variance of flood occurrence during a year. Figure 4 illustrates the application of this method and resulting mean day for two gauging stations in the Elbe River basin. Magnitude of the radial vector determines the variance r.

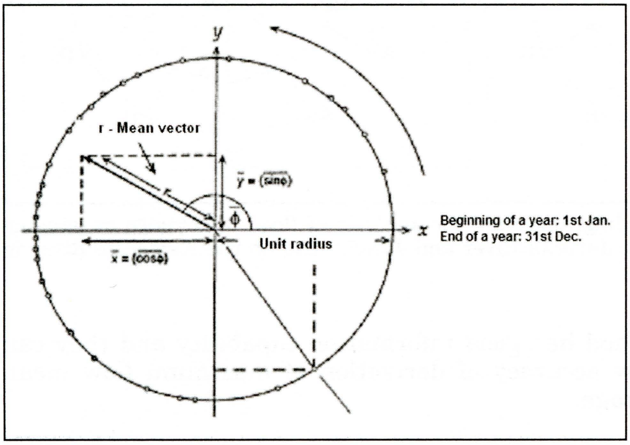

Fig. 3 – Application of the method of directional statistics for flood flow series (according to Black, Werritty 1997)

The use of the method of directional statistics has two main advantages. First, it permits to express the information on seasonality occurrence of flood flows by a single value and, second, it permits to classify the studied localities by the mean date of maximum flow occurrence with accuracy of one day. Disadvantage of this method is in the error of the averaging because identical values of the mean can be obtained from different distributions of the data series.

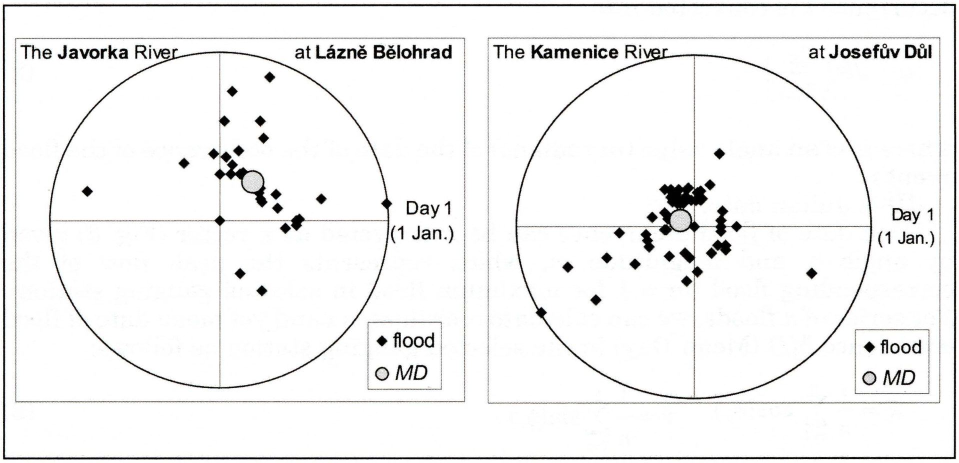

Fig. 4 – Method of directional statistics used for analysis of flood occurrence at gauging stations Lázně Bělohrad on the Javorka River and Josefův Důl on the Kamenice River

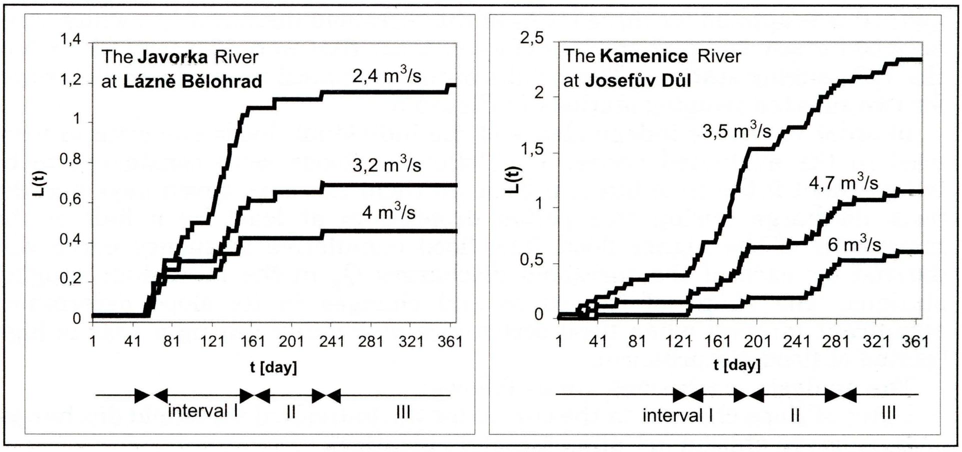

Fig. 5 – Method of flood cumulative frequency curves used for analysis of flood occurrence at gauging stations Lázně Bělohrad on the Javorka River and Josefův Důl on the Kamenice River in the period 1975–2000

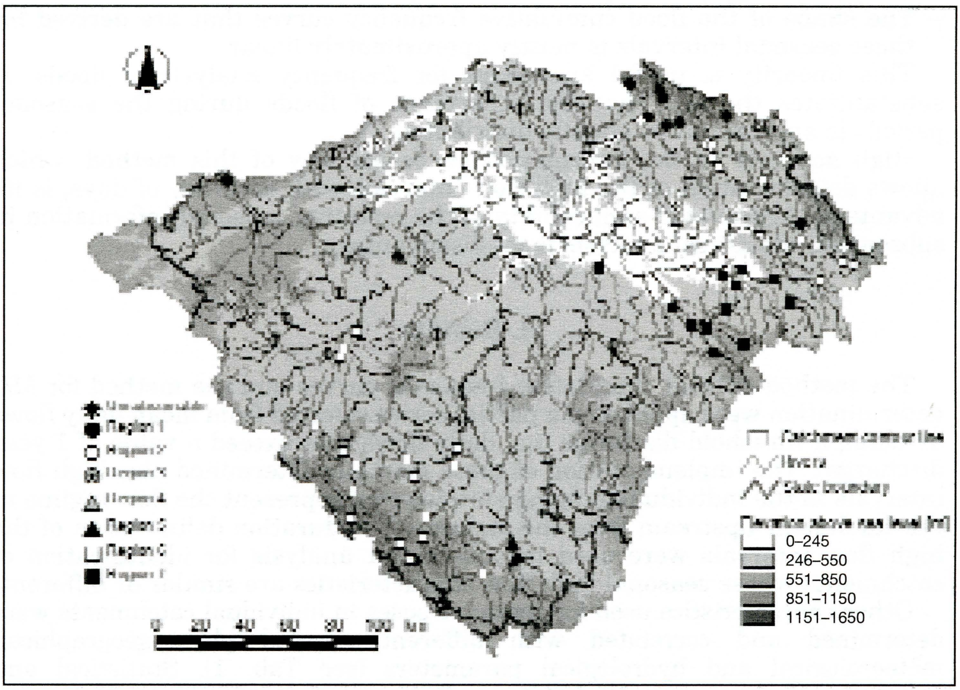

Fig. 6 – Map of derived regions according to seasonality of the flood occurrence

3.3 Method of flood cumulative frequency curves

The method is based on visualisation of mean numbers of floods *L(t)* that exceeded given discharge Q_B in time *t*. The values of variable *t* range in time interval (0,T), which is relevant to a period of one year (Ouarda 1993). The method was applied for three levels of the threshold discharge Q_B, which were derived for selected probabilities of exceedance that were identical for each of the 110 gauging stations. The results of this graphical method are illustrated for two selected gauging stations in Figure 5.

In order to ensure independence of the individual floods two criteria were used in the evaluated series. Two following floods were considered to be independent if the time interval between them exceeded seven days and the peak discharge during this period dropped to at least by a half of the magnitude of the higher flood. The flood cumulative frequency curve was derived for each of the threshold discharges Q_B in the individual gauging stations. The shape of the curve and changes in its slope determined significant interval when flood occurrence probability during a year is high (period of flood disturbance).

The analysis conclusions are as follows:

- Dates of slope changes in the curves for the individual threshold discharges Q_B in given station are approximately identical.
- The slope changes divide a year into three intervals, whose durations are different and which differ also in flow magnitude (I – interval when probability of flood occurrence is high, II – transitional interval and III – interval when probability of flood occurrence is low).
- The shape of the flood cumulative frequency curves that are derived for these seasonal intervals is mostly approximately linear.

This linearity is useful knowledge for frequency analysis of floods. It substantiates the fact that the occurrence of floods during the seasonal periods is approximately equally distributed.

High accuracy of the information on seasonality of this method, which allows determination of the high flow intervals with accuracy of days, is its advantage. Aggravated applicability of the resulting seasonal information in subsequent statistical analysis is its disadvantage.

4. Results

The method of flood cumulative frequency curves and the method for *MD* determination were applied on a partial series selected from mean daily flows by using a threshold discharge (i.e. daily flows that exceed a value of 1 year discharge). The implementation of these methods determined also high flow intervals in the individual gauging stations that represent the flow regime in the catchment upstream from the stations. The duration delimitation of the high flow intervals were used in subsequent analysis for identification of catchments whose seasonal high flow characteristics are similar or different.

Other characteristics used for these purposes in individual catchments were determined and correlated with different selected physic-geographical, meteorological and hydrological parameters (see Tab. 1). Statistical and correlation analyses prove that *MD* as well as scatterings of flooding occurrences *r* show higher correlations in connection to the end of flood disturbance (period with higher probability of floods) than to its beginning. This reflects the properties of flood wave falling branches which correspond with basic hydraulic law defining depletion of water storage from catchments. The rising branches show greater differences between courses of summer and winter flood waves. It is also important if and how often the winter flood types are accompanied with occurrence of summer floods or if both types of floods exist in the catchments.

Tab. 1 – Correlation matrix of seasonal characteristics and physic-geographical data

FAKTOR	MD	r	PO	KO	SR	NV	SK	PL	PU	SN1	SN15	TER	TEB	L	α	ME	OR	LO	LE	S	J	V	Z
MD	**1,00**	-0,42	0,29	**0,54**	0,34	**0,56**	0,17	-0,04	0,45	0,44	0,47	-0,44	-0,39	-0,11	0,39	-0,24	-0,39	0,28	0,40	0,33	-0,31	0,14	-0,11
r	-0,42	**1,00**	-0,04	**-0,57**	-0,04	-0,17	0,05	-0,10	-0,25	-0,05	-0,08	0,09	0,06	-0,14	0,05	0,11	0,12	-0,08	-0,18	-0,36	0,36	-0,01	0,05
PO	0,29	-0,04	**1,00**	0,26	**0,55**	0,40	0,49	-0,15	0,33	**0,53**	**0,56**	-0,27	-0,43	-0,17	0,09	-0,21	-0,35	0,03	0,26	-0,13	0,18	-0,16	0,24
KO	**0,54**	**-0,57**	0,26	**1,00**	0,09	0,28	0,00	-0,06	0,21	0,14	0,17	-0,12	-0,08	-0,01	0,09	-0,17	-0,08	0,20	0,16	**0,57**	**-0,54**	0,06	-0,05
SR	0,34	-0,04	**0,55**	0,09	**1,00**	**0,73**	**0,79**	-0,24	**0,51**	**0,96**	**0,94**	**-0,68**	**-0,84**	-0,28	0,23	-0,35	**-0,66**	0,18	**0,57**	-0,30	0,38	-0,24	0,37
NV	**0,56**	-0,17	0,40	0,28	**0,73**	**1,00**	**0,57**	-0,16	**0,80**	**0,79**	**0,79**	**-0,86**	**-0,80**	-0,22	0,31	**-0,50**	**-0,78**	**0,59**	**0,68**	0,03	0,05	0,14	-0,03
SK	0,17	0,05	0,49	0,00	**0,79**	**0,57**	**1,00**	-0,22	0,23	**0,76**	**0,76**	**-0,50**	**-0,62**	-0,24	0,06	-0,20	**-0,60**	0,25	0,46	-0,36	0,48	-0,03	0,24
PL	-0,04	-0,10	-0,15	-0,06	-0,24	-0,16	-0,22	**1,00**	-0,09	-0,23	-0,21	0,20	0,25	**0,89**	-0,24	0,11	0,19	-0,04	-0,26	0,08	-0,12	0,43	-0,49
PU	0,45	-0,25	0,33	0,21	**0,51**	**0,80**	0,23	-0,09	**1,00**	**0,52**	**0,53**	**-0,71**	**-0,65**	-0,09	0,16	-0,42	**-0,56**	0,47	0,47	0,16	-0,15	0,11	-0,09
SN1	0,44	-0,05	**0,53**	0,14	**0,96**	**0,79**	**0,76**	-0,23	**0,52**	**1,00**	**0,99**	**-0,72**	**-0,85**	-0,29	0,35	-0,32	**-0,71**	0,22	**0,63**	-0,26	0,34	-0,13	0,26
SN15	0,47	-0,08	**0,56**	0,17	**0,94**	**0,79**	**0,76**	-0,21	**0,53**	**0,99**	**1,00**	**-0,70**	**-0,83**	-0,28	0,37	-0,31	**-0,70**	0,21	**0,63**	-0,24	0,31	-0,12	0,24
TER	-0,44	0,09	-0,27	-0,12	**-0,68**	**-0,86**	**-0,50**	0,20	**-0,71**	**-0,72**	**-0,70**	**1,00**	**0,91**	0,24	-0,30	0,41	**0,68**	-0,45	**-0,60**	-0,02	-0,04	-0,08	-0,02
TEB	-0,39	0,06	-0,43	-0,08	**-0,84**	**-0,80**	**-0,62**	0,25	**-0,65**	**-0,85**	**-0,83**	**0,91**	**1,00**	0,28	-0,29	0,33	**0,69**	-0,29	**-0,59**	0,11	-0,18	0,12	-0,23
L	-0,11	-0,14	-0,17	-0,01	-0,28	-0,22	-0,24	**0,89**	-0,09	-0,29	-0,28	0,24	0,28	**1,00**	**-0,50**	0,11	0,28	-0,06	-0,35	0,08	-0,12	0,43	-0,49
α	0,39	0,05	0,09	0,09	0,23	0,31	0,06	-0,24	0,16	0,35	0,37	-0,30	-0,29	**-0,50**	**1,00**	-0,12	-0,27	0,09	0,42	0,01	-0,04	0,08	-0,12
ME	-0,24	0,11	-0,21	-0,17	-0,35	**-0,50**	-0,20	0,11	-0,42	-0,32	-0,31	0,41	0,33	0,11	-0,12	**1,00**	0,23	-0,30	-0,36	-0,13	0,09	0,01	-0,07
OR	-0,39	0,12	-0,35	-0,08	**-0,66**	**-0,78**	**-0,60**	0,19	**-0,56**	**-0,71**	**-0,70**	**0,68**	**0,69**	0,28	-0,27	0,23	**1,00**	**-0,55**	**-0,85**	0,24	-0,32	-0,11	-0,03
LO	0,28	-0,08	0,03	0,20	0,18	**0,59**	0,25	-0,04	0,47	0,22	0,21	-0,45	-0,29	-0,06	0,09	-0,30	**-0,55**	**1,00**	0,41	0,11	-0,07	0,31	-0,26
LE	0,40	-0,18	0,26	0,16	**0,57**	**0,68**	0,46	-0,26	0,47	**0,63**	**0,63**	**-0,60**	**-0,59**	-0,35	0,42	-0,36	**-0,85**	0,41	**1,00**	-0,20	0,28	0,11	0,02
S	0,33	-0,36	-0,13	**0,57**	-0,30	0,03	-0,36	0,08	0,16	-0,26	-0,24	-0,02	0,11	0,08	0,01	-0,13	0,24	0,11	-0,20	**1,00**	**-0,97**	0,28	-0,32
J	-0,31	0,36	0,18	**-0,54**	0,38	0,05	0,48	-0,12	-0,15	0,34	0,31	-0,04	-0,18	-0,12	-0,04	0,08	-0,32	-0,07	0,28	**-0,97**	**1,00**	-0,22	0,34
V	0,14	-0,01	-0,16	0,05	-0,24	0,14	-0,03	0,43	0,11	-0,13	-0,12	-0,08	0,12	0,43	0,08	0,01	-0,11	0,31	0,11	0,28	-0,22	**1,00**	**-0,94**
Z	-0,11	0,05	0,24	-0,05	0,37	-0,03	0,24	-0,49	-0,09	0,26	0,24	-0,02	-0,23	-0,49	-0,12	-0,07	-0,03	-0,26	0,02	-0,32	0,34	**-0,94**	**1,00**

MD – mean day, **r**-scatter, **PO** – beginning of flood disturbance, **KO** – end of flood disturbance, **SR** – annual precipitation, **NV** – altitude, **SK** – inclination, **PL** – catchment area, **PU** – soil types, **SN1** – snow cover 1st March, **SN15** – snow cover 15th March, **TER** – mean annual temperature, **TEB** – mean March temperature, **L** – thalweg lenght, α – catchment shape index, **ME** – urban land, **OR** – arable land, **LO** – meadows, **LE** – woods, **S** – northern orient. slope, **J** – southern orient. slope, **V** – eastern orient. slope, **Z** – western orient. slope.

Evaluated physic-geographical factors prove that *MD* is influenced by the altitude first of all. A distinct correlation is proved also to the snow cover height at the 15th March which is the decisive datum for estimation of snow storage in catchments before the spring melting. The altitude is significant even for extent of forests.

A tight direct proportional correlation of flood period ends was proved for catchments with north oriented slopes (and an indirect proportionality for south oriented slopes). The higher ratio of northern oriented slopes the later is the end of periods with higher probability of flood occurrence. This phenomenon can be explained with the longer period of snow melting.

Based on analyses of mutual relations between tested parameters the following factors were determined as the most significant: *MD*, the beginning and the end of seasonal periods of flood disturbances, mean annual precipitation height and mean annual temperature, snow cover height to the 15th March, altitude, inclination of slopes and forest extent rate. The influence of other factors is already incorporated in major factors or it is less significant.

The selected catchments were divided into seven regions based on similarity of major factors and on the application of cluster analysis in the GIS environment. Geographical division of regions illustrates Figure 6. Individual regions can be considered as hydrologically homogeneous as to seasonality of flood occurrence.

The first region (north-eastern mountain ranges) includes 8 gauging stations, the second one (north-eastern foothills) 13, the third (uplands) 48, the fourth ("precipitation shadow" bellow the Krušné Mountains) 9, the fifth (areas affected with the Novohradské Mountains) 3, the sixth (the Šumava Mountains and the Otava River areas) 18 and the seventh one (areas affected with the Žďárské Mountains) 13 stations in question.

Other catchments, being without observation system, having influenced flow regime or laying in peripheral areas with unavailable flow data, were analysed with help of altitudes and distribution of average annual precipitation totals.

Conclusion

(1) A number of methods have been developed for assessing seasonality of flood regime in given region. With respect to various causal factors affecting flood occurrence, none of them however can universally be used as the best method. For the purposes of the objective of the study, which was to derive spatial patterns of seasonal distribution of flood flows, three methods were compared.

Polar diagrams provide good information, they are easily derivable but they are less accurate in terms of the results of statistical analysis. High transparency and reliability are advantages of the method of directional statistics, which determines a season of a year when the extreme flows are frequent. In addition, this approach can provide information on distribution of flood magnitudes of the individual events. The illustrated variability of the floods is also valuable information for assessments of the flood risks. On the other hand, its disadvantage is in the fact that the information on seasonal flood distribution that is concentrated into the averaged value can be insufficiently representative.

It was shown that the method based on flood cumulative frequency curves is relatively the most effective approach for derivation of suitable division of a year into three periods, which differ in terms of the high flow occurrence. Its advantage is in reliable detection of the beginning, end and duration of the probable high flow frequency interval, which is the most substantial information for the seasonal analysis.

(2) With respect to the objective of the study, which was to derive spatial patterns of seasonal distribution of flood flows, the method based on flood cumulative frequency curves provided the best results and was therefore applied. The results of the application of this method were used for the, region delimitation according to the flood flow seasonality in the Elbe River basin.

Majority of the detected high flow season interval showed good their correlation between onset, mean catchment altitude and long-term basin precipitation.

In terms of the similarity of the identified high flow periods, the individual water gauging stations and their basins were divided into seven hydrologically homogeneous regions.

References:

BAYLISS, A. C., JONES, R. C. (1993): Peaks over threshold flood database: Summary statistics and seasonality. Report No. 121. Institute of Hydrology, Wallingford, UK. 61 p.

BLACK, A. R., WERRITTY, A. (1997): Seasonality of flooding: a case study of North Britain. Journal of Hydrology, 195, pp. 1–25.

BRÁDKA, J. (1967): Meteorologické příčiny povodní ve Slezku (Meteorological causal factors of floods in Silesia). Meteorologiké zprávy, 20, ČHMÚ, Praha.

BUCHTELE, J. (1972): Kategorizace povodňového režimu na tocích vltavské kaskády (Categorisation of flood regimes on the rivers discharging into the Vltava Cascade of Reservoirs). Sborník prací HMÚ, 18, Praha.

BURN, D. H., ZRINJI, Z., KOWALCHUK, M. (1997): Regionalization of Catchments for Regional Flood Frequency Analysis. Journal of Hydrologic Engineering, pp. 76–82.

FISHER, N. I. (1993): Statistical Analysis of Circular Data. Cambridge University Press, Cambridge, UK.

HLADNÝ, J. (1971): K rajonizaci povodňových situací na území ČSR pro potřeby povodňové služby (To regionalisation of flood events on the territory of the Czech Republic for the purposes of the Flood Forecasting Service). Proceedings of papers of Hydrological Conference in Brno, Studia Geographica, 22, GÚ ČSAV, Brno.

HLADNÝ, J., CHALUŠOVÁ, J., VLASÁK, T. (2001): Hydrosynoptické přístupy k identifikaci povodňového mechanismu (Hydro-synoptic approaches to identification of flood development mechanisms). Acta Universitates Carolinae–Geographica, XXXVI, No. 2, UK v Praze, Praha.

KAKOS, V. (1983): Hydrometeorologický rozbor povodní na Vltavě v Praze za období 1873–1982 (Hydrometeorological analysis of floods on the Vltava River in Prague in 1873–1982). Meteorologické zprávy, 36, No. 6, ČHMÚ, Praha, pp. 171–181.

KAKOS, V. (1985): Hydrometeorologická analýza povodňových situací v povodí Labe (Hydrometeorological analysis of floods in the Elbe River basin). Meteorologické zprávy, 38, No. 5, ČHMÚ, Praha, pp. 148–151.

KAŠPÁREK, L. a kol. (1999): Hodnocení modelování srážko–odtokových vlastností povodí (Assessment of modelling of rainfall-runoff attributes of catchments). VÚV T.G.M., Praha, 47 p.

MARDIA, K. V. (1972): Statistics of Directional Data. Academia Press, London, 38 p.

OUARDA, T. B. M. J., ASHKAR, F., EL-JABI, N. (1993): Peaks Over Threshold Model for Seasonal Flood Variations. Engineering Hydrology, USA, pp. 341–346.

ŠERCL, P., LETT, P. (2002): Výpočet rastru srážek v prostředí GIS s využitím ArcView Spatial Analyst (Calculation of precipitation grid using GIS and ArcView Spatial Analyst). User guide, version 2.0.1, ČHMÚ, OPV, Prague.

TODOROVIC, P., ZELENHASIC, E. (1970): A stochastic model for flood analysis. Water Resources Research, 6, No. 6, pp. 1641–1648.

VAVRUŠKA, F. (1989): Meteorologické příčiny povodní na Otavě a Lužnici (Meteorological causal factors of floods on the Otava and Lužnice Rivers). Meteorologické zprávy, 42. ČHMÚ, Praha, pp. 111–115.

Shrnutí

REGIONALIZACE POVODÍ LABE NA ZÁKLADĚ SEZONÁLNÍ ANALÝZY VÝSKYTU POVODNÍ

Poznatky o sezonalitě výskytu maximálních průtoků jsou jedním z důležitých podkladů především pro rajonizaci krajiny z hlediska jejího zatížení povodňovým nebezpečím. Region se v těchto souvislostech chápe jako seskupení menších povodí, která mohou být považována za podobná z hlediska zvolených charakteristik odtokové odezvy. Vyhledání takového kvazi-homogenního shluku povodí z hlediska výskytu kulminace průtokových vln bylo prováděno na základě korelační a shlukové analýzy příčinných klimatických, fyzicko-geografických a hydrologických faktorů v povodí českého Labe. Potřebné datové soubory byly odvozeny pro 110 vybraných vodoměrných stanic na menších povodích, které splňovaly podmínku neovlivněného anebo jen málo ovlivněného průtokového režimu (viz obr. 1). Rovněž nebyly zahrnuty stanice s přerušenou nebo neúplnou řadou měření v uvažováním referenčním období let 1975–2000. Základním problémem bylo určení spolehlivých reprezentativních sezonálních charakteristik.

Pro vyjádření charakteristik sezonality výskytu povodní existuje řada metod. V závislosti na různých příčinných vlivech působících při vzniku povodně však neexistuje žádná univerzálně nejlepší. Vzhledem ke stanovenému cíli, vyjádřit prostorové rozdíly sezonálního rozložení extrémních průtokům, byly porovnávány tři metody. U všech se pracuje s řadami průměrných denních průtoků nad hodnotou 1letého průtoku v souladu s obecnou definicí podle výrazu (1).

Metoda polárních grafů je založena na grafické analýze růžicového grafu, kde průvodiče odstupňované vždy po 30° představují jednotlivé měsíce roku a jsou na nich vyneseny četnosti výskytu povodní v příslušném měsíci (viz obr. 2). Polární růžicové grafy mají dobrou vypovídací schopnost a jsou snadno sestrojitelné. Z hlediska statistického zpracování jsou však méně přesné.

Druhá metoda směrových statistik převádí datum výskytu kulminace povodní rovněž do polárního souřadnicového systému určením příslušné polohy v jednotkové kružnice. Úhlový převod ϕ_i se uskutečňuje podle vzorce (2) a velikost kulminačního průtoku m je reprezentována jeho relativním podílem na hodnotě kulminace největší povodně ve sledovaném profilu, přičemž ta je rovna 1 (viz obr. 3). Pro soubor povodní (viz obr. 4) v daném referenčním období se určuje souřadnice průměrného dne výskytu povodní *MD* (Mean Day) podle rovnice (3) a rozptyl výskytu povodňových případů r podle rovnice (4). Přínosem metody směrových charakteristik je získání detailnějších informací o sezonalitě povodní a tím i větší spolehlivost, se kterou je vymezena část roku se zvýšeným výskytem extrémních průtoků. Navíc tento přístup umožňuje získat informace o sezonálním rozložení velikosti jednotlivých maximálních průtoků. Znázorněný rozptyl je proto cennou informací pro hodnocení zatížení povodí povodňovým nebezpečím. Naopak nevýhodou může být zatížení sezonálních informací známým nedostatkem průměrování, tzn., že téhož průměru lze dosáhnout z velmi rozdílného rozložení hodnot vstupních veličin.

Proto byla udržována ještě jako třetí metoda čar kumulativních četností výskytu povodní. Čára se sestrojuje pro danou stanici postupným součtem kulminací (nad určitou prahovou hodnotou průtoku), které byly zjištěny v jednotlivých dnech každého roku v uvažovaném referenčním období. Průběh čáry (časový počátek a konec výrazné změny sklonu čáry viz interval I v obr. 5, interval ustálené tendence – II a interval přechodový – III) vymezují signifikantní období se zvýšenou pravděpodobností rozvodnění (období povodňového neklidu) v každém uvažovaném období. Bylo ověřeno, že volba různé prahové hodnoty průtoku nemá vliv na určení počátku a konce povodňového neklidu, protože změna sklonu čáry kumulativních četností výskytu povodní nastává i při rozdílných mezních průtocích ve stejném dni. Spolehlivost určení délky trvání povodňového neklidu, což u sezonální analýzy stěžejní informace, je hlavní předností této metody.

Jako další charakteristiky pro tyto účely byly pro každé vybrané povodí určeny a korelovány mezi sebou určené fyzicko-geografické, meteorologické a hydrologické parametry, viz tabulka 1. Statistická a korelační analýza prokázala, že *MD* stejně jako rozptyl výskytu povodní vykazují vyšší korelaci ve vztahu ke konci povodňového neklidu než ve vztahu

k jeho počátku. Je to dáno větší podobností poklesových větví průtokových vln, které se řídí jednotným hydraulickým zákonem pro vyčerpávání zásob vody v povodí. U vzestupných větví se odráží větší rozdíly mezi průběhem letních a zimních průtokových vln. Rozhoduje také zda a jak často jsou rozvodnění zimního typu doprovázeny letními výskyty povodní neboli zda v povodí existuje dvojí povodňový režim.

Z hlediska zkoumaných fyzicko-geografických faktorů je *MD* nejvíce ovlivněn nadmořskou výškou povodí. Zřetelnou korelaci vykazuje i výška sněhu k 15. březnu, což je rozhodující datum pro odhad sněhových zásob v povodí před jarním táním. Rovněž plochy pokrytí lesem signifikantně souvisejí s nadmořskou výškou.

Úzká přímoúměrná vazba konce povodňového období byla prokázána i u povodí se severně orientovanými svahy (a naopak nepřímoúměrná s jižně orientovanými svahy). Čím větší je podíl severně orientovaných svahů tím později v daném povodí končí období zvýšené pravděpodobnosti výskytu povodní. Tento vztah je zřejmě možné vysvětlit pozdější dobou odtávání sněhu na severních svazích.

Na základě analýzy vzájemných vztahů uvažovaných parametrů byly mezi majoritní faktory zařazeny následující veličiny: *MD*, počátek a konec sezonálního období povodňového neklidu, průměrná roční výška, srážky a průměrná roční teplota, výška sněhové pokrývky ke dni 15.3., nadmořská výška, sklonitost svahů a lesnatost povodí. Vliv ostatních veličin byl buď implicitně již zaveden některým z majoritních faktorů anebo byl méně významný.

Vybraná povodí byla pak podle podobnosti, charakterizované majoritními faktory a dále pomocí aplikace metody shlukové analýzy v prostředí GIS, rozdělena do 7 oblastí. Geografické znázornění regionů ilustruje obr. 6. Výsledné regiony lze z hlediska sezonality výskytu povodní považovat přibližně za hydrologicky homogenní.

Do prvního regionu (severovýchodní pohoří) bylo zařazeno 8 stanic, do druhé 13 (severovýchodní podhůří), do třetího 48 (vrchoviny), do čtvrtého 9 (podkrušnohorský stín), do pátého 3 (oblast vlivu Novohradských hor), do šestého 18 (Pošumaví-Otavsko) a do sedmého 13 vodoměrných profilů (oblast vlivu Žďárských vrchů).

U dalších povodí, mimo těch vybraných, která nemají pozorování anebo mají ovlivněný odtokový režim či u sporných případů v okrajových oblastech regionů bylo přihlíženo k rozložení průměrných ročních srážkových úhrnů a k nadmořské výšce.

Obr. 1 – Vybrané vodoměrné stanice v povodí českého Labe
Obr. 2 – Metoda polárních grafů výskytu povodňových případů u profilů Lázně Bělohrad na Javorce a Josefův Důl na Kamenici
Obr. 3 – Aplikace metody směrových statistik na řadu dat povodňových průtoků
Obr. 4 – Metoda směrových statistik při analýze výskytu povodňových případů u profilů Lázně Bělohrad na Javorce a Josefův Důl na Kamenici
Obr. 5 – Metoda čar kumulativních četností výskytu povodňových případů u profilů Lázně Bělohrad na Javorce a Josefův Důl na Kamenici
Obr. 6 – Mapa odvozených regionů podle sezonality výskytu povodní

(Authors are with Czech Hydrometeorological Institut, Na Šabatce 17, 143 06 Praha 4, Komořany; Czechia; e-mail: chalus.spol@volny.cz, hladny@chmi.cz, cekal@chmi.cz.)

Arrived to the editorial board on August 28, 2006

GEOGRAFIE – SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI
ROK 2006 • ČÍSLO 3 • ROČNÍK 111

MAREK KŘÍŽEK, FILIP HARTVICH, TOMÁŠ CHUMAN, LUDĚK ŠEFRNA, MIROSLAV ŠOBR, TEREZA ZÁDOROVÁ

FLOODPLAIN AND ITS DELIMITATION

M. Křížek, F. Hartvich, T. Chuman, L. Šefrna, M. Šobr, T. Zádorová: *Floodplain and its delimitation.* – Geografie–Sborník ČGS, 111, 3, pp. 260–273 (2006). – The article is conceived as an introduction to the study of the floodplain. It deals with the delimitation of the floodplain from geomorphologic, pedologic, hydrologic and geoecologic point of view. It also describes the basic geomorphological forms and natural processes, constituting the floodplain system and participating in its formation.
KEY WORDS: floodplain – geomorphology – fluvial processes – fluvial sediments – fluvisoils, floods – invasive species.

The presented research was funded by the Research Plan MSM 0021620831 "Geographical Systems and Risk Processes in Context of Global Changes and European Integration" of the Czech Ministry of Education and Research Project VaV-SM/2/57/05 "Long-term changes of river ecosystems in floodplains affected by extreme floods" of the Ministry of Environment of the Czech Republic which is fully appreciated by the authors.

1. Introduction

In the context of landscape, the floodplain is a specific area typical of great dynamics of natural, especially fluvial, processes. Also, the anthropogenic influence and use are intensive in this area. Yet, the delimitation is not easy since there are a number of natural processes participating in the floodplain formation, which also modify individual forms within the floodplain. These forms have been created by preceding processes and also by the floodplain itself, and therefore the difference between the floodplain and the surrounding relief forms may be blurred and the borders of the floodplain thus become less clear. The understanding of past and present natural processes in the floodplain makes it possible to optimize the human impact in floodplains, established with economic and settlement activities, with the aim to minimalise the damage caused by the flooding water courses.

The main target of this article is describing of delimitation of floodplain from the geomorphological, hydrological, pedological and geoecological points of view, including determination of principles of its delimitation.

2. Methods

The characterization and delimitation of floodplains were based on scientific literature search and the results of the field research above all in the Otava River catchment (2002–2005) and selected parts of Rusava River catchment (1997–2006), Trkmanka River catchment (1993–2006) and Sázava River catchment (2006).

Geomorphological delimitation of floodplain was made on the basis of geomorphological mapping and morphometric analyses of DMT with grid size 5x5 m. Geomorphological mapping was based on searching real edges between neighbouring basic genetic geomorphological units of relief – plane floodplain and steeper slopes of fluvial terraces steps or valley slopes, which have different inclination.

Hydrological delimitation of the floodplain is possible carry out with use marks of flood situation (fluvial sediments, elevation of water level). We can use terrain mapping or aerial photographs evaluation.

Pedological methods of floodplain delimitation are based on distribution of fluvisols. In the soil survey, the soil types are mostly identified on the basis of the distribution of diagnostic horizons and properties in the soil profile.

Delimitation of the floodplain from the viewpoint of biology and landscape ecology is primarily based on a field research. It considers the change of plant communities on the moisture gradient outwards the stream.

3. Definitions of the floodplain

There are several different basic definitions to delimit the floodplain, corresponding to scientific disciplines concerned. Apparently, every discipline approaches the definition in a different way and therefore we shall outline at least the basic distinctions of the concepts of individual disciplines.

Foreign, similarly as Czech, general physical-geographical literature considers particularly the morphology, or rather geomorphology of the

Tab. 1 – Natural processes forming the floodplain according to Brierley, Fryirs (2005), modified

Geomorphological process	Description
Lateral accretion	Transported material deposits on the convex bank of the curve. It accumulates inside the channel and then it is transported.
Vertical accretion	Material from suspension sediments after a stream overspill. It is incorporated into floodplain sediments by bioturbation and it occurs destruction of primary lamination.
Braid channel accretion	Material sediments during extreme floods inside the channel and big stabile islands originate. This process is typical of multi-channel rivers.
Oblique accretion	It happens inside the channel. Muddy-sandy sediment sheeds are gradually joined to the bank and they increase in magnitude till they become a part of accumulation level.
Counterpoint accretion	Depositing of sediments near curves and meanders in places of secondary circulation and back current origination. The way of depositing is similar to vertical accretion.
Abandoned channel accretion	It happens when an abandoned channel fills with flood sediments, most frequently after a meander cut-off.

Tab. 2 – Natural processes taking part in re-modelling of the floodplain, according to Brierley, Fryirs (2005), modified

Geomorphological process	Description
Lateral migration	Meander movement in space of the floodplain as a result of gradual siltation and lateral erosion within a channel.
Downcutting /cutoffs/	Incising and cutting-off a part of a channel, mostly a meander.
Channel transition /avulsion/	Significant change of channel position, genesis of a new channel, typically after an extreme flood.
Stripping	Process of upper surfaces floodplain layersremoval by rapidly flowing water.
Flood channel formation /floodchannels/	Formation of otherwise abandoned channels run through during flooding.
Channel expansion	Process of channel enlargement typically by side bank erosion.

floodplain. This is, however, complemented by pedological, landscape and landuse characteristics, as for example "Columbia Electronic Encyclopedia" (www.answers.com/topic/flood-plain. Retrieved May 05 2005): "The floodplain is an area along the course of a river formed by the deposition of sediment during periodic floods. The floodplain is typical of such features as levees, oxbow lakes and delta plains. Floodplains are generally very fertile, thus forming rich agricultural lands. The disadvantage of farming on a floodplain is the natural hazard of ."

3.1 Geomorphological definitions of the floodplain

Demek (1988) defines the floodplain as an accumulation plain along a water course constituted by unconsolidated sediment, transported by and deposited in this stream, usually partially or fully flooded during high floods. This and similar definition describing the floodplain from a geomorphological point of view occurs with slight modifications analogically with other authors (Whittow 1984; Collin 1988; Anhert 1996; Hugett 2003). Allen (1997) and Levin (1978) in Brierley, Fryirs (2005) interpret the floodplain as an area delimited by forms originated by fluvial geomorphological processes. Brierley, Fryirs (2005) determine the area of the floodplain between the borders of the channel and the valley, i.e. valley floor.

The geomorphological view of the floodplain thus emphasises its genesis and relief morphology, making these features prior for its definition. The definition implies that the floodplain is formed by fluvial sediments accumulated as a result of fluvial geomorphological processes in this area. Thus, the floodplain can also be described and delimitated by specific geomorphologic processes, which take place in this area, and shapes that originate.

System of fluvial processes (Tab. 1 and Tab. 2), may be divided into two basic groups: erosional fluvial processes with predominant removal of material, and accumulation fluvial processes, with predominant sedimentation. The character of mentioned fluvial processes changes,

Tab. 3 – Main natural geomorphological forms of fluvial origin located outside the channel, according to Brierley, Fryirs (2005), modified

Landform	Description
Floodplain	Alluvial surface formed by fluvial sediment aggradation; distant gradation of sediment grain-size is typical.
Alluvial terrace	Terrace formed by fluvial material which had originated before the current floodplain, typically lying above the current channel and floodplain. Three types may be distinguished: accumulation, erosional and embedded terraces. Within the terrace, plateau and the terrace step may be distinguished according to inclination.
Levee	Asymmetrical wall above flat surface of the floodplain along the channel.
Crevasse splay	Accumulation body, typically cone-shaped, formed under a crevasse behind aggradational, flood protection or other anthropogenic levee.
Floodchannel, back channel	Side, otherwise abandoned, channel formed and flooded by high floods, above the current channel, mostly at a side of a floodplain.
Flood runner	Direct linear depression in the floodplain, which diverts water during floods, connects individual parts of the channel and shortens the length of the stream.
Backswamp, floodplain wetland	Wet depression, where inundation lakes originate during floods.
Sand wedge	Asymmetrical (inclined towards the channel with steeper side) wedge-shaped fluvial accumulation, which is typically formed near the channel, mostly in places with less developed levee. A typical feature is that particles are well-assorted according to grain-size.
Floodplain sand sheed	More or less equally mighty and disposed accumulation in a floodplain covering a larger area. These accumulations participate in floodplain vertical profile and cause increase in its magnitude.
Abandoned channel, paleochannel	A channel with no stream flowing through. Over time, it is usually filled with fluvial material in case of overspill from the main channel.
Ridge and swale topography	They are relicts of former positions of channels in intensive lateral accretion.
Valley fill	Relatively flat, not well-pronounced, not clearly delimited area filling in the bottom, where indistinct channel irregularly appears. This area is often wet.
Floodout	Cone- or lobe-shaped acumulation body formed as a result of channel elevation (e.g. because of siltation) to the level of the floodplain surface and subsequent sedimentation.
Meander cutoff, ox bow	Part of meander channel separated from the watercourse channel.
Chute cutoff	New channel formed after cutting off (incision) of a meander
Channel	Place of watercourse concentration; involves bed and banks.
Anabranch (secondary) channel	Side channel (with lesser depth and width than the main channel), run through by a flow water. Typical of anastomose streams.
Crevasse	Place through which water leaks into a floodplain after bank disruption. Fluvially incised area of a levee.
Alluvial fan	Cone-shaped accumulation body intersecting the floodplain of the main stream from an adjacent valley, ravine or gorge as a result of a sudden decrease in drift capacity of the side stream.

depending on the position of a given part of a floodplain in terms of gradient curve of river, which may change due to endogenous processes (tectonic movements), exogenous processes (e.g. damming river by landslide) or anthropogenic processes (e.g. construction of dams, stream diversion, etc.).

In the floodplain area, there is a range of fluvial shapes (Tab. 3) or shapes, whose origination was at least partly participated by fluvial action (cf. Hrádek 2003). Still we can find such geomorphological forms, whose genesis is not inherently connected with fluvial processes. Landslide bodies can intervene in floodplain areas from adjacent slopes or they may block them completely (Křížek 2003).

3.2 Geological definition of the floodplain

Among other scientific disciplines, geological understanding of the floodplain is the most similar to geomorphological conception of this area. Geological definition describes the floodplain as "flat valley floor activated during flooding of a stream"; the floodplain is composed of horizontal young (Holocene), gravel, sandy, loamy or clay sediment, often displaying irregularities caused by braiding of a stream, origin of islands, meanders, alluvial fans and delta plains, debris, landslides etc. (Collin 1988). Geology thus concentrates especially on geological composition and stratigraphy of the floodplain, and the genesis is only secondary (cf. Collins, Walling, Leeks 1997). Apart from fluvial material grain size, which decreases with the length of particle transport and thus also with the length of the floodplain, geological composition of sediments can change as well, depending on the variability and position of source areas. A typical example is the Morava River, which carries particles from the Czech massive downstream and after joining the Bečva River, sediments of flysch origin appear within transported and deposited material. Inhomogeneity and spatial variability of fluvial sediment was examined by Walling, He (1998) and Nakamura, Kikuchi (1996).

3.3 Hydrological definition of the floodplain

Hydrologically speaking, the floodplain is influenced by hydrological aspects of the stream (Ehrlich 2006) and at the same time by an extreme flow of running water during floods. Hydrology focuses on groundwater level, porous permeability of sediments, permanent saturation (e.g. Gilvear 1999) and on the character and magnitude of discharge through the floodplain during floods. From the viewpoint of hydrology and water management, the floodplain is sometimes associated with the flooded area during floods.

Hydrologists view the floodplain as natural inundation area, suitable for water retention in the landscape during floods (Janský 2004). Inundation area is a space adjacent to a stream, where water floods during high flood fluxes. Thus, a wide stretch of water flows in the direction of the steepest slope of the valley, ignoring the direction of the channel. In time of these high flood discharges, water is overburdened with suspension load, depositing in the inundation area. During an overspill of the channel into the floodplain, the depth of water is relatively small and because of significant hydraulic resistance the flow has a relatively low speed (Kemel 2000). Sediments, especially larger particles, mostly deposit along the banks (and thus bank levees originate), finer particles sediment further from the banks. Thanks to its high diffusion capacity, the floodplain (inundation area) is important during floods because it can reduce the speed of the flood wave. The flood wave flattens in large inundation areas and culminates with lower flow and water magnitude than in areas of narrow valleys with not very developed floodplains.

3.4 Pedological definition of the floodplain

The floodplain is an area with the occurence of fluvisols and gleysols – hydromorfic and semihydromorfic soils are typically situated in the bottom positions of valleys, forming the flat strips of land adjacent to the riverbed outside older sandy gravel terraces. Recent, mostly fine textured fluvial sediments can be used as bedrocks. Originating from the soil cover of upper reaches of the catchment, they are eroded, transported and resedimented in the inundation zone. All the main soil classification systems (USDA, 1990; WRBS 1999; RPF 1995) define the fluvisol as a genetically young (recent) soil whose formation does not reflect some processes, which are typical for mature soils. The alluvial groundwater impact on the fluvisol can be permanent or temporary, but the reduction features in the profile are restrained thanks to the groundwater flowing and oxidation. Only in case of stream-channel regulations, which can be the cause of the groundwater level decreasing or elimination of the seasonal flooding, the soils become relict.

According to our recent soil classification (Němeček et al. 2001), the floodplain contains fluvisols (original floodplain soils), which may (on the subtype level) reach a significant variability in grain size (modal, psefitic, arenic, and pelic), hydromorphism (gleyic, pseudogleyic), chemical composition of sediments (carbonated, non-carbonated) and formation (stratified, cambic).

To address all possible varieties of fluvisol soil profile composition character, Kubiena's (1953) classification should be also referred to. This classification emphasises ecological aspects and resembles the differentiation of typical floodplain and forest vegetation. This categorization of floodplain soils distinguishes rambla (gravel, light, not rich in nutrients, with alderwoods), paternia (middle-heavy to heavy, nutritive, hydromorphic, typical of willow-poplar forests) and vega (heavy soils with stabile profile, only exceptionally flooded, hardwood forests). They are ordered according to grain-size, pedogenic processes and hydromorphism. Traditionally, the terms are used by ecologists and geobotanists (Chytrý, Kučera, Kočí, eds. 2001).

3.5 Floodplain definition and delimitation from the viewpoint of biology and landscape ecology

Biology and landscape ecology delimit the floodplain according to regionalization of floodplain biochores, ecosystems, and plant and animal communities (Collin, 1988; Gruell, Gregory 1995). Floodplains are considered significant landscape features, defined by the law – Act No. 114/1992 (218/2004) as well as forests, fish ponds, peat bogs, streams and lakes. Floodplains are indispensable ecological corridors for plant and animal migration and have other vital ecological functions in the landscape (climatic, water retention, stabilizing, etc.) Despite its exceptional biological and landscape ecological value, floodplains have been heavily modified in many places to the extent that is difficult to recognize its natural character.

In contrast with other significant clearly distinguishable and identifiable landscape features, the delimitation of floodplain happens to be quite complicated from the viewpoint of biology and landscape ecology. There are only few clear biological definitions of the floodplain. These definitions are mostly based on plant communities that play a significant role in determining the floodplain. According to Novotná (2001) floodplain is delimitated by characteristic herbaceous vegetation. Ložek (2003) delimitates the floodplain not only by typical plant communities but also by typical fauna. More complex definition was presented by Bayley (1995), who defines the floodplain as a part of the river-floodplain ecosystem that is regularly flooded and drained, and it represents a type of wetland.

The integration of the floodplain among the significant landscape features, defined by the law – Act No. 114/1992 (218/2004), was followed by the definition of the floodplain from the conservation point of view issued by the Ministry of the Environment. The floodplain is delimitated as a biotope whose creation and typical plant communities depend on hydrological characteristics of the stream. Plant communities play a significant role in determining the floodplain and finding the floodplain border is more a question of a complex biological evaluation of a particular area.

4. Principles of a floodplain delimitation

4.1. Geomorphological principles of the floodplain delimitation

The floodplain is separated from other parts of the relief (e.g. from valley slope or fluvial terrace level) by an edge with more or less significant inclination change, which is manifested in cross-section profile (Křížek, Engel 2004; Hartvich 2006). The morphological significance of the delimitation of the floodplain depends on geomorphological processes, which function not only in the floodplain area, but also outside, in subcatchments or in other parts of the whole catchment. These processes relate to variability and changes of energy of geomorphological processes based on relief energy and energetic input of exogenous processes based on cyclic and long-term climatic changes.

Geomorphological definitions of the floodplain are based on its specific geometrical properties, qualitatively distinct from its surroundings. Its morphology may be observed by morphometric methods or geomorphological mapping.

A principle of floodplain delimitation with the assistance of geomorphological mapping takes advantage of searching and determination of position and shape of edge between different basic genetic units of relief, i.e. floodplain and valley slopes, possibly fluvial terrace step (fig. 1). These units with regard to different origination have dissimilar shape, aspect and inclination etc.. Boundary of floodplain is run the length of noticable change of inclination between plane or moderately inclined floodplain and sloping neighbouring relief. This boundary is identical with the edge between both types of genetical geomorphological units.

Hartvich in Langhammer et al. (2006) defines the floodplain with the aid of relatively simple calculation applied to DEM grid, which relates to detailed surface contour maps. Apart from direct calculation in the grids, the floodplain may be defined morphometrically on the basis of cross-section shape (fig. 2). The shape may be quantified using various indices based on

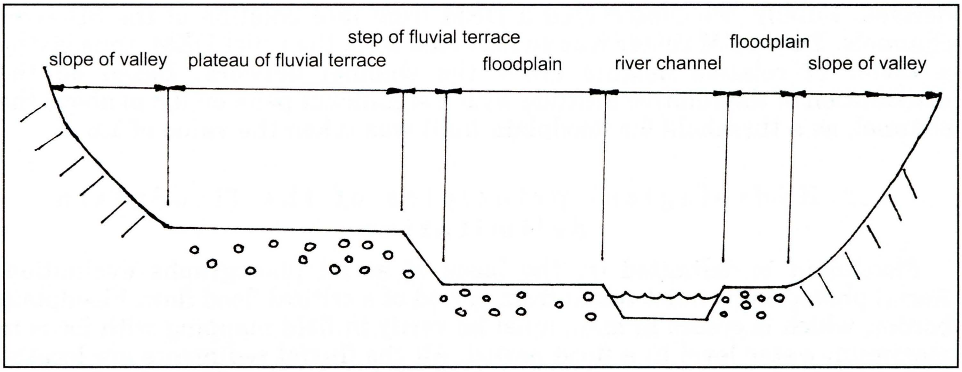

Fig. 1 – Cross-section scheme of valley bottom with genetic units of relief. Orthogonal lines show position of edges of these units.

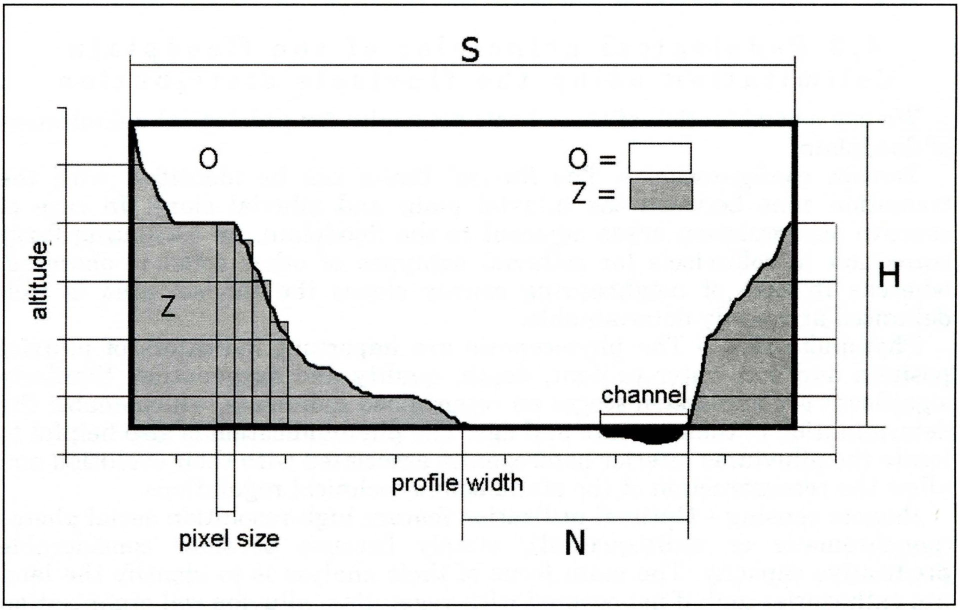

Fig. 2 – Elementary parameters used for the calculation of the morphometrical indices – width of the valley (S), depth of the valley (H), width of the valley floor (N) and the ratio of the area under the relief on the rectangle, given by the width and depth of the valley (Z) and the same above the relief (O).

several simple parameters, particularly the valley width (S), the depth of the valley (H), the width of the valley floor (N) and the proportion of the area under the terrain in a rectangular cross-section given by the depth and width of the valley (Z); Hartvich in Langammer et al. 2006.

As an input into the morphometrical floodplain span analysis we used a DEM based on DMU25, a contour line layer with an interval of 5 m, and a layer of streams from ZABAGED 1:10,000. The DEM was treated in ArcHydro Tools and turned into AgreeDEM, a smoothened raster with the continuous flow path solution. From the AgreeDEM a raster of slope inclination was derived. Finally, we constructed a DEM from interpolation of the 3D river channels. This DEM raster was substracted from the relief DEM, thus giving a raster of relative heights above the channel network. Based on the distribution of the relative altitude with a significant peak on 0,8 m above the channel, as a threshold for floodplain limit was taken the value of 1,6 m.

4.2 Hydrological principles of the floodplain delimitation

Floodplain is delimited on the basis of aerial photographs evaluation. Aerial photographs must result from period of a critical flood flow. Floodplain border, which is create in map, must be verify in field mapping with focus to maximum water level in a flood period. All the fluvial sediments are located in floodplain, in some cases they create floodplain border. Fluvial sediments, especially larger particles, mostly deposit along the banks, finer particles sediment further from the banks.

4.3 Pedological principles of the floodplain delimitation using the fluvisols distribution

We use a combination of three basic principles for pedological delimitation of floodplain:

Terrain configuration – The fluvisol limits can be identified with the transition zone between the alluvial plain and alluvial slope. In case of concave accumulation areas adjacent to the floodplain, an oscillating fuzzy transition to colluvisols (or colluvial subtypes of other soils) is observed, whereas in case of neighbouring convex slopes the fluvisol area is well delimited and easily determinable.

Phytoindication – The phytocenosis are important indicators of alluvial position and soil water content, depth, quality and oxygenation. Similarly significant are succession stages on recent flood sediments, which enable the determination of their texture and age. The phytoindication is also helpful to locate the alluviums interior heterogenity associated with their evolution and allow the reconstruction of the stand before technical regulations.

Remote sensing – Optimal utilization feature high-resolution aerial photos (panchromatic or multispectral), mainly because of their considerable predicative capacity. The main focus of their analyse is to identify the land use cathegories and, if not covered with vegetation, alluvion soil organization according to humus and water content.

4.4 Principle of the floodplain delimitation from the viewpoint of biology and landscape ecology

The floodplain may be defined as flat valley floor, periodically flooded, with high level of groundwater, typical of a mosaic of areas with vegetation of different succession stages – ranging from herb vegetation of young fluvial sediments, stages of willow shrub, to alluvial forests – and it can by also distinguished by its fauna (Ložek 2003).

Although vegetation patterns vary widely among different stream and river types, sizes and regions, the following are some of the more common vegetative patterns. Vegetation is highly variable in the longitudinal as well as lateral view.

In floodplains of mountain and submountain streams, vegetation is mechanically disrupted by large amounts of material move every year, and exists only in herb formations. Every year powerful disturbances prevent the occurrence of tree layer. Gravel bed load is colonized by rare herb vegetation not rich in species (*Calamagrostis pseudophragmites, Myricaria germanica, Phalaris arundinacea*) that belongs, according to Habitat Catalogue of the Czech Republic, to a group of habitats M4 – River gravel banks. In calmer sections, there occur willows (*Salix daphnoides, S. eleagnos, S. purpurea*). With decreasing stream gradient willows start to dominate (*Salix fragilis, S. purpurea, S. triandra, Salix daphnoides*) together with rich herb undergrowth of different ecological demands from the group of habitats K1–Willow carrs, K2–Riverine willow scrubs and M1–Reed and tall-sedge beds. In calm parts of lowland watercourses, willow shrub changes into alluvial forests (group of habitats L2) which, according to the Habitat Catalogue of the Czech Republic, can be divided into Montane grey alder galleries, Ash-alder alluvial forests, Hardwood forests of lowland rivers, Willow-poplar forests of lowland rivers. Alluvial forests are species-rich azonal stands with species tolerant of temporary flooding, with highly developed spring herb aspect. *Alnus glutinosa, A. incana, Fraxinus excelsior, Ulmus laevis, U. minor, Salix alba, S. fragilis, Populus alba, P. nigra, Quercus robur* typically occur in tree layer. In the shrub layer, *Sambucus nigra* or *Prunus padus* can be found. Herb layer is rather rich in species and typical of the occurrence of spring geophytes.

In most parts, alluvial forests have been converted into agricultural land throughout the history. In places with less intensive farming (mowing, pastures), ecologically valuable communities of alluvial meadows developed, distinguished according to the Habitat Catalogue of the Czech Republic as Alluvial Alopecurus meadows, Wet Cirsium meadows, Continental inundated meadows, Intermittently wet Molinia meadows, and Continental tall-forb vegetation. Alluvial meadows biotopes depend on the existence of the management which led to its origination. All biotopes naturally occurring in floodplains are then dependent on the maintenance of natural dynamics of a watercourse with regular flooding.

Floods also help spreading of invasive plant species, which have recently become numerous in some river floodplains. These are especially *Impatiens glandulifera, Solidago gigantea, Helianthus tuberosus, Reynoutria japonova, R. sachaliensis* or the hybrid R. × *bohemica.*

5. Discussion

From more geomorphological definitions (e.g. Demek 1988; Whittow 1984; Collin 1988; Anhert 1996; Hugett 2003; Allen 1997 and Levin 1978 in Brierley, Fryirs 2005; Brierley, Fryirs 2005) of floodplain follow that river channel is not element of floodplain, but we understand a floodplain area from the general geomorphology point of view, which includes also a river channel, because processes making a river channel participate in origin and development of a floodplain too. That´s why we can define a floodplain to the all intents and purpose as an area which is created by water course channel and an accumulation plain constituted by fluvial unconsolidated sediment situated along a water course, and which is divided from other parts of relief by an edge with more or less significant inclination change.

Geomorphological delimitation of floodplain based on inclination changes of basic genetic geomorphologigal units of relief, which are distinguished by field geomorphological mapping, has a lot of strong points:

A value of a limit inclination is not set "ad hoc" (predetermine) and that´s why it respects specific features of neighbouring relief and development of valley from its upper to lower parts. In the concrete floodplain need not be flat or slightly concave but it can be slightly convex in cross-section (Huggett 2003). With convex floodplains, the surroundings of the river are lie higher than the areas under the foothill of valley slopes, which is related to higher accumulation especially of bottom sediments (bedload) than material in suspension (suspension load), which is distributed to parts of the floodplain further from the river in case of overspill. This type of floodplain is typical of major rivers. This morphological type of floodplains is frequent in cultural landscape. It is connected with flood protection dike construction along channels and piling-up of material on original natural levees. In contrast, flat floor is a consequence of lateral accretion, i.e. sedimentation inside the meander, or more frequent channel change (Huggett 2003). Changing behaivour of cross-section curves of floodplain implies changing of strength of edges, which delimit floodplain.

In the valley bottom field geomorphological mapping can differentiate floodplain from lower fluvial (alluvial) terraces and alluvial fans. It makes essential merit in comparison with GIS morphometrical methods. Also this method of delimitation of floodplain is more detailed than GIS morphometrical methods and it does not include fault in cartography documents.

On the other hand this method has constriction with floodplain delimitation in flat relief without well-developed edges between neighbouring basic genetic geomorphological units of relief. These non-developed edges are result of specific evolution of wide relief, which are remodelled by intensive exogenic geomorphological processes, for example mass movement or eolic processes. Some floodplain like that are developed in sedimentary rocks of a fore-deep in the West Outer Carpathians. Next drawback of field geomorphologic mapping and its delimitation of floodplain is huge time demands.

Simple rule of GIS morphometrical delimitation of floodplain is not absolutely perfect and there are certain complications, which may confuse the results. That is why field geomorphological research is necessary.

The most obvious source of confusion is some inaccuracy or incompatibility of the input data, such as incorrect position of the rivers on the valley side. This is due to data inaccuracies, but there are also intrinsic problems – for example, lower quaternary terraces, which may appear as floodplains, as their vertical difference may not reach the contour interval, thus the terraces appear to be a direct continuation of the floodplain. Also in areas where the floodplain is not significantly limited by morphological borders (wide, shallow valley bottom), the GIS delimitation may overestimate real flood span.

On the other hand, the GIS floodplain delimitation has also advantages. Granted that the input data are accurate enough, it is very simple and fast technique for rough floodplain delimitation for practically unlimited area at once. It is also completely unbiased by the subjective attitude of the operator. Also within the urbanised areas the field mapping brings problems with the floodplain delimitation, which may be solved using the DEM delineation for these difficult places.

From the viewpoint of hydrology and water management, the floodplain is sometimes associated with the flooded area during floods, which is, however, ambiguous and inaccurate delimitation because of the variability of flood events. Culmination discharges of different magnitude during different flood situations cause different spillage of water into inundation area. Bridge (2003) defines the floodplain as a regularly flooded area with seasonal floods. Because in our country flood discharges are not seasonal this definition cannot be fully accepted.

Pedological methods of delimitation of the floodplain based on the fluvisol profile stratigraphy or reduction feature has some limits. The direct method is not applicable in sufficiently dense sampling network and thus the indirect methods based on landforms, phytoindication and remote sensing are broadly used. Distribution of fluvisols is very influenced by human activity in the landscape. For example regular alluvial sedimentation and alluvial groundwater level is frequently disrupted by anthropogenic channel transformation. Moreover the fluvisol distribution does not very often correspond to the maximum extent of floods. In addition, the transition zone between floodplain and fluvio-deluvial or deluvial substrate is highly subjective. In case of substrate homogenity and high contrast of soil types (e.g. molic humus horizons and unconsolidated carbon substrates) the remote sensing is the most valuable for delimitation of the floodplain. The phytoindication can be used as supportive method in extensively used floodplains.

As mentioned above plant communities provide great opportunity to determine the floodplain. To do so the habitat mapping within the NATURA 2000 preparation provides definitely the most valuable and up to date information about the natural vegetation. The Territorial Systems of Ecological Stability (TSES) mapping could be the second valuable source of information. Particular attention was given to the natural vegetation in the TSES concept as well. The above mentioned data are however only available for the floodplains with natural or semi natural character. In cases of heavy floodplain transformation e.g. channel metamorphism, converting the natural floodplain into building sites or arable land, the method based on vegetation mapping is impracticable and other approaches to delimit the floodplain should be used.

6. Conclusion

Geomorphological definition of the floodplain is most outright if we consider spatial delimitation of this area. That´s why we can define a floodplain to the all intents and purpose as an area which is created by water course channel and an accumulation plain constituted by fluvial unconsolidated sediment situated along a water course, and which is divided from other parts of relief by an edge with more or less significant inclination change. In fact, other definitions, based on different disciplines, implicitly draw on it. The area of the floodplain is highly dynamic in terms of natural and anthropogenically accelerated changes of geomorphological, hydrological, pedological and vegetational conditions.

References:

ANHERT, F. (1996): Introdution to geomorphology. Arnold, London, 352 p.

ALLEN, P. A. (1997): Earth Surface Processes. Blackwell, Oxford, 404 p.

ANDRYSIAK, P. B., MAIDMENT, D. (2000): Visual Floodplain Modeling with Geographic Information Systems (GIS). MS, University of Texas at Austin, http://www.crwr.utexas.edu/online.html.

BAYLEY, P. B. (1995): Understanding Large River-Floodplain Ecosystems, Bioscience, 45, No. 3, pp. 153–158.

BRIDGE, J. S. (2003): Rivers and floodplains. Blackwell, Oxford, 491 p.

BRIERLEY, G. J., FRYIRS, K. A. (2005): Geomorphology and River Management. Blackwell, Oxford, 397 p.

COLLIN, P. H. (1988): Dictionary of Ecology and the Environment. Teddington Park, Peter Collin Publishing, 198 p.

COLLINS, A. L., WALLING, D. E., LEEKS, G. J. L. (1997): Use a geochemical record preserved in floodplain deposits to reconstruct recent changes in river basin sediment sources. Geomorphology, 19, pp. 151–167.

DEMEK, J. (1988).: Obecná geomorfologie. Academia, Praha, 480 p.

EHRLICH, P., ZAHRÁDKOVÁ, S. (2006): Vodní ekosystémy. In: Němec, J., ed.: Voda v České republice. Consult, Praha, 255 p.

GILVEAR, D. J. (1999): Fluvial geomorphology and river engineering: future roles utilizing a fluvial hydrosystems framework. Geomorphology, 31, pp. 229–245.

HARTVICH, F. (2006): Hodnocení morfometrických parametrů nivy, vymezení nivy v GIS a využití příčných profilů In: Langhammer, J. (ed.) a kol. (2006): Povodně a změny v krajině. Monografie. KFGG, PřF UK, Praha.

HUGGETT, R. J. (2003):Fundamentals of geomorphology. Routledge, London, 408 p.

HRÁDEK, M. (2003): Návrh některých českých termínů z povodňové geomorfologie. Geomorfologický sborník, 2, pp. 81–86.

CHYTRÝ, M., KUČERA, T., KOČÍ, M. (2001): Katalog biotopů České republiky, AOPK, Praha, 304 p.

JANSKÝ, B. (2004): Retence vody v krajině. In Hodnocení vlivu změn přírodního prostředí na vznik a vývoj povodní. In: Langhammer, J., Engel, Z. (eds.): Sborník příspěvků závěrečného semináře grantu GAČR 205/03/Z046, Přf UK, Praha, pp. 59–70.

JURČA, V. (1974): Základní údaje o půdách centrálních částí holocénních niv povodí českého Labe. Sborník VŠZ v Praze, Fak. agron., A, pp. 69–214.

KEMEL, M. (2000): Klimatologie, meteorologie, hydrologie. ČVUT, Praha, 290 p.

KŘÍŽEK, M. (2003): Geomorfologický výzkum, In: Vilímek,V., Langhammer, J., Šefrna, L., Lipský, Z., Křížek, M., Stehlík, J.: Posouzení efektivnosti změn ve využívání krajiny pro retenci a retardaci vody jako preventivní opatření před povodněmi. Závěrečná zpráva k vládnímu projektu – Vyhodnocení katastrofální povodně v srpnu 2002, Přf UK, Praha, pp. 17–23.

KŘÍŽEK, M., ENGEL, Z. (2004): Geomorfologické projevy povodně 2002 v povodí Otavy, In Hodnocení vlivu změn přírodního prostředí na vznik a vývoj povodní. In: Langhammer, J., Engel, Z. (eds.): Sborník příspěvků závěrečného semináře grantu GAČR 205/03/Z046, Přf UK, Praha, pp. pp. 86–103.

KUBIENA, W. L. (1953): Bestimmungsbuch und Systematik der Boden Europas. F. Enke Verlag, Stuttgart, 392 p.

LANGHAMMER, J. et al. (2004): Hodnocení vlivu změn přírodního prostředí na vznik a vývoj povodní. PřF UK, Praha, 87 p.

LOŽEK, V. (2003): Povodně a život nivy. Bohemia centralis, 26, AOPK, Praha, pp. 9–24.

LOŽEK, V. (2003): Naše nivy v proměnách času I. Ochrana přírody, 58, No. 4, pp. 101–106.

LOŽEK, V. (2003): Naše nivy v proměnách času II. Ochrana přírody, 58, No. 5, pp. 131–136.

MAYHEW, S. (2004): A Dictionary of Geography. Oxford University Press. Oxford Reference Online. Oxford University Press. Charles University. 16 June 2005, http://www.oxfordreference.com/views/ENTRY.html?subview=Main&entry=t15.e1240. The Columbia Electronic Encyclopedia, Sixth Edition. www.answers.com/topic/flood-plain. 30.5.2005.

NOVÁK, P., ZLATUŠKOVÁ, S., ŠEFRNA, L. (1997): Změny půdního krytu v důsledku povodní. Sborník přednášek Povodně a krajina, 97, ICID-CIID, Brno, listopad 1997, 7/54.

ŠEFRNA, L., VILÍMEK, V. (2003): Dynamics of Pedogenetic processes exempled in the Haraska. River drainage area. Moravan geographical report, 1/11, pp. 27–35.

NĚMEČEK, J. a kol. (2001): Taxonomický klasifikační systém půd České republiky. ČZU Praha, 79 p.
WALLING, D. E., HE, Q. (1998): The spatial variability of overbank sedimentation on river floodplains. Geomorphology, 24, pp. 204–229.
WHITTOW, J. (1984): Dictionary of physical geography. The penguin, Oxford, 591 p.

Shrnutí

ÚDOLNÍ NIVA A JEJÍ VYMEZENÍ

Článek je koncipován jako úvod do studia údolní nivy, který se zabývá problematikou jejího vymezení a charakteristikou z fyzickogeografického hlediska, především pak z pohledu geomorfologie, pedologie, hydrologie a krajinné ekologie. Také popisuje její základní geomorfologické formy a přirozené procesy, které jsou součástí systému údolní nivy a které se na jejím formování podílejí. Cílem této studie je charakterizovat vymezení údolní nivy z pohledu základních fyzickogeografických disciplín, které se tímto prostorem zabývají, včetně nastínění principů jejího vymezení, a určit její základní definici.

Údolní niva představuje v rámci krajiny specifický prostor, který se vyznačuje velkou dynamikou přírodních procesů, především fluviálních. Zároveň je tento prostor výrazně antropogenně ovlivněn a využíván. Přesto vymezení údolní nivy není triviální, protože na její modelaci se podílí celá řada přírodních procesů, které modifikují jednotlivé tvary v rámci údolní nivy vytvořené předešlými procesy, ale i samotnou nivu a mohou stírat rozdíl mezi ní a okolními formami reliéfu. Hranice údolní nivy se pak stávají méně zřetelné.

Při vymezování údolní nivy byla použita široká škála geomorfologických, pedologických, hydrologických a geoekologických metod, které se opíraly o terénní průzkum, tvorbu a analýzu digitálního modelu území a vyhodnocení dat z dálkového průzkumu Země.

Z rešeršní části článku vyplývá, že prostor a ohraničení údolní nivy je v jednotlivých fyzickogeografických disciplínách vymezován různě. Z toho plynou disproporce v určení průběhu jejích hranic vzhledem k okolí. Průběh a zřetelnost těchto hranic je navíc výrazně ovlivněna antropogenní činností. To se projevuje zejména ve změnách rozmístění fluvizemí a ve změnách vegetačního pokryvu, tedy v rozhodujících ukazatelích pro vymezení údolní nivy z pedologického, resp. krajinně ekologického hlediska. Taktéž se u nich, stejně jako u hydrologického vymezení, projevuje větší časová závislost vázaná na periodicitu a rozsah záplav. Ukazuje se, že geomorfologické vymezení údolní nivy je z prostorového hlediska nejjednoznačnější. Údolní nivu lze pak definovat v širším slova smyslu jako území tvořené korytem vodního toku a akumulační rovinou budovanou fluviálními nezpevněnými sedimenty podél vodního toku, která je od okolního reliéfu z každé strany oddělena hranou, na níž dochází k víceméně nápadné změně sklonu. Princip vymezení údolní nivy pomocí terénního geomorfologického mapování je založen na hledání a určení polohy a průběhu hran mezi rozdílnými geneticky stejnorodými plochami, tj. údolní nivou a údolním svahem, případně stupněm fluviální terasy (obr. 1). Hranice údolní nivy je vedena v linii výrazné změny sklonu mezi rovinnou či mírně skloněnou údolní nivou a sklonitějším okolním reliéfem, která je totožná s hranou oddělující obě genetické plochy. Druhý (morfometrický) princip vychází z vymezení ploch podle předem stanoveného mezního sklonu, na základě vytvořeného DMR. Tento způsob je rychlejší, ovšem je limitován kvalitou DMR, tedy musí být korigován terénním mapováním.

Obr. 1 – Příčný profil částí údolního dna se zakreslením jednotlivých genetických stejnorodých ploch a vymezením hran, které je oddělují.
Obr. 2 – Základní parametry pro výpočet morfometrických indexů – šířka údolí (S), hloubka údolí (H), šířka údolního dna (N) a podíl plochy pod terénem na obdélníkovém průřezu, vymezeném výškou a šířkou údolí (Z) a nad terénem (O).

(M. Křížek, T. Chuman, L. Šefrna, M. Šobr, T. Zádorová are with Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology, Albertov 6, 128 43 Praha 2, Czechia; e-mail: krizekma@natur.cuni.cz, chumant@natur.cuni.cz; sefrna@natur.cuni.cz; sobr@natur.cuni.cz; Tereza.Zadorova@seznam.cz. F. Hartvich is with The Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, V Holešovičkách 41, Praha 8, 182 09, Czechia; e-mail: hartvich@itsm.cas.cz.)

Arrived to the editorial board on August 28, 2006

GEOGRAFIE – SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI
ROK 2006 ● ČÍSLO 3 ● ROČNÍK 111

JAKUB LANGHAMMER, MILADA MATOUŠKOVÁ

MAPPING AND ANALYSIS OF RIVER NETWORK MODIFICATION AS A FACTOR OF FLOOD RISK IN THE BLANICE RIVER BASIN

J. Langhammer, M. Matoušková: *Mapping and analysis of river network modification as a factor of flood risk in the Blanice river basin.* – Geografie–Sborník ČGS, 111, 3, pp. 274–291 (2006). – Anthropogenic modifications of river network represent a significant phenomenon that influences runoff conditions in river basins, both under normal water level conditions as well as in the period of hydrological extremes. Modifications of watercourses on various levels influence the speed and timing of floodwave progress as well as the potential to efficiently transform the floodwave in the floodplain and to lessen the extremity of the flood event. The paper presents the methodological framework for analysis of historical and current intensity and nature of man-made modifications of river network. There are presented two essential approaches: First represents the analysis of distance data, e.g. the water management maps, historical maps or aerial imagery. The second approach is based on field mapping of various parameters of river network and floodplain modifications. The presented methodologies are applied on the Blanice river basin that represents the core zone of extreme flood in August 2002 that heavily affected the Central Europe. The GIS analysis of results revealed the spatial differentiation of anthropogenic changes in river basin and their potential importance in the context of the flood risk. The results and the applied methodologies are discussed from the viewpoint of their practical applicability and of limitations in terms of data accuracy, availability and reliability.
KEY WORDS: river network transformation - floods - mapping - land-use changes - GIS.

The presented research was funded by the Research Plan MSM 0021620831 „Geographical Systems and Risk Processes in Context of Global Changes and European Integration“ of the Czech Ministry of Education and Research Project VaV-SM/2/57/05 „Long-term changes of river ecosystems in floodplains affected by extreme floods“ of the Ministry of Environment of the Czech Republic which is fully appreciated by the authors.

1. Introduction

Anthropogenic modifications of riverbeds represent a significant phenomenon that influences runoff conditions of river basins, both under normal water level conditions as well as in the period of hydrological extremes. Modifications of watercourses on various levels - ranging from interventions in the stream route geometry to presence of artificial steps in its longitudinal profile and to modifications of the riverbed or modifications of the riparian zone, influence markedly the speed and nature of water runoff from the river basin during floods. They affect especially the speed of the flood wave progress, the possibility of its efficient transformation, they alter the timing of concurrence of flood waves from various parts of the river basin, and last but not least, they contribute in various extents to the character of damages incurred to property, infrastructure, as well as the landscape.

The goal of the research presented has been to assess the current condition of modification of the river network and the riparian zone in the Blanice River basin that represents the core area of the extreme flood hitting the Central Europe region in August, 2002. The assessment stems from the combination of two approaches - Field mapping and evaluation of the distance data available. The paper is focused on assessment of the current situation of the watercourse modification and its spatial variability, and on assessing the possibility of using individual data sources to obtain objective sources for complex evaluation of the flood risk and their practical application.

2. Material and Methods

2.1 Current approaches for river network modification assessment

Various approaches can be applied in assessment of the river network modification, allowing obtaining a different type of information on anthropogenic transformation of watercourses and the floodplain; they are based on different methodical approaches and require a specific nature of input data.

Analysis of distance data – maps, digital materials, aerial or satellite images – provides basic information on the time-spatial dynamics of interventions in the river network. Analysis of historical cartographic materials plays an important role here, as it allows evaluating the dynamics of changes of ground-plan courses of the watercourse riverbeds. Concerning the territory of Czechia, it is thus possible to utilize e.g. the maps of military mapping for the territory of the former Austro-Hungarian Empire; these maps allow to evaluate changes in the time horizont of the previous ca. 150 years, a period for which data from regular observation of hydrological and climatic elements are available in numerous regions, at the same time. However, concerning limited accuracy and different level of generalization of the historical map works, the analysis is limited especially to significant watercourses and their main tributaries (Langhammer, Vajskebr 2003). Changes of the river network in the course of the 2nd half of the 20th century are also well documented by aerial images (Matoušková 2003). Accuracy of the materials derived is always determined by accuracy of georeferencing of historical map data as well as by the level of their content generalization (Langhammer, Vajskebr 2003). Data of good quality for the spatial structure analysis of the river network modification are provided by current digital maps, especially the Water Management Maps (WMM) and Map Data of the Agricultural Water Management Authority (Matoušková in Langhammer 2003).

Field mapping, as opposed to distance data, allows obtaining substantially more detailed information on the nature and intensity of human impact on the river network and flood plain. Besides basic classification of the segments as modified and non-modified, it allows to classify the intensity of modification according to numerous parameters – e.g. modification of the riverbed route, of the longitudinal profile, of the watercourse riverbed, utilization of the riparian zone, etc. Methodology of mapping of the watercourses modification stems from the general ecomorphological approaches (e.g. Barbour et al. 1999; Havlík et al. 1997; Landson White 1999; Matoušková 2003, 2004; Niehoff 1996; Raven et al. 1997; Rosgen 1996; Vlček, Šindlar 2002 etc.), however the direct use of these methods is not applicable due to their complexity. The methodology developed for the purpose of assessment of stream modification in regard to the flood risk is thus based on the subset of selected parameters that correspond with specific needs of the evaluation.

2.2 Analysis of river network modification of river network based on distance data

Analysis of the distance data has been focused on assessment of the degree of the river network modification based on available mapping materials and based on performing mutual comparative analysis of different information sources.

The raster form of the WMM 1:50,000 have represented the basic data source, showing segments of modified channels, and at the same time, artificial built channels. Individual WMM map sheets were geo-coded, geo-registered and modified channels were digitised. The degree of river transformation was calculated for the whole catchment's area of the Blanice river and also for 6 sub-catchments on the bases of WMM 1:50,000.

Another source of information was represented by digital map layers of the Agricultural Water Management Authority (AWMA) that contains hydro-amelioration measures performed, as well as related modifications of the riverbeds. Registry of channel modifications and the registry of surface and subsurface drainages were available for this analysis. The mapping materials obtained did not have the character of a geodatabase, which made the assessment analysis difficult. The detail mapping materials 1:10,000 only for a part of the lower course of the Blanice River were available and therefore the analysis was processed only for the selected sub-catchment Blanice V., where the highest degree of anthropogenic modification of the river network has been observed, at the same time.

2.3 Methodology of field mapping of river network modification

Mapping and subsequent evaluation of modification of the watercourses and floodplain in the Blanice River basin has been based on the methodology developed at the Faculty of Science of the Charles University for the needs of research of the environmental changes impact on the course and consequences of floods (Langhammer 2003).

The methodology has been designed to allow assessment of the connections between individual aspects of anthropogenic modification of the river network and floodplain, and the course and consequences of floods. The extent of the indicators evaluated has been chosen in such a manner so that the mapping allows to obtain the necessary spectrum of information, and at the same time, so that it allows for rapid advancement of mapping in the field and processing of the large territory in the time period needed. The methodology is based on integration of the results with the GIS, representing geostatistical assessment of the results, as well as, however, their usage as input data for further applications. The spectrum of evaluation indicators has been selected in such a manner so that the methodology can be used in general geographic and hydrological conditions of Czechia.

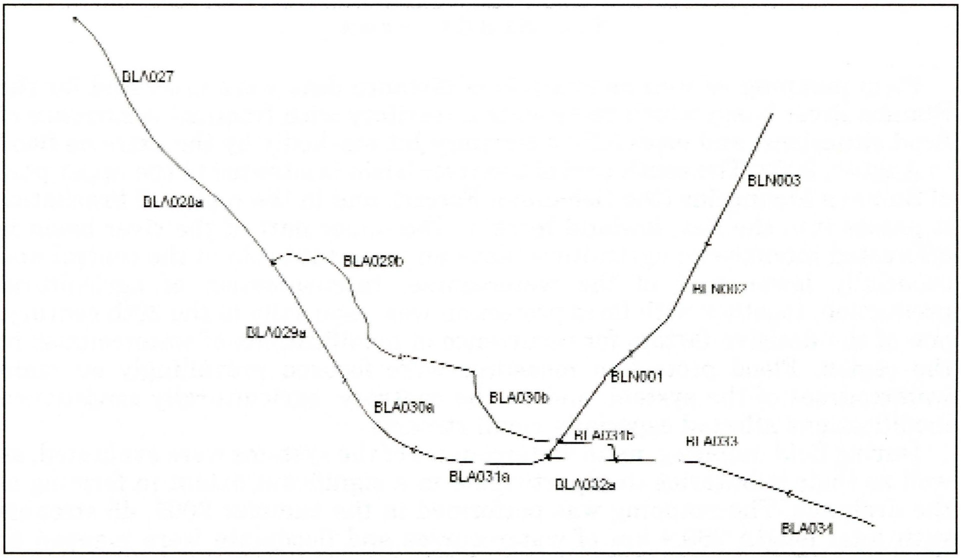

Fig. 1 – Principle of dividing the watercourses in partial segments and their linkage to database records by means of a unique identifier of individual segments.

For the mapping purses, the watercourses are divided in segments of variable length (Fig. 1). Borders of the segments have been chosen in such a manner so that the watercourse segment obtained is homogeneous as for one of the key parameters at least: The riverbed route, modification of the riverbed, landuse of the riparian zone. Borders of the segment are marked in the map, while a typical segment length is 100-500 meters.

A unique indicator has been assigned to individual segments, allowing distinguishing even complicated hydrographic structures. Intensity and nature of modification in individual parameters is evaluated for every segment together with the given segment code, stored in a form, and subsequently transferred to the database. Using the segment identifier, the map elements are linked to database records, and they allow for further geoinformatic processing.

Modification of the watercourses and the floodplain is evaluated in five main indicators, while every indicator is divided internally within the scale of categories, pursuant to the intensity of anthropogenic modification (Langhammer 2004):

– modification of the stream route
– modification of the watercourse riverbed
– modification of the watercourse longitudinal profile
– utilization of the riparian zone
– presence of flow obstacles in the floodplain.

Supplementary indicators are added to these basic ones, evaluating e.g. the nature of flood protection, the retention potential of the floodplain or the course and consequences of floods.

In mapping of large areas, systematic training and supervision of the mappers as well as a transparent digitising method, checking, and processing of the results, play a key role. These operations help to eliminate inaccuracies caused by different approach of individual mappers, as well as errors in processing and interpretation of the results.

2.4 Study area

Field mapping as well as analysis of distance data were processed for the Blanice River basin which represents a territory with frequent occurrence of flood situations, and especially a territory hit markedly by the extreme flood in August, 2002. The south part of the river basin is situated in the upper part of Šumava Mountains (the Bohemian Forest), and in the region of Prachatice it passes into the flat, lowland terrain. The upper part of the river basin is afforested intensively; agriculture plays an important role in the central and especially lower part of the watercourse. Intensification of agricultural production, together with flood protection was, especially in the 20th century, one of the decisive factors for occurrence of modifications of watercourses in the region. Flood protection measures were focused prevailingly on main watercourses of the system, and on the contrary, agriculturally conditioned modifications affected especially small streams.

During field mapping, main watercourses of the systems were evaluated, as well as their tributaries that participate in a significant extent in forming of the drainage. The mapping was performed in the summer 2005; 45 streams with total length 289.9 km of watercourses and floodplain were mapped at this time. These watercourses were divided in 918 segments representing elementary units for which individual aspects of anthropogenic modification and manifestations of the flood were assessed.

3. Results

3.1 Analysis of river network modification based on distance data

3.1.1 Modification of the river network based on the Water Management Map

The primary output is represented by the map of anthropogenic transformation of the river network of the Blanice River basin, see Figure 6, and furthermore, by subsequent assessment of the river network modification in selected sub-catchment, see Figure 7. The total length of the watercourses based on the digital layer WMM 1:50,000 amount to 1035.5 km. The length of river reaches modified by human intervention, based on the analysis WMM 1:50,000, is 264.3 km. Average degree of anthropogenic transformation of the river network reaches 25.5%. Approximately one fourth of watercourses in the Blanice River basin are modified.

Significant regional differences in the extent of river modification were identified. Relatively low proportion of river alteration was recorded on the upper course of the Blanice, especially in the area of its right-sided and left-sided tributaries. An exception is represented only by the right-sided tributary Zbytinský potok (the Zbytinský Brook), in the river basin of which extensive hydro-amelioration measures have been taken. Channels have been straightened, deepened and fortified by quarried stones or concrete prefabricated materials. Furthermore, modifications of the channel were performed in the main course of the upper Blanice at the turn of the 19th and 20th centuries, however, these modifications have not brought any significant change of the course or character of the channel, and it is possible to identify them in the present landscape with difficulty only.

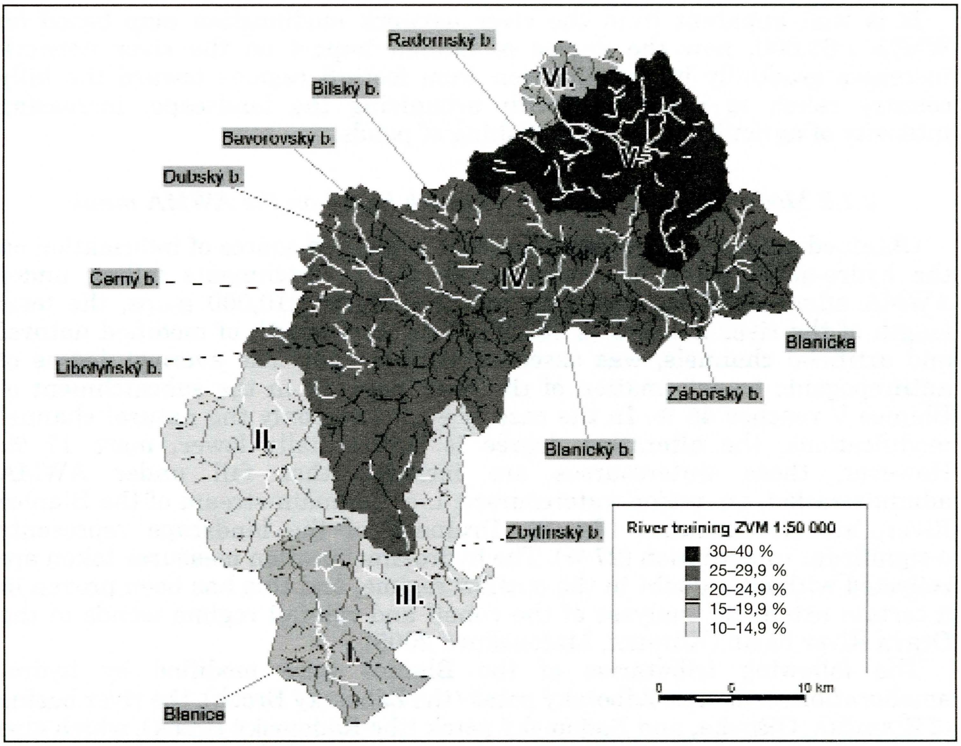

Fig. 2: – The channel modification in the Blanice River basin. Source: WMM (ZVM) maps 1:50,000.

Tab. 1 – The river network modification in the Blanice V. subcatchment. Source maps of the AWMA 1:10,000.

Blanice V.	Watercourse modifications	Drainage	Total modifications	Length of the river network
Length (km) % modification	32.18 17.77	49.09 27.10	81.27 44.87	181.13 100.00

A marked degree of anthropogenic transformation is shown on the middle course of the Blanice River, especially its left-sided tributaries: the brooks Libotyňský potok, Dubský potok, Černý potok, and Bavorovský potok. Further downstream, higher level of modification of right-sided tributaries can be seen, as well in the river basins of the brooks Blanický potok, Radomský potok, Zábořský potok, and Blanička. A high proportion of modified reaches is shown on the lower course of Blanice itself, which is related to the technical flood protection measures.

Furthermore, the river training was studied from the viewpoint of sub-catchments. Six sub-catchments were delimited within the Blanice River basin.

The highest degree of the river network modification (D) has been achieved on the lower and middle course of the Blanice River (Blanice V., D = 40 %, Blanice IV., D = 27 %), see Fig. 2. On the contrary left side tributaries, i.e. the subcatchments II. and III., show lover degree of modification (D = 12%), see Tab. 1.

It is well apparent from the river network modification map based on WMM 1:50,000, how the degree of human impact on the river network increases gradually in the direction from foothill regions toward the hilly country relief, in connection with urbanizing the landscape, increasing intensity of agriculture and establishing of ponds.

3.1.2 Modification of the river network based on the AWMA maps

Obtained mapping materials represent a detailed source of information on the hydro-amelioration measures performed in catchments falling under AWMA administration. Based on the ZABAGED 1:10,000 maps, the total length of the river network is 181 km. The total length of modified natural and artificial channels, was assessed to be 81 km. The average degree of anthropogenic transformation of the river network in the subcatchment of Blanice V reaches 45 %. In the case of evaluating only the natural channel modifications, the alteration degree is substantially lower, mere 17 %. However, those watercourses are included that fall under AWMA administration, i.e. major watercourses, i. e. the main stream of the Blanice River, are not included (fig. 3). Drainage of the landscape represents a significant intervention (27 %). The hydro-amelioration measures taken are reflected without a doubt in the outflow regime, and this has been proven in a certain extent by analyses of the runoff and rainfall regime trends in the Otava River basin (Kliment, Matoušková 2005).

The following tributaries of the Blanice were modified by hydro-amelioration measures: Zábořský potok (the Zábořský Brook), the river basins of Blanička, Olšovka, and Radomský potok (the Radomský Brook), which also

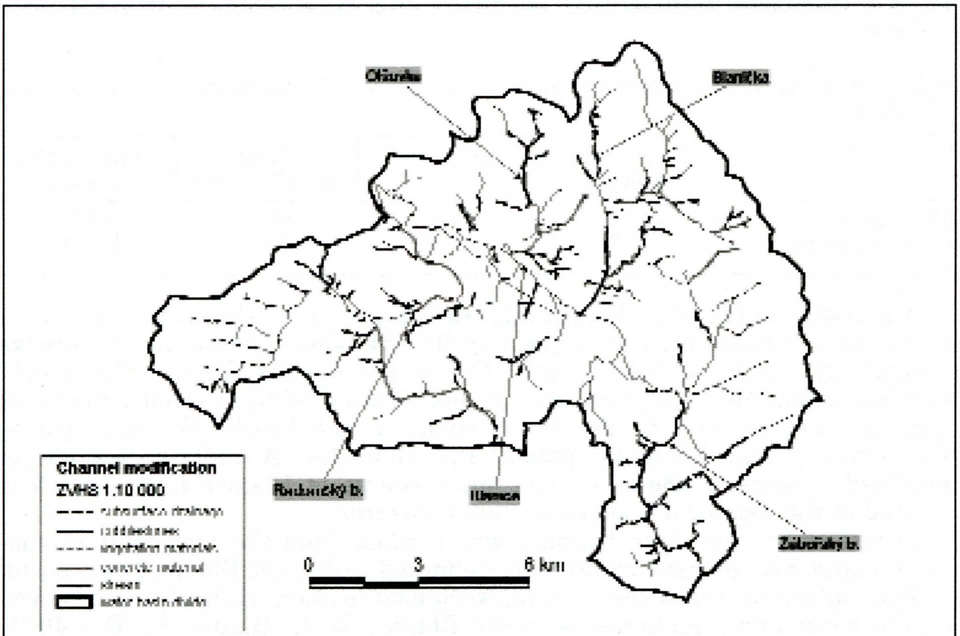

Fig. 3 – River network modification in the Blanice V. subcatchment. Source: AWMA (ZVHS) maps 1:10,000.

corresponds with the analysis performed based on WMM 1:50,000. The oldest river alteration were performed in the period of 1926–1938, namely at the lower course of the Radomský potok and in the Blanička River basin. The modifications concerned a fortification of the riverbeds by cobblestones. Further modification was performed in the 60ies of the 20th century, especially within the catchments Zábořský potok and Olšovka. Concrete materials represent the prevailing type of the fortification. Other channel alteration occurred in the 70ies and 80ies, specifically in the river basins of Olšovka and Blanička. Concrete prefabricated materials were applied mostly. Subsurface drainage was generally performed in linkage to the performed modification of channels in the 60ies – 80ies in the river basins mentioned above.

3.2 Analysis of river network modification based on field mapping

Field mapping of stream and riparian zone modification provided information on the current intensity and spatial differentiation of anthropogenic transformation of the river system of the Blanice River basin. The following was assessed as fundamental modification parameters: Modification of the stream route, modification of the longitudinal profile, and modification of the watercourse riverbed. Mapped indicators, individual categories of modification, and results of evaluation of their participation in the total length of the river network under assessment are summarised in Table 2.

3.2.1 Modification of stream route

Analysis of the stream route modification confirmed a significant share of anthropogenically modified segments in the total length of the river network, as well as strong spatial differentiation of interventions in the ground-plan course of the riverbeds, shown by the analysis of historical changes of the Blanice river network (Langhammer, Vajskebr 2003).

Segments with artificial straightening of the riverbed are found over 40.6 % of the river network length under assessment, while, together with sinuous segments where anthropogenic influence can be expected, as well, they represent more than 75 % of the total length of the river network.

Meandering segments, important for potential usage for transforming the flood wave in the floodplain, are found on 17.4 % of the watercourses length. However, out of this length, only a small part of the segments is usable for passive flood protection. This concern, especially in the lower part of the watercourse, often left meanders, separated from the watercourse by flood protection dykes that prevents their usage as retention area in the event of increased water levels (Fig. 4).

The analysis of transformation of the watercourses riverbed route indicates considerable variability of the modification intensity among individual parts of the

Tab. 2 – Degree of river network modification in subcatchments of the Blanice River basin based on WMM 1:50,000

Subcatchment	Modification (%)
I.	16.2
II.	11.2
III.	11.8
IV.	26.8
V.	39.6
VI.	23.5

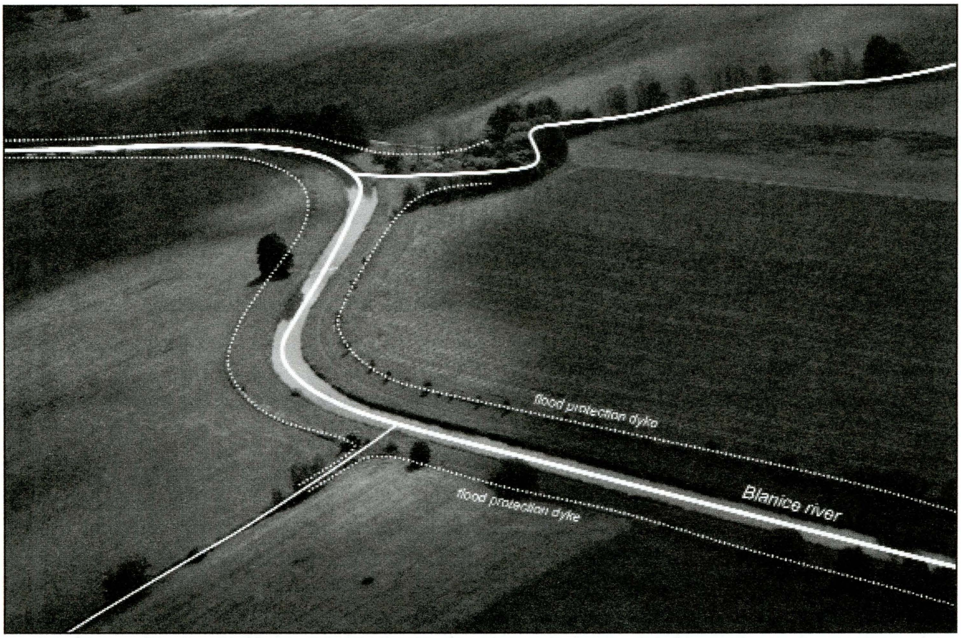

Fig. 4 – Straightened stream of the Blanice River on the down course with flood protection embankments. Flood protection dykes protect here the agricultural land and thus impede efficient usage of the retention potential of the flat floodplain. Photo J. Langhammer 2005.

Tab. 3 – Assessed categories of river network modification and their share on the total lenght of the river network. Data: Field mapping, 2005

Stream route modification	%	Longitudinal profile modification	%	Riverbed modification	%
1. Braided	0.4 %	1. Segment without modifications	70.4 %	1. Natural (without signs of modifications)	46.2 %
2. Branched	1.6 %	2. Naturally low levels in the riverbed (0-50 cm)	16.5 %	2. Vegetation consolidation of the shore	13.7 %
3. Meandering	17.4 %	3. Naturally high levels in the riverbed (above 50 cm)	0.5 %	3. Shore consolidated by wooden round timber	0.3 %
4. Sinuous	35.2 %	4. Low weir (0-1 m)	7.2 %	4. Shore consolidated by non-consolidated stone material	9.3 %
5. Naturally straight	4.9 %	5. Weir in steps, slide	0.7 %	5. Shore or bottom consolidated by quarry stone – levelling material	6.4 % 6.4 %
6. Artificially straightened	40.6 %	6. High weir (above 1 m)	3.2 %	6. Shore or bottom consolidated by semi-vegetation blocks	3.6 %
		7. Dam	1.5 %	7. Shore or bottom consolidated by concrete	18.5 %
				8. Continuous consolid ation of the shore as well as the bottom by concrete	0.7 %
				9. Pipelined stream	1.3 %

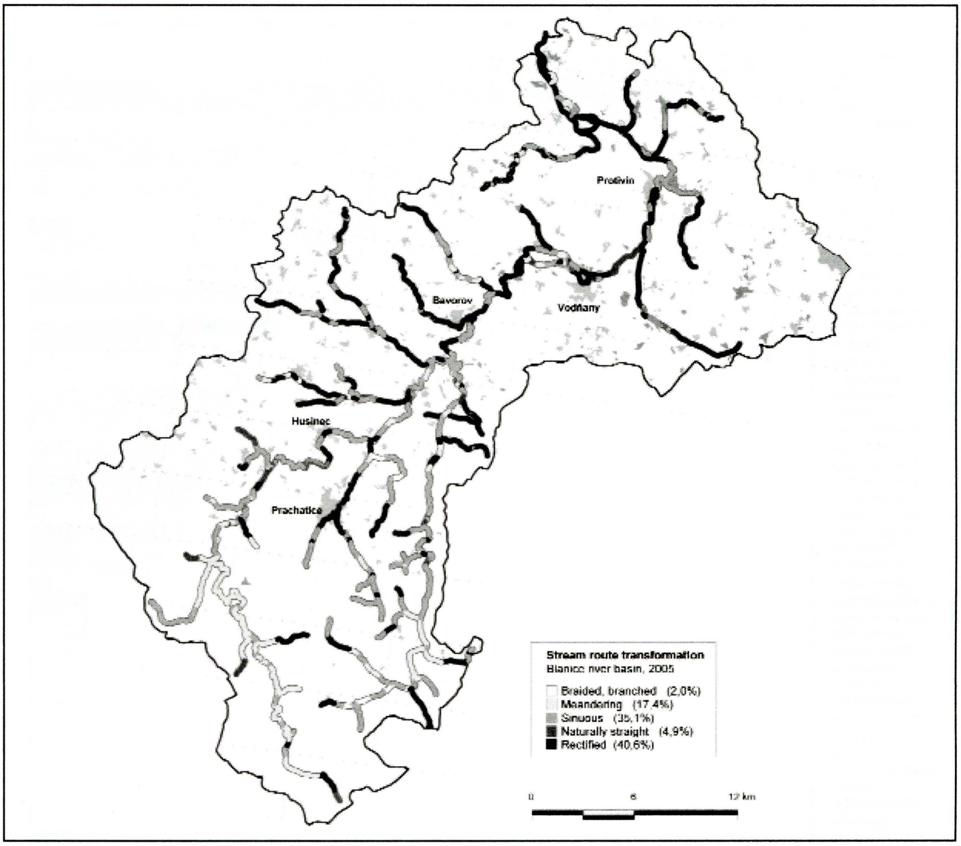

Fig. 5 – Modification of the stream route based on field mapping. Percentage values give the share of the stream length with the given degree of modification of the stream route. Data: Field mapping 2005.

river basin, among individual watercourses as well as among individual watercourse segments. Main watercourses of the river system - Blanice and Zlatý potok - just like their main tributaries, show high variability of modification in individual parts of the river basin - while in the upper watercourse part, virtually natural watercourses are found with a minimum amount of interventions, the route in the lower part of the watercourse is modified considerably in long segments. The highest intensity of modification can be observed on small watercourses in the lower river basin part, in the agricultural region where changes of the stream route geometry are often apparent along the entire length of the watercourse (Tab. 3, Fig. 5).

3.2.2 Modification of longitudinal profile

Modification of the longitudinal profile, i.e. presence of natural or artificial steps in the riverbed, affects significantly the nature of the flow. In flood situations, places of change in the longitudinal profile accelerate erosion as well as accumulation processes, and they thus usually represent centres of increased destructive effects of the flood (Křížek, Engel 2003).

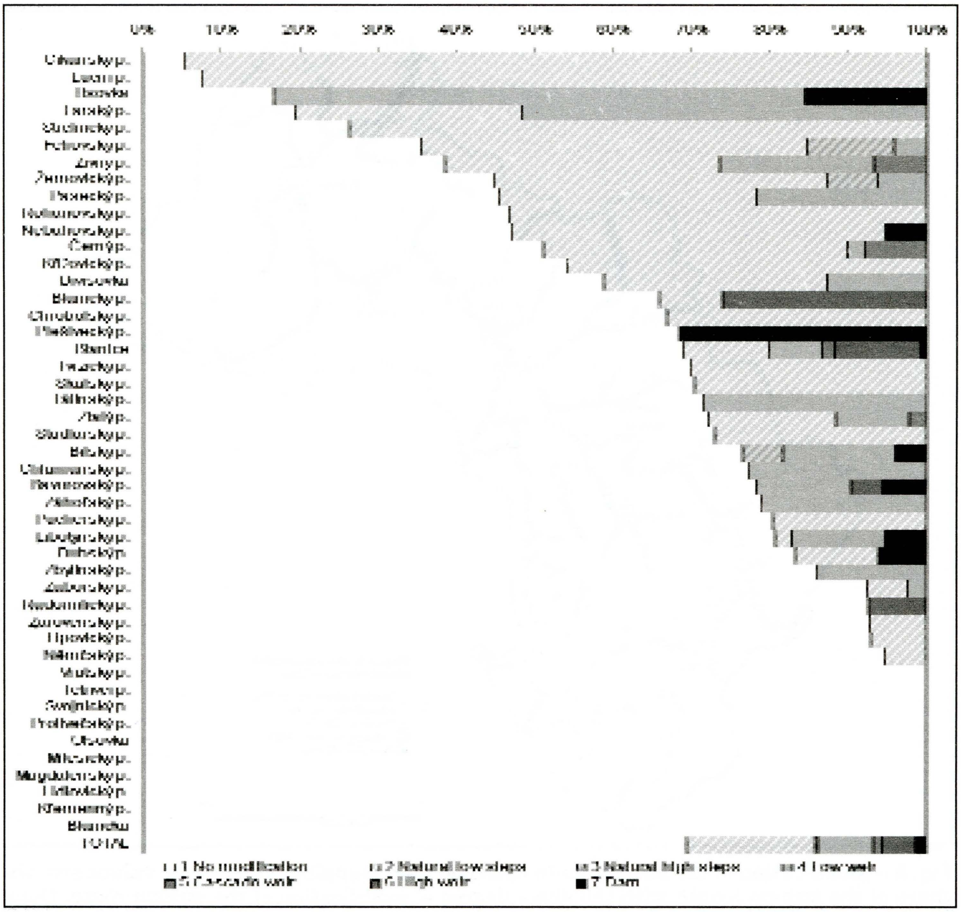

Fig. 6 – Structure of the stream longitudinal profile modification in the Blanice River basin. The percentage values show the share of length of segments with a given degree of modification within the watercourse. Data: Field mapping 2005.

In the Blanice River basin, segments of the longitudinal profile modifications represent a minority in the river network length. More than 70 % of length of the segments does not show traces of modification in the longitudinal profile, however, there are substantial differences between individual watercourses (Fig. 6). Modifications of the longitudinal profile are usually accompanied by straightening of the watercourse, when artificial steps compensate changes in the water level declination and speed of flowing in the straightened segments.

Artificial steps in the riverbed are concentrated spatially especially in the lower part of the Blanice River basin. Lower segments of Blanice and Zlatý potok and their tributaries show modifications of the highest intensity. Watercourses in the mountain part of the Blanice River basin show minimum modifications, on the contrary - the proportion of modified segments with artificial steps in the part of the river basin does not exceed 5 % of the aggregate watercourses length.

3.2.3 Modifications of riverbed

Anthropogenous modification of the watercourse riverbed affects the condition of the flow in the riverbed under normal as well as under extreme water levels. Interventions in the watercourse riverbed are leading, according the material used, into reduction of the riverbed hydraulic roughness, and consequently into increase of the flow velocity.

Modification of the watercourses riverbeds was evaluated separately during mapping for the right and left river bank, in categories summarized in Table 2. For the overall evaluation the modification level in the given segment was evaluated as the highest modification intensity value recorded for the right or left bank of the given segment.

There are remarkable regional differences in the Blanice river basin, as for intensity and nature of modification of the watercourses riverbeds. In the river basin as a whole, there is a marked high proportion of non-modified segments along the total length of the river network assessed - the total of 46.2 % and together with the slight modification forms they represent 60 % of the entire river network length.

Segments with the highest transformation intensity, i.e. segments with the riverbed partially or completely consolidated by concrete including tubing, represent more than one fifth of the whole river network length. Such a high proportion of intensively modified segments of watercourses is not adequate to the nature of the land use. Share of the segments in urban or industrial areas, where intensive modification may form part of flood protection measures, does not exceed 5 % in the river basin. A considerable part of the intensive modifications of the watercourses riverbeds, especially in the case of small watercourses, is a result of agricultural ameliorative measures from the second half of the 20th century. From the viewpoint of the current view of management of watercourses as well as needs of complex flood protection, this manner of watercourses modification is obsolescent, and revitalization modification could represent a suitable solution for a number of such watercourses.

Besides the nature of the riverbed modification, the watercourse modification structure, i.e. alternation of modified and non-modified segments, is of extraordinary importance for water flowing during a flood and for the nature of the consequences. Long modified segments increase the flowing speed and when passing into non-modified segments, especially at places of bends or meanders, acceleration of erosion and accumulation manifestations occurs. From the viewpoint of flood protection, pipelined segments and culverts represent an element with extraordinary risk, as these elements become blocked by materials drifted by the flood, with subsequent destruction of the respective structure and formation of the secondary flash-flood wave (fig. 7).

4. Discussion

Comparison of results of the watercourse modification assessment obtained from the field mapping and analysis of distance data is difficult in respect of the different nature of input data and methodology of their acquisition. In spite of that, it is apparent that the results are comparable as for the basic parameters.

First, this is a confirmation of results of the watercourse changes analysis from historical mapping materials (Langhammer, Vajskebr 2003) with

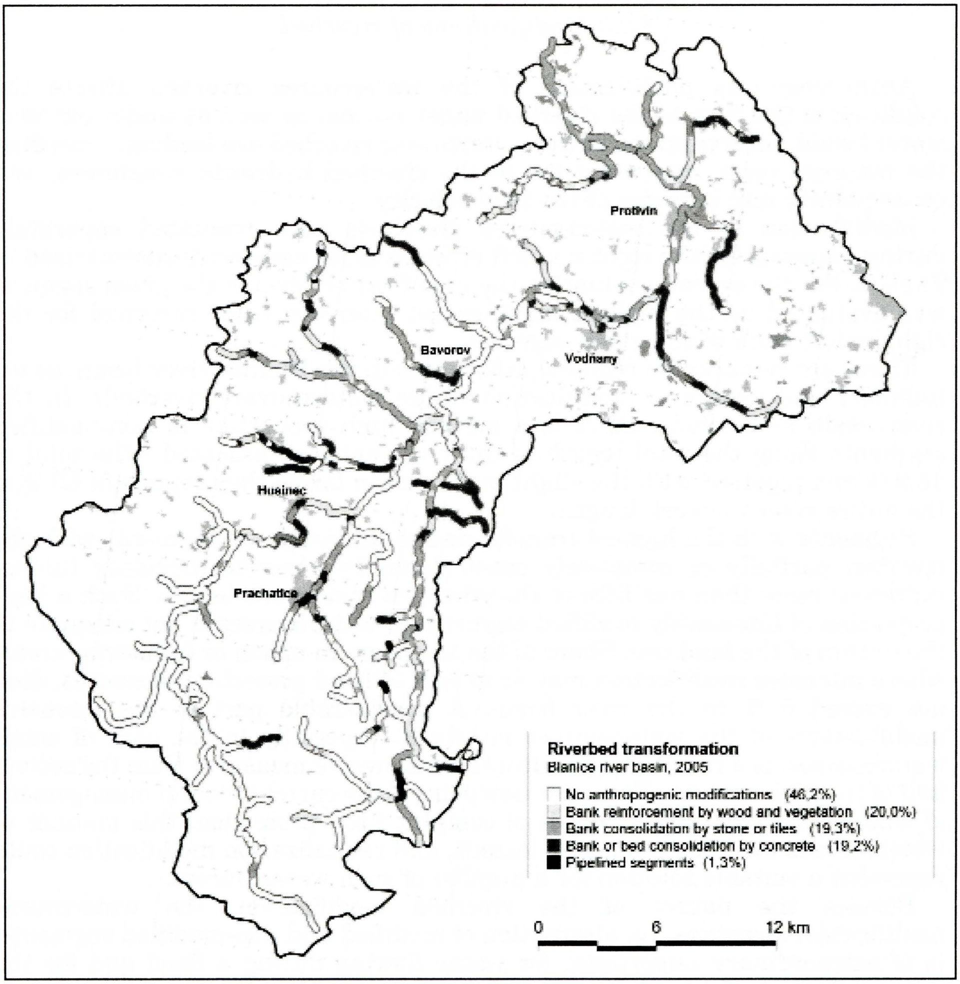

Fig. 7 – Modification of watercourses in the Blanice River basin. Data: Field mapping 2005.

results of field mapping. Segments identified as straightened based on assessment of the historical watercourse changes show signs of modifications of the stream route in field mapping, as well.

Comparison of the degree of anthropogenic transformation from the Water Management Map analysis also corresponds with findings from the terrain investigation, both from the viewpoint of the whole river basin of Blanice, as well as in comparison of regional differences. Accurate comparison of the values obtained is not possible in respect of varying scales of the used topographical maps and methodology; in spite of that, the results show identical relationships as for basic categories of modification.

Therefore, usage of distance mapping and data materials can be recommended as the fundamental data source for identification of anthropogenically affected segments of the river network, and for assessment of overall values of modification intensity of individual river basins. For accurate assessment of the nature and intensity of the modifications and identification of critical segments, in respect of possible affecting of the course and consequences of floods, it is necessary to use field mapping. Specifically focused field mapping provides the accurate data that can be used both to evaluate the current state of the river network transformation, as well as the data for further analysis, like, for example, hydraulic modelling or geostatistical assessment. As for practical application of assessment of anthropogenic modification of the river network, it is necessary to stem from limits given by individual methodical approaches, availability, and nature of the data used, and the exacting character of their acquisition.

Analysis of modification of the watercourses and the floodplain based on field mapping offers possibilities of assessment of a large amount of aspects of the river network anthropogenic transformation, together with further indicators, such as, for example, evaluation of the course and consequences of floods. Experience from mapping of the watercourses and river network modification within medium-sized river basins shows that for practical usage, it is important to fulfil the following conditions:

- precise formulation of the assessment goal and definition of the corresponding mapping parameters and categories
- ensuring of the assessment objectivity in field mapping methodology
- ensuring of data consistency obtained from multiple mappers
- choice of a suitable data collection technique and sound preparation of materials for mapping
- choice of suitable results processing technology
- balancing of the proportion between the informative value of the data obtained and the exacting character as far as time and costs are concerned of their acquisition
- ensuring of broader usability of the results obtained and compatibility of the information obtained with general standards.

Formulation of the assessment goal, and definition of suitable indicators and the structure of mapped parameters, represents a key condition for successful acquisition, analysis, interpretation, and usage of the watercourse modification data. For the specific purpose of assessment, it is desirable to pay attention to selection of only those indicators that are relevant for the resulting evaluation, and selection of those categories that can provide the information needed. Input data of non-suitable structure may make proper assessment and interpretation of the results more difficult or impossible. Parameters not used in the assessment moreover markedly extend the time needed for field mapping as well as digitising of the results, and they thus results in higher costs of the mapping. If a more extensive region is the subject of assessment, a key condition to obtain reliable data is represented by preserving the consistency of assessment of multiple mappers. The decisive role is played by sound preparation of ground materials, training of the mappers, their supervision, and checking of the results.

The present dynamic evolution of geospatial technology allows the usage of new tools for field mapping. This applies mainly to the usage of handheld devices equipped with mobile GIS applications like e.g. ESRI ArcPad. Experience from field testing of these mobile technologies however shows that in case of mapping with complex set of assessed features these tools offer lower flexibility in routine usage compared to traditional procedures, require specialized training technical help for mappers, prove sensitivity to atmospheric conditions, and are considerably more demanding as far as the financial costs are concerned.

Informative value of the source data represents a significant limiting element for assessment based on distance data. The informative value is influenced by the differing nature of various data sources, as well as by the degree cartographic generalization. The data obtained from WMM 1:50,000 capture modification of the major watercourses and their tributaries. The AWMA database records channel modifications of small and middle-sized catchments and drainage measures that fall within the AWMA administration. As for modification of individual tributaries, both of the mapping sources match. In order to perform overall balance of modification of the river network in the entire Blanice River basin, the assessment applied based on WMM 1:50,000 provides good informative value. The analysis performed in the scale 1:10,000 makes the information more accurate, and at the same time, it allows to perform basic qualitative assessment of the river network modification, i.e. assessment of the channel fortification and their age. A disadvantage is represented by the fact that AWMA maps do not have the character of a geodatabase. It must be also mentioned that the analysis performed does not take into account anthropogenic modifications performed in the longitudinal profile of the watercourse, i.e. slope modifications and building of weirs and water reservoirs.

5. Conclusions

The Blanice River basin can be termed as a region where the river network has been remodelled in a significant extent. A relatively high degree of modification is present here, especially on middle and lower courses. Marked spatial differentiation of intensity of anthropogenic interventions in the river network is characteristic in individual parts of the river basin as well as between individual watercourses assessed. In general, it can be stated that from mountain and foothill regions toward middle and lower courses, the degree of modification of the river network increases. This is clearly related with the growth of agriculturally cultivated areas and urbanized areas. The highest degree of modification of the river network was recorded in the lower part of the Blanice River. The main cause is represented by flood protection and hydro-amelioration measures in the landscape. The majority of the hydro-amelioration was performed in 1960-1980. Concrete materials and cobblestones represent the prevailing type of fortification of the riverbeds. It follows clearly from both analyses that the degree of anthropogenic modification of the river network reaches more than 40 % on the lower course of the Blanice River. Such remodelling of the river network has changed the flow regime, and especially has an influence on transformation of flood waves. Moreover, the high intensity of channel modification in a number of segments, especially in the area of the flat floodplain in the lower course of the Blanice River, represents an obstacle for efficient usage of the natural retention and transformation potential of the floodplain for the needs of passive flood protection (Janský 2003).

The methodologies used for mapping of channel modification and of the riparian zone, and the distance data analyses applied on the Blanice River basin, have shown the possibilities as well as limits of their usage. The results have confirmed that analysis of anthropogenic transformation of the river network represents a significant tool both to evaluate the intensity of affecting the environment, as well as to provide valuable information to assess vulnerability of the territory by the flood risk and identification of risk elements in the river systems.

References:

BARBOUR, M. T., GERRITSEN, J., SNYDER, B. D., STRIBLING, J. B. (1999): Rapid bioassessment protocols for use in streams and wadeable rivers: Periphyton, Benthic Macroinvertebrates and Fish. Second Edition. EPA/841-B-98-010. U.S. EPA. Office of Water. Washington. D.C., 344 p.

BICANOVÁ, M. (2005): Použití metody ekomorfologického monitoringu v povodí Košínského potoka s využitím nástrojů GIS. Thesis. PřF UK v Praze, Praha, 108 p.

HAVLÍK, A., JUST, T., SLAVÍK, O. (1997): Ekologická studie povodí Bíliny, VÚV TGM, Praha, 70 p.

JANSKÝ, B. (2003): Water Retention in River Basins. Acta Universitatis Carolinae – Geographica, XXXVIII, No. 2, UK, Praha, pp. 173-184.

KLIMENT, Z., MATOUŠKOVÁ, M. (2005): Trendy ve vývoji odtoku v povodí Otavy. Geografie-Sborník ČGS, 112, No. 1, pp. 32-45.

KŘÍŽEK, M., ENGEL, Z. (2003): Geomorphological consequences of the 2002 Flood in the Otava River Drainage Basin. Acta Universitatis Carolinae-Geographica, XXXVIII, No. 2, pp. 125-138.

LADSON, A. R., WHITE, L. J. et al. (1999): Development and testing of an Index of Stream Condition for waterway management in Australia. Freshwater Biology, 41, No. 2, pp. 453-468.

LANGHAMMER, J. (2003): Anthropogenic Transformation of river network in the Otava River Basin. Acta Universitatis Carolinae-Geographica, XXXVIII, No. 2, pp. 139-156.

LANGHAMMER, J. et al. (2003): Hodnocení vlivu změn přírodního prostředí na vznik a vývoj povodní. Charles University Report - GAČR 205/03/Z046, Praha, 87 p.

LANGHAMMER, J., VAJSKEBR, V. (2003): Historical Shortening of river network in the Otava River Basin. Acta Universitatis Carolinae-Geographica, XXXVIII, No. 2, pp. 109-124.

MATOUŠKOVÁ, M. (2003): Ekohydrologický monitoring jako podklad pro revitalizaci vodních toků. Ph.D. Thesis, Department of Physical Geography, Faculty of Science, Charles University in Prague, Prague, 218 p.

MATOUŠKOVÁ, M. (2004): Ecohydrological Monitoring of the River Habitat Quality. Geografie-Sborník ČGS, 109, No. 2, pp. 105-116.

MATOUŠKOVÁ, M. (2005): Assessment of the human impact on the river network as a basis for ecohydrological monitoring of streams. Geographical Review CXXIX. (LIII.), pp. 35-46.

NIEHOFF, N.(1996): Ökologische Bewertung von Fliessgewässerlandschaften: Grundlage für Renaturierungund Sanierung. Springer-Verlag, Berlin, Heidelberg. 300 p.

RAVEN, P. J., FOX, P. J. A, EVERARD, M, HOLMES, N. T. H., DAWSON, F. D. (1997): River Habitat Survey: a new system for classifying rivers according to their habitat quality. In: Boon, P. J., Howell, D. L. (eds): Freshwater Quality: Defining the Indefinable? The Stationery Office, Edinburgh, pp. 215-234.

ROSGEN, D. L. (1996): Applied River Morphology. Wildland Hydrology Books, Pagosa Springs. 352 p.

VILÍMEK, V., LANGHAMMER, J., KŘÍŽEK, M. (2003): Posouzení efektivnosti změn ve využívání krajiny pro retenci a retardaci vody jako preventivní opatření před povodněmi. Závěrečná zpráva do vlády z dílčí etapy projektu Vyhodnocení katastrofální povodně v srpnu 2002. Přírodovědecká fakulta UK, Praha, 67 p.

VLČEK, L., ŠINDLAR, M. (2002): Geomorfologicke typy vodnich toku a jejich vyuziti pro revitalizace. Vodní hospodářství, 6, p. 172-176.

VÚV TGM (2003): Vyhodnocení katastrofální povodně v roce 2002. Průběžná zpráva o řešení projektu, Praha, http://www.vuv.cz/povoden/main.html.

Shrnutí

MAPOVÁNÍ A GEOINFORMATICKÁ ANALÝZA UPRAVENOSTI TOKŮ A ÚDOLNÍ NIVY JAKO FAKTORU POVODŇOVÉHO RIZIKA

Antropogenní zásahy do koryt toků představují významný fenomén, který ovlivňuje odtokové poměry zasažených povodí jak za normálních vodních stavů, tak v období hydrologických extrémů. Úpravy toků na různé úrovni – od zásahů do geometrie trasy toku přes přítomnost umělých stupňů v jeho podélném profilu až po úpravy vlastního koryta či úpravy příbřežní zóny, při povodních výrazně ovlivňují rychlost a charakter odtoku vody z povodí. Jedná se zejména o rychlost postupu povodňové vlny, možnost její efektivní transformace, změnu časování souběhu povodňových vln z různých částí povodí a v neposlední řadě přispívají rozdílnou měrou k charakteru vzniklých škod na majetku, infrastruktuře i krajině.

Příspěvek představuje metodický rámec pro hodnocení antropogenní upravenosti toků na základě dvou základních přístupů, vycházejících z analýzy distančních dat a z terénního mapování. Analýza distančních dat vychází z analýzy GIS historických a recentních kartografických podkladů, jaké představují např. historické mapy či ortofoto snímky. Pozornost je věnována zejména těm datovým podkladům, které vzhledem ke kartografické kvalitě umožňují více či méně realistické srovnání se stávajícím stavem. Takovými podklady jsou na našem území např. mapy 2. a 3. vojenského mapování Rakousko-Uherské monarchie či mapy Stabilního katastru, které umožňují analýzu vývoje jednotlivých prvků krajiny v posledních cca 160 letech. Jako další datový vstup pro hodnocení dynamiky změn v podrobném měřítku jsou diskutovány ortofoto snímky, umožňující zachytit změny krajiny od 30. let 20. století, tj. včetně nejdynamičtějších fází vývoje zahrnujících období kolektivizace a intenzifikace zemědělství i změny po roce 1990.

Terénní mapování naproti tomu umožňuje zachytit změny v krajině v nejvyšší míře detailu a především v parametrech, které není možné odečíst nebo odvodit z distančních podkladů. Jde zejména o hodnocení intenzity a charakteru antropogenní upravenosti říční sítě na úrovni trasy toku, podélného profilu, příčného profilu, břehové vegetace či využití příbřežní zóny či identifikaci potenciálních překážek proudění při povodni. Výsledky mapování upravenosti toků a příbřežní zóny je možné díky integraci v GIS vyhodnotit společně s informacemi odvozenými z distančních podkladů či popisujícími jiné aspekty hodnoceného procesu.

Oba přístupy - hodnocení na základě distančních dat i na základě terénního mapování, jsou aplikovány na konkrétním příkladu povodí Blanice ležící v jádrové oblasti extrémní povodně, která v srpnu 2002 zasáhla oblast střední Evropy. Autoři se zde zaměřují na vyhodnocení současného stavu upravenosti říční sítě a její prostorové variability a zároveň diskutují možnosti a limity praktického využití jednotlivých přístupů a zdrojů dat pro získání objektivních podkladů pro komplexní hodnocení povodňového rizika a jejich praktickou aplikaci.

Výsledky provedených analýz ukazují, že povodí Blanice představuje území, kde byl významně přemodelován charakter říční sítě. Setkáváme se zde s relativně vysokým stupněm upravenosti, především na jejím středním a dolním toku. Charakteristická je výrazná prostorová diferenciace intenzity antropogenních zásahů do říční sítě v jednotlivých částech povodí i mezi jednotlivými hodnocenými toky. V obecné rovině lze konstatovat, že od horských a podhorských oblastí směrem ke středním a dolním tokům stupeň upravenosti říční sítě roste, což zcela jednoznačně souvisí s nárůstem zemědělsky obhospodařovaných ploch a urbanizovaných území. Největší upravenost říční sítě byla zaznamenána na dolním toku Blanice. Hlavní příčinnou jsou protipovodňová a hydromeliorační opatření v krajině. Většina hydromelioračních úprav byla provedena v období 1960-1980. Převládajícím typem opevnění koryt jsou betonové prefabrikáty a kamenná dlažba.

Z obou analýz jednoznačně vyplývá, že stupeň antropogenní upravenosti říční sítě dosahuje na dolním toku Blanice více než 40 %. Takovéto přemodelování říční sítě, má nepochybně vliv na charakter odtokového režimu a především na transformaci povodňových vln. Vysoká intenzita upravenosti koryt toků navíc v řadě úseků, zejména v oblasti ploché údolní nivy na dolním toku Blanice, představuje překážku pro efektivní využití přirozeného retenčního a transformačního potenciálu údolní nivy pro potřeby pasivní protipovodňové ochrany.

Použité metodiky mapování upravenosti koryta toku a příbřežní zóny a analýzy distančních dat, aplikované na povodí Blanice, ukázaly možnosti i limity jejich využití. Výsledky potvrdily, že analýza antropogenní transformace říční sítě je významným nástrojem jak pro hodnocení intenzity ovlivnění přírodního prostředí, tak poskytuje cenné informace pro hodnocení zranitelnosti území povodňovým rizikem a identifikaci rizikových elementů v říčních systémech.

Obr. 1 – Princip členění toků na úseky a jejich propojení s databázovými záznamy.
Obr. 2 – Upravenost toků v povodí Blanice. zdroj. ZVM 1:50 000
Obr. 3 – Upravenost říční sítě v dílčím povodí Blanice V. Upravenost koryta: podpovrchová drenáž, dlažba, vegetační opevnění, beton, tok, rozvodnice

Obr. 4 – Napřímené koryto Blanice na dolním toku s protipovodňovými valy. Povodňové hráze zde chrání zemědělskou půdu a brání tak efektivnímu využití přirozeného potenciálu ploché údolní nivy. Foto J. Langhammer 2005.

Obr. 5 – Upravenost trasy toku na základě terénního mapování. Procentuální hodnoty udávají podíl délky toku s daným charakterem upravenosti na celkové délce hodnocené říční sítě. Data: Terénní mapování, 2005. Upravenost trasy toku: rozvětvený, divočící (2,0 %), meandrující (17,4 %), zákruty (35,1 %), přirozeně přímý (4,9 %), napřímený (40,6 %)

Obr. 6 – Struktura upravenosti podélného profilu v povodí Blanice. Procentuální hodnoty udávají podíl délky toku s daným charakterem upravenosti na celkové délce hodnocené říční sítě. Data: Terénní mapování, 2005

Obr. 7 – Upravenost koryt toků v povodí Blanice. Upravenost koryta toku: bez úprav (46,2 %), vegetační zpevnění a dřevěná kulatina (20,0 %), zpevnění břehu lomovým kamenem nebo kamennou dlažbou (19,3 %), zpevnění břehu nebo dna betonem (19,2 %), zatrubnění (1,3 %). Data: terénní mapování, 2005.

(Authors are with Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology, Albertov 6, 128 43 Praha 2, Czechia; e-mail: langhamr@natur.cuni.cz, matouskova@natur.cuni.cz.)

Arrived to the editorial board on August 28, 2006

GEOGRAFIE – SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI
ROK 2006 • ČÍSLO 3 • ROČNÍK 111

ZDENĚK KLIMENT, MILADA MATOUŠKOVÁ

CHANGES OF RUNOFF REGIME ACCORDING TO HUMAN IMPACT ON THE LANDSCAPE

Z. Kliment, M. Matoušková: *Runoff changes according to human impact on the landscape.* – Geografie–Sborník ČGS, 111, 3, pp. 292–304 (2006). – The main aim of our research project was to determine the extent to which the outflow can be influenced by the human interventions in three-selected water basins in Bohemian Forest (Šumava Mountains) and foothills. The rainfall-runoff analyses using both the single and double mass curves over the period of the hydrologic observations were taken as a basic methodology. Beside mean discharge, precipitation, snow and air temperature trends, analysis of land cover change and human impact on the river network and drainage areas development were applied too. The greatest deviations were widely observed in the period between the 2nd half of the seventies and in the 1st half of the eighties. The whole system came slowly back to its initial condition in the early nineties. The runoff trend deviation has been related to the nature and human factors, mainly to current climatic changes and changes of landscape retention potential.
KEY WORDS: trend analysis – runoff – climate change – human impact – Otava River – Czechia.

The presented research was funded by the Research Plan MSM 0021620831 "Geographical Systems and Risk Processes in Context of Global Changes and European Integration" of the Czech Ministry of Education and Research Project VaV-SM/2/57/05 "Long-term changes of river ecosystems in floodplains affected by extreme floods" of the Ministry of Environment of the Czech Republic which is fully appreciated by the authors.

1. Introduction

The floods experienced recently in Czechia gave rise to numerous discussions over the changed environment and related potential impacts on the rainfall and runoff processes. Besides climate change, attention is being drawn to human influence. The Czech landscape has developed in a specific way, which differs from region to region in terms of the intensity of anthropogenic intervention into water balance. Not even mountain and foothill areas have escaped such changes.

The impact of human activities on runoff regimes has been proven by a number of experimental studies from various parts of the world, including several from Czechia. An example of this is the long-term research in the experimental water basins concentrated on monitoring the influences of forest and deforestation (Válek 1953; Netopil 1955; Křeček 1980; Kříž 1981, Jařabáč, Chlebek 1984; Šeborová 1994, Blažková 1994). The studies by Kulhavý (1999) and Krečmer (2003) revealed the ambiguity of the results on surface runoff in respect to forest age and species. A higher and less balanced outflow was observed in agriculturally cultivated areas (Föhrer et al. 2001; Klöcking, Haberlandt 2002, Robinson et al. 2003). Another problem is drainage, which affects on average up to 25.5 % of farmland in the Czechia,

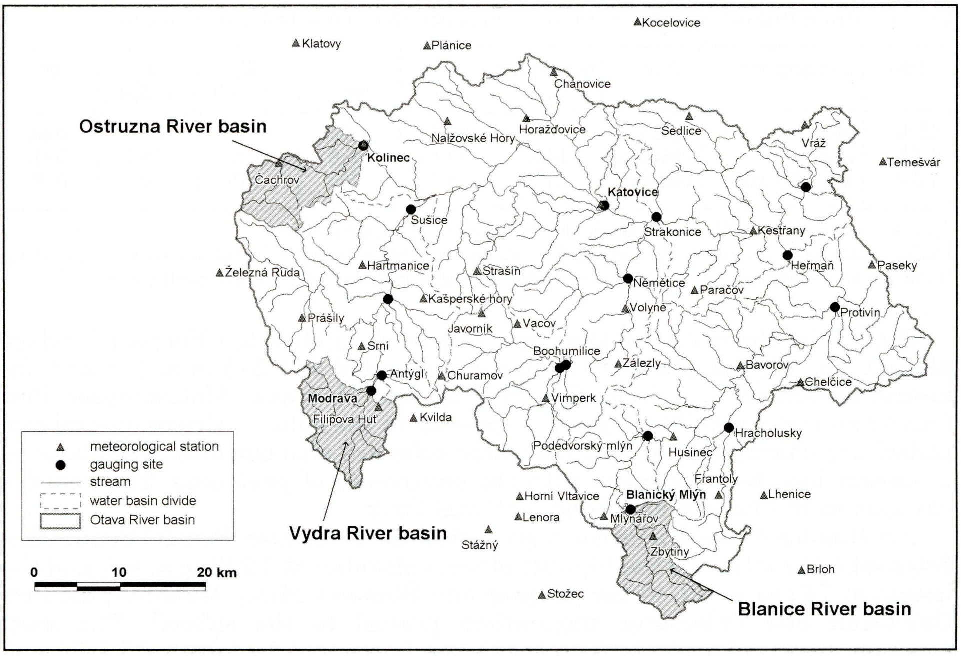

Fig. 1 – Location of the study areas in the Otava River basin: Vydra, Blanice and Ostružná River basins. Source: Basic Water Management Map 1:50 000.

the highest rate in Europe. In general, drainage reduces the level of subsurface water and accelerates and increases the outflow average and minimum (Švihla 1992). The surface drainage contributes to an increase in the discharge effect during the floods (Doležal 2004). Special attention is paid to urban areas often associated with channelization, water reservoirs construction and taking water from rivers (Goudie 1992; Meyer 2001; Sochorec 1977; Lhotský 1999; Kaňok 1999; Kříž 2003).

The main aim of this study is to monitor and try to explain changes in the development of the rainfall - runoff relationship in three water basins situated in the Vltava River headstream area: the Vydra, the Ostružná and the Blanice River basins (see Fig. 1). The selected water basins represent areas of diverse land use with different levels of anthropogenic intervention in the runoff regime. All three basins played an important role during the initial formation of outflow during the catastrophic floods in Czechia in August 2002 (Langhammer et al. 2003; Kliment, Matoušková 2005).

2. Characteristics of water basins

The upper stream of the *Ostružná* River drains the high part of the Bohemian Forest (the Kocháňské plains). Most of the basins belong under the Bohemian Forest foothills. The highest place is situated at 1 177 m a. s. l., the lowest part at 528 m a. s. l. in the gauging site Kolinec. Metamorphic Pre-Cambrian rocks, orthogneisses and paragneisses, prevail in the subsoil. Cambisols merge into cryptopodsols and podsols at higher altitudes. The landscape is used for agriculture. The forestation reaches 40.7 %, arable land accounts for only 17.2 % in the present. The countryside settlement is typical for this area (see Tab. 1).

Tab. 1 – Basic rainfall and water runoff characteristics of the test water basins

DBNr.	Gauging site	River	monitoring from	A (km^2)	P* (mm)	Q_a (m^3.s^{-1})	q_a (l.s^{-1}.km^{-2})	φ*
1350	Modrava	Vydra	1931	93.41	1 327	3.18	35.2	0.84
1390	Kolinec	Ostružná	1949	92.42	916	1.20	13.1	0.45
1450	Blanický Mlýn	Blanice	1953	85.21	760	0.79	9.2	0.38

*Data from 1961–2002, other from the beginning of measurement.
DBNr: database number; A – area, P – mean annual amount of precipitation; Q_a – long-term mean discharge, q_a – long-term mean specific outflow, φ – runoff coefficient

The *Vydra* River drains the high part of the Bohemian Forest (Kvildské plains). The highest place of the basin is situated at 1 373 m a. s. l. and the lowest at 935 m a. s. l. in the gauging site Modrava. Metamorphic Pre-Cambrian rocks with biotic granites prevail in the subsoil. Crypto-podsol and podsol are characteristic, hydromorphic soils are also common. The basin is a natural forested landscape with the occurrence of peat bogs. The basin is situated in the Bohemian Forest National Park.

The *Blanice* River drains the high part of the Bohemian Forest (Boubínsko-želnavské Mountains). The highest place is situated at 1 228 m a. s. l. and the lowest at 743 m a. s. l. in the gauging site Blanický Mlýn. Metamorphic Pre-Cambrian and Palaeozoic migmatites prevail in the subsoil. The most common are cryptopodsols. The landscape is covered by forest (66.7 %) and meadows (27.7 %). At present, a cattle breeding is typical for the area.

3. Methods and data sources

The methodology of the research comprises analytical and synthetic procedures. The basic analytical procedure can be regarded as the analysis rainfall and runoff trend regime supplemented by an analysis of air temperature and snow parameters relationships. The method of simple and double mass curves was used as the main method for the evaluation of the trend in outflow values development in the selected water basins. Significant deviations from the linear course together with sudden variations can indicate changes in the runoff regime. Besides simple mass curves for basic discharge characteristics and precipitation, double mass curves for cumulative precipitation and discharge values were plotted for a better identification of changes in the trend. The analysis itself was preceded by the necessary step of homogenizing the precipitation data, during which missing data was completed on the results of a regressive analysis of the time sequences of monthly precipitation from adjacent stations. Thiesen polygons method was used first to derive the precipitation in the water basins. Subsequently, a method taking into account the altitude was used (Kavan 2004).

During the next step, a frequency analysis of high water level events was carried out. The frequency was assessed based on the occurrence of five-year and larger events respecting the separation of individual flood waves. The analysis of runoff changes trend was followed through by an analysis of changes in the runoff distribution during the year.

The development of runoff in the given water basins was further supplemented by an analysis of the development of air temperature and snow characteristics (number of days with snow cover; average and maximum snow cover depth). Trends were described in the form of 5-year moving averages of monthly, annual and seasonal values. The basic source of input outflow and climate values was the Czech Hydrometeorological Institute (CHMI) database.

Following the analysis of the trends in runoff, rainfall and air temperature regimes, analysis of changes in landscape use, river network training and land drainage were carried out. The results were related to the duration of the water level monitoring in the given water basins, i.e. over approximately the last 50 years. Changes in land use were assessed based on cadastre register (Bičík et al. 2003) and with the help of database CORINE Land cover (1992, 2000). The human impact on the river network was evaluated based on Water Management Maps (WMM) 1:50 000 and on materials provided by the Agricultural Water Management Authority (AWMA). Land drainage and its development over time was derived from map documents with a scale of 1:10 000, as provided by AWMA. The existing analogue and digital databases, as well as the terrain research itself, were used.

3.1 Analysis of rainfall-runoff regime trends

The method of simple and double mass curves was used for the identification of significant changes in the water runoff regime. Considerable changes were identified in the Ostružná River basin, where an increase in runoff was recorded in the period 1975–1980. A less considerable change in the trend in the period 1975–1982 was also confirmed on the Blanice River. On the contrary, on the Vydra River no changes in the water runoff regime were identified (see Fig. 2).

An analysis of the high water level occurrence was carried out in order to explain the cause of significant changes in the runoff trend. The 5-year event level was used as the limit for high discharges. It was derived empirically using

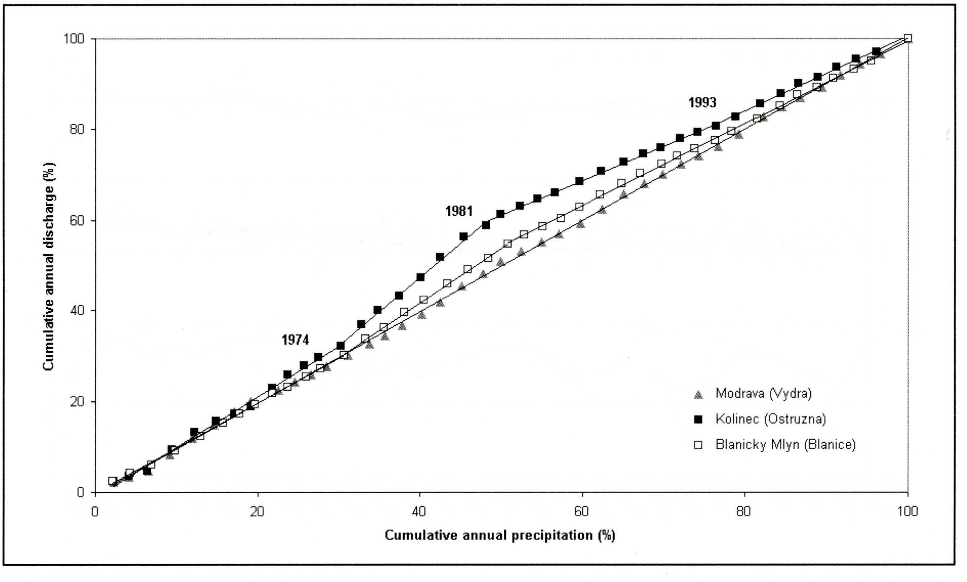

Fig. 2 – Double mass curves of annual precipitation and discharge for gauging sites: Modrava, Kolinec, Blanický Mlýn. Source: CHMI.

probability curves. The analysis confirmed that the identified trend in the water runoff increase is connected with the occurrence of a high water level. In the period 1979–1981, a concentrated occurrence higher water level events recorded all the observed gauging sites. The occurrence of a high water level was on the Vydra River did not manifest itself significantly changes in the long-term runoff regime. Based on these facts the occurrence of flood discharge is not a determining factor in changes in the water runoff development.

Seasonal runoff changes within a year were assessed based on the development of the percentage share of runoff both in individual months and individual seasons. What is characteristic for the water runoff regime in the last 50 years is the considerable increase (of more than 5 %) in the winter months, particularly after 1975. On the other hand, we can see a gradual decrease in the runoff in summer months for the same period, with exception floods in August 2002. The largest increase is in December and the largest decrease is in July. Monthly and seasonal shares of precipitation remain approximately the same in the given seasons without perceptible trends or deviations. The Vydra River basin does not display any significant changes in its water runoff distribution.

Tab. 2 – Mean annual air temperature and snow cover characteristic

Climatic stations	Klatovy	Kašperské Hory	Churáňov
Altitude (m a.s.l.)	430	737	1 118
Mean air temperature (°C)	8.1	6.2	4.4
Mean precipitation (mm)	607	830	1 098
Mean snow cover depth (cm)	6.6	14.3	39.1
Mean maximum snow cover depth (cm)	17,5	39.3	97.5
Mean numbers of day with snow cover	49.9	88	143.9

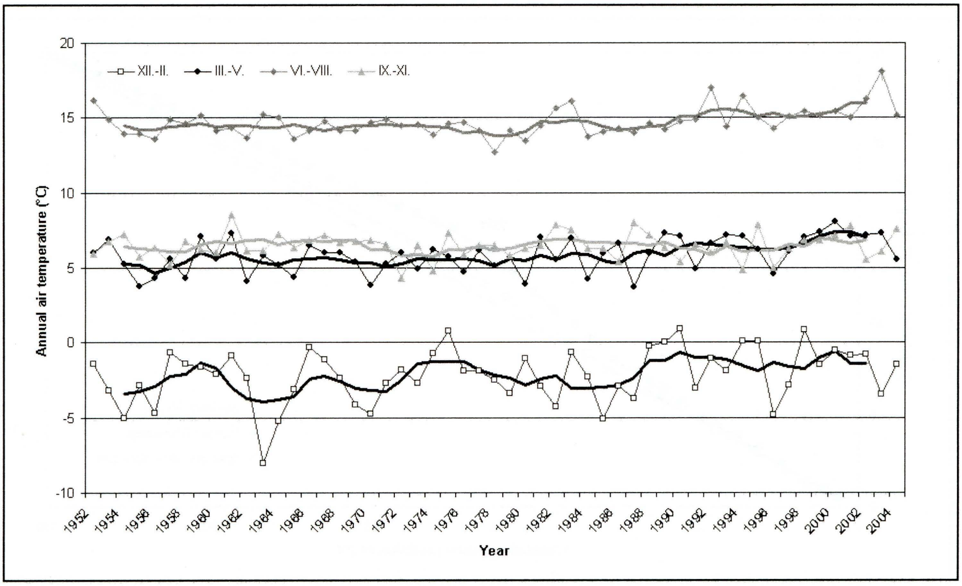

Fig. 3 – Development of mean air temperature in season periods. 5-years moving averages were used. Climatic station Kašperské Hory. Source: CHMI.

3.2 Air temperature and snow parameters analysis

Changes associated with global warming have been frequently discussed in the last few decades. Snow and air temperature parameters were compiled from three climate stations. The stations are at different altitudes in the Bohemian Forest and foothills: Churáňov, Kašperské hory and Klatovy (see Tab. 2). The Klatovy station has the longest monitoring sequence, allowing air temperature characteristics to be related to the beginning of the last century. By comparing average values for the periods 1901–1950 (Vesecký et al. 1961) and 1951–2003, a rise in temperature from 7.6 °C to 8.1 °C was identified. The last 50-year monitoring period shows a significant rise in air temperature in the 1980s and, in particular, from the beginning of the 1990s. Certain signs, particularly during the winter season, can already be observed in the 1970s. The biggest rises in air temperature are observed in February and August and also in January, May and March. The situation is depicted in Figure 3. Similar trends were observed for all three stations.

The average number of days with snow covers for the period 1950/51–2003/04 is practically the same as the average value for the period 1920/21–1949/50 (about 50). A certain reduction in the number of days of snow cover can be seen from the 1970s and, more significantly, during the 1990s. At the same time, despite the apparent increase in winter precipitation, the average snow cover depth was reduced by almost a half for comparable amounts of winter precipitation.

The period of the identified increase in water runoff (1975–1982) can be characterized as average from a temperature perspective, with a higher average snow cover depth and a higher number of days with snow cover. The significant increase in spring and summer temperatures from the beginning of the 1980s could then contribute to the reduction in water runoff, particularly in the summer months.

3.3 Land Cover Changes Analysis

The long-term trends of the changes in the mountain and foothill landscape in the Bohemian Forest can be monitored based on statistical data from cadastre

Tab. 3 – Land cover changes for study water basins (source: CORINE Land cover)

Units	CORINE land cover	Ostružná (Kolinec)		Blanice (Blanický Mlýn)		Vydra (Modrava)	
		1992 (%)	2000 (%)	1992 (%)	2000 (%)	1992 (%)	2000 (%)
112	Discontinuous urban fabric	0.9	1.3	0.3	0.3	0.0	0.0
211	Non-irrigated arable land	45.7	17.2	5.7	0.3	0.0	0.0
222	Fruit trees and berry plantations	0.3	0.0	0.0	0.0	0.0	0.0
231	Pastures	4.7	30.2	22.3	16.9	4.2	5.7
243	Land principally occupied by agriculture with significant areas of natural vegetation	11.1	10.1	6.7	3.9	0.0	0.0
311	Broad-leaved forest	0.0	0.5	0.2	0.8	0.0	0.0
312	Coniferous forest	32.5	37.9	41.9	61.2	65.2	58.1
313	Mixed forest	1.7	1.2	7.2	2.3	0.3	1.0
321	Natural grassland	0.0	0.0	3.0	10.8	1.1	1.1
324	Transitional woodland shrub	3.0	1.7	12.6	3.4	29.2	34.2
	Total area of the river basins	100.0	100.0	100.0	100.0	100.0	100.0

unit records. The landscape changes reflect changes in political and economic conditions. According to Bičík et al. (2003), which compared the structure of land use in the periods 1845–1948–1990, there was a significant decrease of arable land at higher altitudes (above 800 m above sea level) after 1948. The decrease in arable soil was compensated by the growth of forest. The amount of arable land at lower altitudes remained approximately constant. However, the structure of the landscape changed significantly during the period of socialistic agriculture mainly during 1960s–1980s. Introduction of large-area farming led to the loss of the stabilizing elements in the landscape. Intensive agriculture was accompanied on the extensive land drainage of swamped areas and the straightening of smaller rivers. Such changes could negatively affect the outflow characteristics. As a result of state subsidies, the Bohemian Forest foothill areas have been extensively grassed over after 1994 (see Tab. 3).

The river basins monitored are different in terms of the land use and their development over the last 50 years. The Ostružná river basin, where arable land used to cover over 45% of the area in the past, has experienced the biggest changes. In the 1990s most of the previously farmed land has been grassed over (see Fig. 4). Similar changes together with the forestation have also occurred in the Blanice River basin. Such changes could contribute to the increase in the landscape retention and to the reduction in average and minimum values of surface runoff.

3.4 River network training and land drainage analysis

River training and amelioration measures represent other significant anthropogenic intervention in the river basins. The first initial modifications

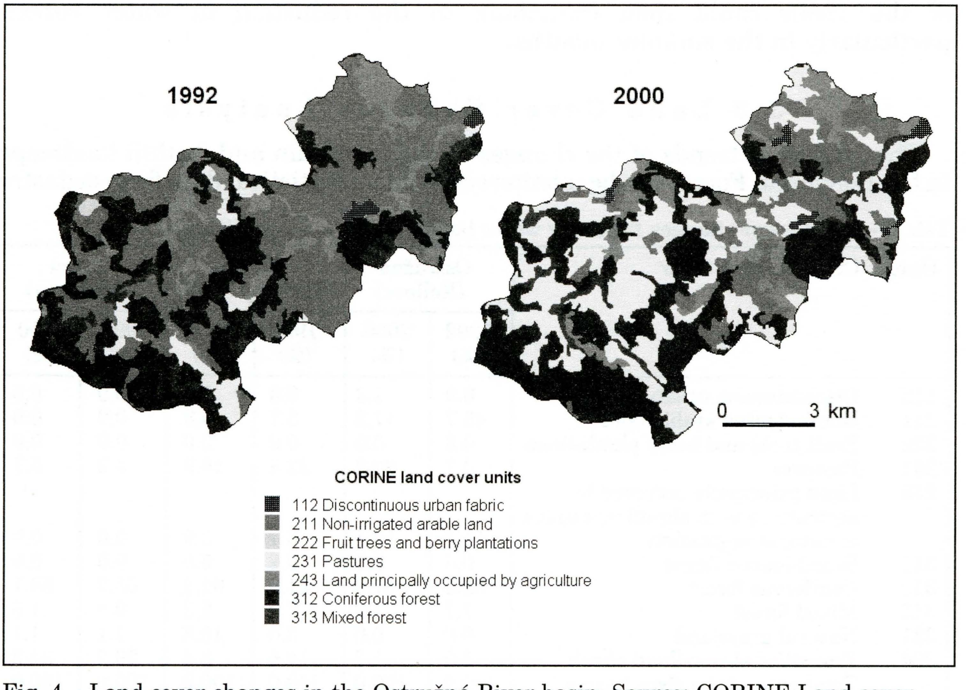

Fig. 4 – Land cover changes in the Ostružná River basin. Source: CORINE Land cover.

Tab. 4 – River altering in the Ostružná and Blanice River basins

	Ostružná	Blanice
River network length (km)	163.9	141.9
River altering length (km)	33.7	8,5 (18.4*)
Transformation degree (%)	20.6	6 (13.0*)

*Including historical alterations, which are now of an almost natural character

of river network in 19th century did not represent significant interventions into the river habitat, i.e. river network lengths did not experience any significant changes. Natural materials were mainly used for the alterations. More significant impact into the river network has occurred in connection with flood protection, urbanization and amelioration measures. The main river alterations were carried out between 1960 and 1987 in connection with the drainage of farmland in the Ostružná and Blanice River basins. The highest level of channelization is displayed in the Ostružná river basin, where the tributaries of the main river are chiefly affected (21 %). The river channels were straightened, deepened and stabilized using concrete prefabricated elements (see Tab. 4).

The Blanice River basin has a significantly lower level of channelized sections mainly in the Zbytinský Brook basin. The level of river altering totals only 6 % in the whole Blanice River basin but in the Zbytinský Brook basin reaches 62 % (Vondra 2004). No significant anthropogenic interventions to the river network were identified in the Vydra River basin except of forest amelioration in the 19th and 20th centuries (Hais 2004).

The land drainage was carried out in connection with intensive agriculture in particular. The first interventions were carried out during the 1960s. The

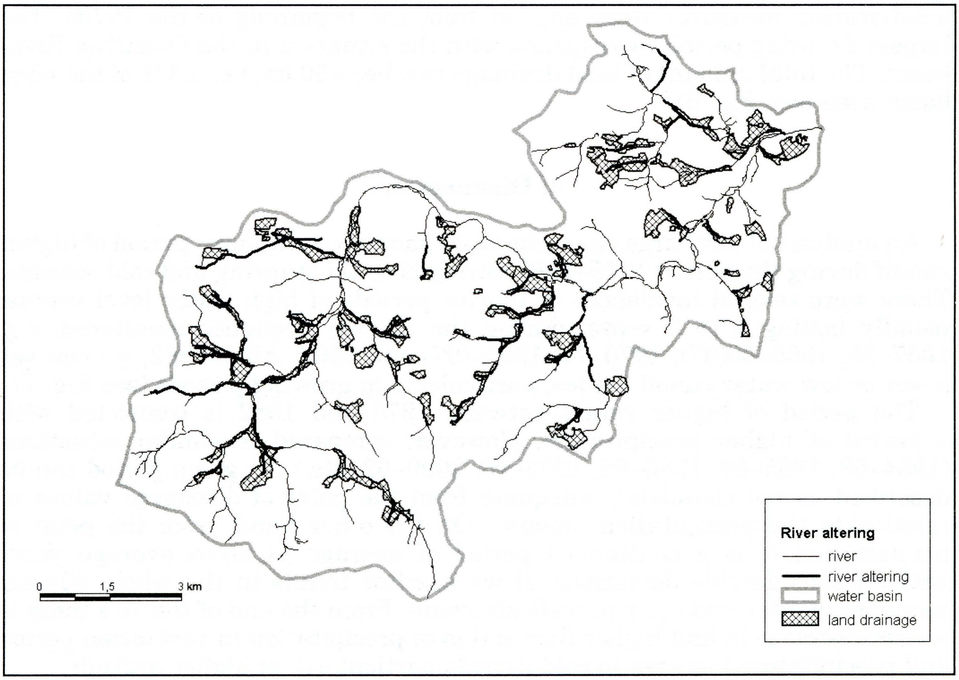

Fig. 5 – River training and land drainage in the Ostružná River basin. Source: AWMA Prachatice.

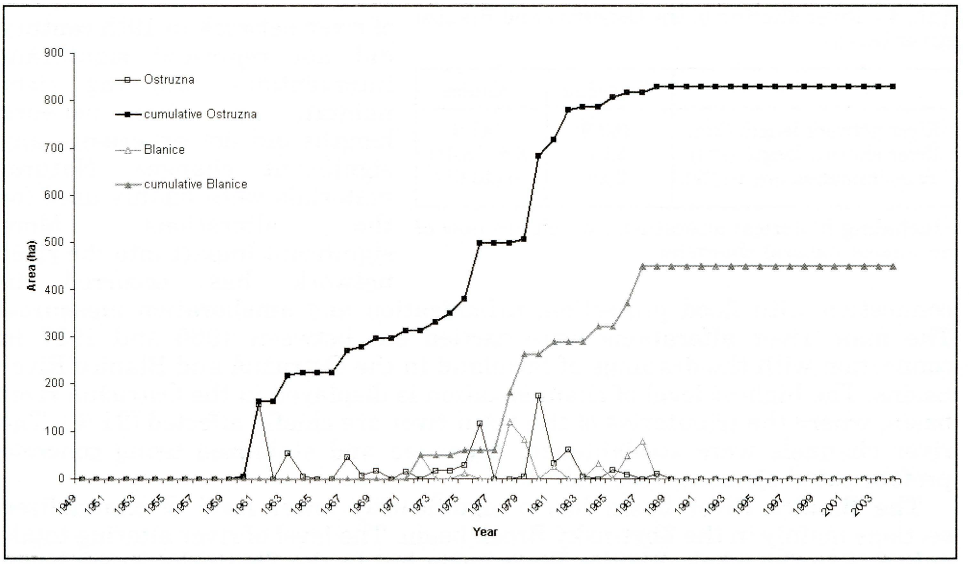

Fig. 6 – Land drainage in the Ostružná and Blanice River basins. Source: AWMA Prachatice.

largest growth in the size of drained areas occurred between 1975 and 1982. The total amount of the drainage reaches 829 ha in the Ostružná river basin, i.e. 8.3 % of the river basin area (see Fig. 5). In the case of the Blanice amelioration measures were applied from the beginning of the 1970s. The largest draining period corresponds with the situation in the Ostružná River basin. The total amount of land drainage reaches 450 ha, i.e. 5.3 % of the river basin area (see Fig. 6).

4. Discussion

An analysis of discharge characteristics shows a continuous period of higher runoff during the period 1975–1982 during both the growing and cold seasons. There were several incidences of shorter periods of high water level events; usually lasting 2 to 3 years, during the 50-year sequence monitored, e.g. 1957–58, 1965–66(67), 1970–71, 1995–(97) and 2002. After 1982, we can see lower or low water runoff values, particularly in growing periods (see Fig. 7).

The period of higher runoff between 1975 and 1982 is connected with a period of higher precipitation. However, compared to similar situations (1954–58, 1965–68, 1986–88, 1995–96, 2000–02, etc.) the given period can be described as not completely adequate from the point of discharge values in relation to the precipitation amount. On the other hand, from the point of precipitation it is a continuous period of average to above-average years without considerable deviations. If we monitor trends in the whole 50-year sequence, wetter and drier periods alternate. From the end of the 70's there is a clear decrease in and higher fluctuation of precipitation in vegetation period and precipitation increase in cold periods particularly at higher altitude.

In terms of air temperature, the period 1975–1982 is one of below-average and very cold periods. Low average temperature values were mainly observed

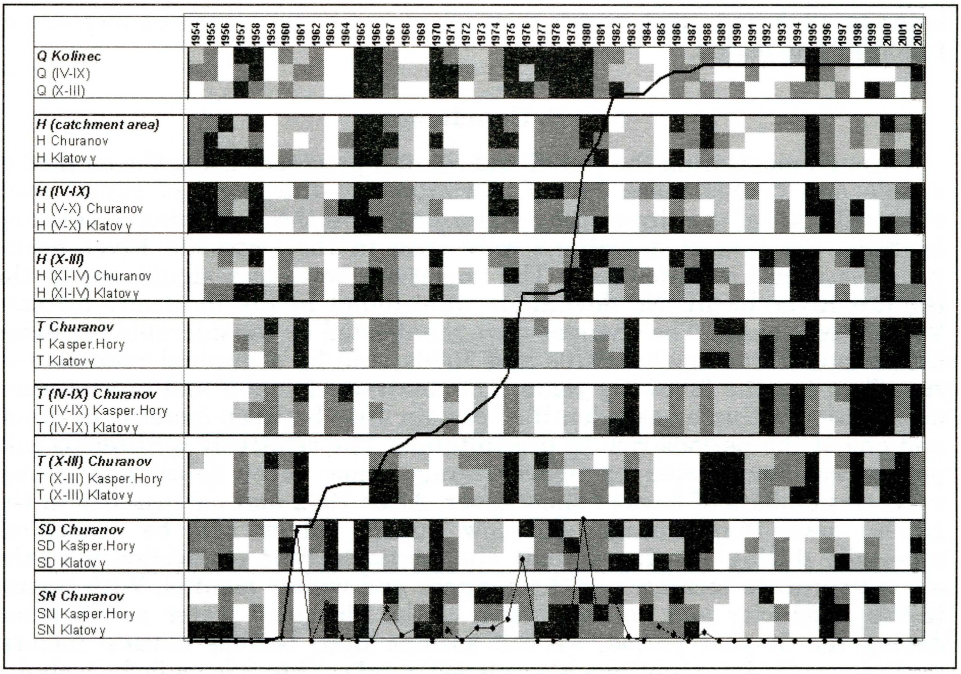

Fig. 7 – Climate development and increase of land drainage in the Ostružná River basin in period 1954–2002. Source: CHMI, AWMA. *Q* – mean discharge, *H* – precipitation, *T* – mean air temperature, *SD* – snow cover depth, *SN* – number of days with snow cover. Black colour areas: values > upper quartil, grey dark: < upper quartil, median>, grey light: <median, lower quartil>, white: <lower quartil. Thin line – development of land drainage, thick line – development of land drainage (cumulative).

in the growing periods. Conversely, slightly above-average temperatures were reached in winter period. Looking at the 50-year sequence as a whole, there is air temperatures increase considerably from the beginning of the 1980s and more so during the 1990s, during both summer and winter months.

Above-average depths of snow cover characterize the period 1975–1982. The number of days of snow cover is also above average. In connection with increased temperatures, reduced snow cover depths and the number of days with snow cover can be observed from the end of the 1980s. One of the consequences of these factors is the change in the water runoff distribution during the year in favour of the winter months (from the mid-1970s).

In the period 1845–1990 no significant land cover changes were identified in study water basins. Nevertheless, there were significant changes in the structure of the landscape as a result of the introduction of large-area farming. A significant reduction of arable land (particularly in the Ostružná River basin) was in the 1990s, which was compensated for by an increase in meadows and forests areas. These changes can be seen as positive in terms of the higher landscape water retention and the evapotranspiration process.

Extensive amelioration measures were carried out in the Ostružná and Blanice River basins in the second half of the 20th century. Large areas used for agriculture were drained and, in connection with this, small river channels were altered. The greatest increase in drained areas occurred between 1975 and 1982, which corresponds with the identified increase in runoff in this period.

5. Conclusion

Through monitoring the runoff and rainfall processes using the method of simple and double mass curves, deviations in the trend of runoff were observed. Out of the three study water basins in the Bohemian Forest and foothills, the largest deviations were seen in the Ostružná River basin, which is used for agriculture. The deviations were less significant in the Blanice River basin. No deviations were found in the naturally forested Vydra River basin. The changes were manifested by considerable increases in the runoff during the 1970s and 1980s, and by a gradual reduction in runoff during the following years. The analysis of runoff and precipitation distribution within a year identified certain links between increase in runoff and one of the periods rich in precipitation. The relatively continuous cold period was manifested by above-average snow cover depth and above-average numbers of days of snow cover. After 1982 and particularly in the 1990s, lower-than-average and low runoff values can be identified; especially during growing periods and particularly in connection with the air temperature increases in the summer and winter months. With regard to the specificity and non-repetition of the identified water runoff trend during the 50-year period, we can assume that, besides natural factors, anthropogenic interventions also played a role. This particularly includes the extensive amelioration measures, river network training and the construction of drainage systems. The period with the most intensive increase in drained areas corresponds with the increase in water runoff. Conversely, the significant reduction in arable land areas in the last ten years, together with the identified climatic trends, could contribute to the increase in the evapontranspiration. It could cause the overall reduction in runoff. Determining the importance and influence of the factors affecting the water runoff seems to be very difficult.

References:

BLAŽKOVÁ, S., KOLÁŘOVÁ, S. (1994): Vliv odlesnění na hydrologický režim v oblasti Jizerských hor. VÚV T.G.Masaryka., Praha, 76 p.

BIČÍK, I. et al. (2003): Vývoj struktury ploch v povodí Otavy. In: Langhammer, J. (ed.): Hodnocení vlivu změn přírodního prostředí na vznik a vývoj povodní. Sborník výstupů z dílčích úkolů grantu GAČR. PřF UK, Praha, pp. 113–121.

DOLEŽAL, F. et al. (2004): Bilanční odhady příspěvku odvodňovacích soustav k průběhu povodní. VÚMOP, Praha.

FÖHRER, N. et al. (2001): Hydrological response to land use changes on the catchment scale. Physics and Chemistry of the Earth, 26, pp. 577–582.

GOUDIE, A. (1992): The human impact on the natural environment. Blackwell Publisher, Oxford.

HAIS, M. (2004): Influence of drainage on landscape functioning in Šumava National Park. In.: Hermann A. (ed.) Extended Abstract – International conference on Hydrology of Mountains Environments. Berchtesgaden, 125 p.

JARABÁČ, M., CHLEBEK, A. (1984): Vliv lesů a lesního hospodářství na odtoky vod a erozi půdy v Beskydech. Vodní hospodářství, No. 4, Praha, pp. 109–116.

KAŇOK, J. (1999): Antropogenní ovlivnění velikosti průtoků řek povodí Odry po profil Kozle. Spisy prací Přírodovědecké fakulty Ostravské univerzity, No. 10, Ostravská univerzita, Ostrava.

KAVAN, J. (2004): Změna odtokových poměrů v povodí Ostružné. Bakalářská práce, PřF UK Praha, 75 p.
KLIMENT, Z., MATOUŠKOVÁ, M. (2005): Trendy ve vývoji odtoku v povodí Otavy. Geografie–Sborník ČGS, 112, No. 1, pp. 32–45.
KLÖCKING, B., HABERLANDT, U.(2002): Impact of landuse changes on water dynamics – a case study in temperate meso and macroscale river basin. Physics and Chemistry of the Earth, 27, pp. 619–629.
KŘEČEK, J.(1980): Prognóza vlivu lesní těžby na změnu vodnosti malého povodí. Práce VÚLHM, 56, Praha.
KŘÍŽ, V. (1981): Nástin prognózy potenciálních změn hydrického režimu Moravskoslezských Beskyd. Sborník ČSG, 86, No. 1, Academia, Praha, pp. 19–27.
KŘÍŽ, V. (2003): Změny a zvláštnosti vodního režimu řeky Ostravice. Geografie, 108, No. 1, pp. 36–48.
KULHAVÝ, Z. (1999): Hodnocení vlivu zemědělského hospodaření na odtokové poměry malých povodí aplikací metod matematického modelování. ZZ EP 7062, VÚMOP, Praha.
LANGHAMMER, J. et al. (2003): Hodnocení vlivu změn přírodního prostředí na vznik a vývoj povodní. Sborník výstupů z dílčích úkolů grantu GAČR, PřF UK, Praha, 200 p.
MEYER, W.B. (2001): Human impact on the Earth. Cambridge University Press, Cambridge.
NETOPIL, R. (1955): Výzkum vlivu lesa na odtok. Sborník ČSZ, 60, No. 1, Academia, Praha, pp. 65–66.
ROBINSON, M. et al. (2003): Studies of the impact of forest on peak flows and baseflows: a European perspective. Forest ecology and management, 186, pp. 85–97.
SOCHOREC, R. (1997): Ovlivnění hydrologických charakteristik odběry povrchové vody a vypouštěním vody do toků v povodí Odry a horního toku Moravy. Vodní hospodářství, 47, No. 9., pp. 291–292.
ŠEBOROVÁ, V. (1994): Režim a jakost povrchové vody v povodí Smědé. Thesis. PřF UK, Praha, 98 p.
ŠVIHLA, V. et al. (1992): Výzkumný objekt Ovesná Lhota. Monographz. VÚMOP, Praha, 92 p.
VÁLEK, Z. (1953): Výzkum vlivu lesa na odtok v povodí Kychové a Zděchovky. Vodní hospodářství, No. 10–11, Praha.
VESECKÝ et al. (1961): Podnebí Československé socialistické republiky. Tabulky. Hydrometeorologický ústav, Praha.
VONDRA, F. (2004): Fyzickogeografická charakteristika a antropogenní ovlivnění povodí horní Blanice. Bakalářská práce, PřF UK, Praha, 68 p.

Shrnutí

ZMĚNY ODTOKOVÉHO REŽIMU V DŮSLEDKU ANTROPOGENNÍCH ZMĚN V KRAJINĚ

Nedávno proběhlé povodňové události v Česku vyvolaly četné diskuse o negativním vlivu člověka na říční systém a následně i na změny ve srážko-odtokových poměrech. Prezentované odborné studie o přímém či nepřímém vlivu člověka na odtokový režim jsou mnohdy protichůdné, což může být způsobeno heterogenitou zvolených povodí, avšak do jisté míry to může souviset i s absencí komplexního pohledu na povodí.

Hlavním cílem prezentované studie bylo objasnění příčin prokázaných změn ve vývoji srážko-odtokových poměrů v pramenné oblasti povodí Otavy (viz Kliment, Matoušková 2005). Vzájemně byla porovnávána tři plošně srovnatelná povodí s rozdílným krajinným pokryvem a různým stupněm upravenosti říčního systému : povodí Vydry (profil Modrava), povodí horní Blanice (profil Blanický Mlýn) a povodí Ostružné (profil Kolinec). Změny v odtokovém režimu byly hodnoceny pomocí metody jednoduchých a podvojných součtových čar za období hydrologického pozorování, tj. cca za posledních 50 let. Vedle průměrných odtokových a srážkových charakteristik byly sledovány minimální a 5leté a vyšší průtoky a změny ve vývoji rozložení odtoku během roku. Vývoj odtoku v daných povodích byl dále doplněn o analýzu vývoje teploty vzduchu a sněhových poměrů. Za reprezentativní byly vzaty údaje ze tří výškově různě položených klimatologických stanic ČHMÚ: Klatovy, Kašperské Hory a Churáňov. V návaznosti na analýzy trendů odtokového, srážkového a teplotního režimu byly provedeny analýzy změn ve využití krajiny, upravenosti říční sítě a plošné-

ho odvodnění pozemků. Při zpracování bylo využito jak existujících analogových a digitalizovaných databází, tak vlastního terénního průzkumu.

Ze třech modelových povodí se odchylky v odtoku nejvíce projevily v zemědělsky využívaném povodí Ostružné, méně výrazně v povodí horní Blanice a nebyly naopak zjištěny v přírodním zalesněném povodí Vydry. Změny se projevily zřetelným nárůstem odtoku v 70. a 80. letech minulého století a postupným úbytkem odtoku v následném období. Analýzou vývoje rozložení odtoku a srážek v průběhu roku byly zjištěny určité vazby nárůstu odtoku na jedno ze srážkově bohatších období s vyšším podílem odtoku v mimovegetačním období. Teplotně chladné, relativně souvislé období bylo charakteristické výskytem srážkově průměrných až nadprůměrných let bez výrazných výkyvů s nadprůměrnou výškou sněhové pokrývky a nadprůměrným počtem dní se sněhovou pokrývkou. Po r. 1982, hlavně pak v 90. letech, lze pozorovat zejména v souvislosti s nárůstem teplot v letních i zimních měsících v průměru nižší až nízké hodnoty odtoku, především ve vegetačním období. Vzhledem ke specifičnosti a neopakovatelnosti zjištěného trendu odtoku za více jak 50leté období a jeho neidentifikaci v přírodním zalesněném povodí Vydry můžeme usuzovat, že se na něm mohly spolupodílet některé antropogenně podmíněné zásahy. V tomto smyslu se jedná zejména o rozsáhlá hydromeliorační opatření v zemědělsky využívaných oblastech, provázená úpravami hydrografické sítě a výstavbou povrchových i podpovrchových odvodňovacích systémů. Období nejintenzivnějšího nárůstu odvodněných ploch časově koresponduje se zjištěným trendem nárůstu odtoku. Významný pokles výměry orné půdy kompenzovaný nárůstem zatravněných a zalesněných ploch v posledním desetiletí mohl naopak přispět spolu se zjištěnými klimatickými trendy ke zvýšení podílu evapotranspirace a tím i k celkovému snížení odtoku. Stanovení váhy a vlivu faktorů ovlivňujících odtok vody z území bude předmětem zahájeného synchronního kontinuálního monitoringu odtoku a srážek na rozdílně využitých dílčích experimentálních plochách s různým stupněm upravenosti říční sítě v lokalitě Zbytiny v povodí horní Blanice.

Obr. 1 – Povodí Otavy – vymezení zájmových území: povodí Vydry, Blanice a Ostružné. Zdroj: ZVM 1:50 000.
Obr. 2 – Podvojné součtové čáry průměrných ročních srážek a průměrných ročních průtoků pro profily: Modrava, Kolinec, Blanický Mlýn. Zdroj: ČHMÚ.
Obr. 3 – Chod průměrných teplot vzduchu v jednotlivých ročních obdobích, 5letý plovoucí průměr. Zdroj: ČHMÚ.
Obr. 4 – Změny krajinného pokryvu v povodí Ostružné. Zdroj: CORINE Land cover.
Obr. 5 – Upravenost říční sítě a odvodnění ploch v povodí Ostružné. Zdroj: ZVHS Prachatice.
Obr. 6 – Plošné odvodnění v povodí Ostružné a Blanice. Zdroj: ZVHS Prachatice.
Obr. 7 – Vývoj klimatu a nárůst plošného odvodnění v povodí Ostružné v období1954–2002. Zdroj: ČHMÚ, ZVHS. *Q* – průměrný průtok, *H* – srážky, *T* – průměrná teplota vzduchu, *SD* – výška sněhové pokrývky, *SN* – počet dnů se sněhovou pokrývkou. Černě > horní kvartil, tmavě šedá < horní kvartil, medián >, světle šedá < medián, dolní kvartil >, bílá:< dolní kvartil. Slabá čára: vývoj plošného odvodnění, silná čára: kumulativní vývoj plošného odvodnění.

(Authors are with Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology, Albertov 6, 128 43 Praha 2, Czechia; e-mail: kliment@natur.cuni.cz, matouskova@natur.cuni.cz.)

Arrived to the editorial board on August 28, 2006

MICHAL JENÍČEK

RAINFALL-RUNOFF MODELLING IN SMALL AND MIDDLE-LARGE CATCHMENTS – AN OVERVIEW

M. Jeníček: *Rainfall-runoff modelling in small and middle-large catchments – an overview.* – Geografie–Sborník ČGS, 111, 3, pp. 305–313 (2006). – A rainfall-runoff modelling is nowadays a dynamically developing department of hydrology and water management. This development is caused by a rapid progress of computers and information technologies. This evolution provides the mankind with new possibilities to use water as its basic need and at the same time to evolve an effective protection against it. The aim of this article is to give some basic information about rainfall-runoff modelling, various approaches to it, methods and possibilities of application. This kind of information may help the user with the choice of the suitable rainfall-runoff model. Rainfall-runoff or hydraulic models have many different applications, e.g. in operational hydrology, water resource management or in research. Typical structure of any rainfall-runoff model, come out from a simplified catchment structure as a system of vertical ordered reservoirs, which form a linear cascade model. The main reservoirs are precipitation, evapotranspiration (together with interception), direct runoff, runoff in unsaturated zone (interflow), base flow and channel flow. For computation of processes running in each of these reservoirs (filling or drainage), many equations (model techniques) are applied. This structure and presented modelling techniques are used in the most common models like HEC-HMS, MIKE-SHE, Sacramento (SAC-SMA), NASIM, HBV and many others.
KEY WORDS: modelling of hydrological processes – mathematical modelling – rainfall-runoff models – hydraulic models – floods.

The presented research was funded by the Research Plan MSM 0021620831 "Geographical Systems and Risk Processes in Context of Global Changes and European Integration" of the Czech Ministry of Education and Research Project VaV-SM/2/57/05 "Long-term changes of river ecosystems in floodplains affected by extreme floods" of the Ministry of Environment of the Czech Republic which is fully appreciated by the author.

1. Introduction

Mathematical representation of rainfall-runoff process has a long history, but until 80s of the last century became, due to rapid computer technology development, an important instrument for hydrologist and water managers, whether for hydrology forecast or for design purposes.

Mathematical model of rainfall-runoff process (R-R process) represents simplified quantitative relation between input and output variables of the certain hydrological system (Daňhelka et al. 2002). This relation is defined as a system of mainly physical processes affecting input values and transforms them to output values. This means, in mathematical sense, a solution algorithm of equation system. It describes system structure and system behaviour (Clarke 1973, In: Fleming 1979).

Currently many authors deal with the issue of rainfall-runoff and hydrodynamic modelling, both in Czechia and in the world. There are e.g.

Buchtele (2002); Daňhelka et al. (2002); Kulhavý, Kovář (2002); Řičicová, Krejčí (2002) or Starý (2004). Hydrologic and hydraulics models are also used in many Czech institutions like Czech Hydrometeorological Institute, Water Research Institute, Academy of Science and some universities.

But the main research centre lies in the world, above all in the articles and publications of Beven (1996, 2001); Bergström (1995); Blöschl, Grayson (2002); Refsgaard, Storm (1996); Smith et al. (2000, 2004) and many others. From these studies an effort to accurate analysis of precipitation input (mainly radar estimations) is evident. Very important is also a development of calibration methods, especially automatic optimisation of input parameters. Developing of methods, which describe processes in the soil column (unsaturated soil profile), is also essential. Substantial progress for both R-R and routing models was DMIP project (Distributed Model Intercomparison Project). The aim of this project was a comparison of different R-R and hydrodynamic models and their approaches. Results were published in Journal of hydrology, Volume 298 (October 1994). Theoretical frame of described part of hydrology gives some articles and publications of Clarke (1973), O´Connor (1976), Bear (1972) and many others. Some of this approaches were implemented in methodology of the WMO (World Meteorological Organisation), e.g. Becker, Serban (1990) or WMO (1983).

Over time of models application, their different approaches to a catchment description, a several groups of models were turned out. Most common is the classification according to the WMO (World Meteorological Organisation) described by Becker, Serban (1990). There we can distinguish several groups of classification criterions. The most common of this criterion is a degree of causality (deterministic and stochastic models) and time or space discretisation (continually vs. event models, lumped vs. distributed or semi-distributed models).

2. Means of application

Rainfall-runoff or hydraulic models have many different applications. It is possible to distinguish three main categories.

First area of application is operational hydrology. Input data are formed, besides state variables, by real-time data from automatic stations or sometimes from meteorological radars. Data are automatically (after checking by hydrologist) given to a model and priority is a velocity of their processing. A result is a short-time forecast of water stage or discharge. Practically it means more specialized models (wave routing or subsurface flow model) which together with software for data collecting and analyses form a Flood Forecast System (FFS).

Second area forms partly long-time solutions of flood protection (dams, dry polders or another flood or drought protection measures) and partly are R-R and hydrodynamic models useful by building of several technical water management project like canals, irrigations, cleaners, weirs or bridges.

Another type of application is a possibility for additional development of models, research of particular components of rainfall-runoff process and their more accurate description. For these purposes some experimental catchments use to be created with above standard network of measurement stations.

Rainfall-runoff model results can be also applied as an input of other applications like pollution diffusion models. Interesting could be also application in climate change impact simulations.

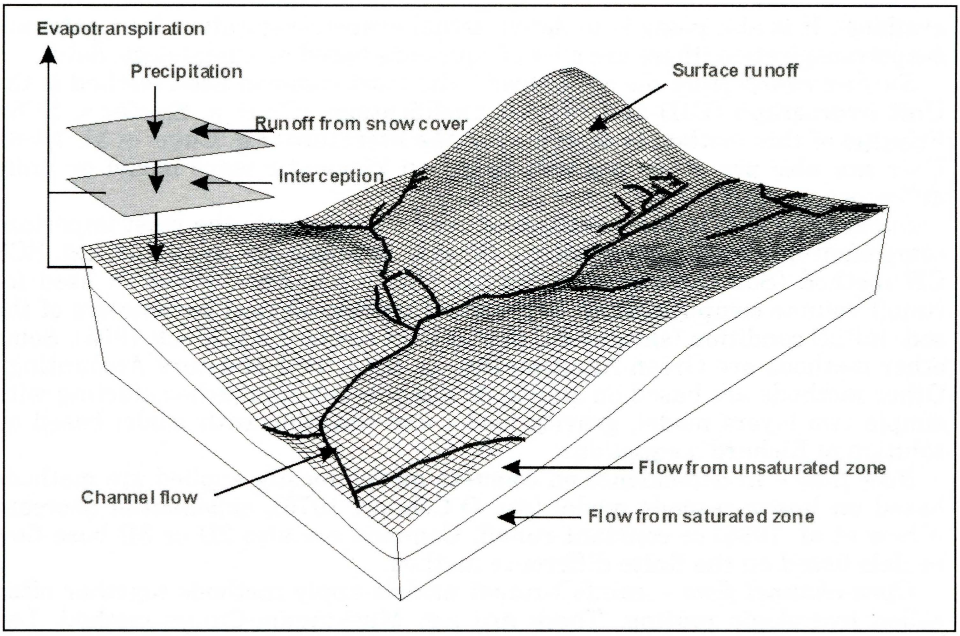

Fig. 1 – General structure of a hydrological model

Here are some concrete types of hydrological tasks, where an application of rainfall-runoff model is possible:

- flood wave run simulation of any time or space step, both in natural and urban areas
- flood protection project designing, support of crisis management systems
- low flows modelling, e.g. for drought period or pollution diffusion
- support of reservoirs, polders, canals or irrigation management
- hydrologic balance computation
- long-time period scenarios, base on climate change models
- statistic parameters computation (excess probability, etc.).

3. General structure of a Rainfall-Runoff model

General characteristic of the most of R-R models is dividing of the catchment to several zones, mainly vertical ordered. These zones are with help of the linear cascade model (O´Connor 1976) computed. Their simplified structure is displayed in the figure 1.

For computation of processes running in each of these reservoirs (filling or drainage), many equations (model techniques) are applied.

Precipitation (both rain and snow) – they are entered into models in the form of time series from meteorological stations (as a point rain) or sometimes meteorological radars (as an area rain). For estimation of the snow precipitation influence methods of temperature index, degree-day method or energy balance are applied.

Evapotranspiration (include interception) – actual evapotranspiration and interception are computed from time series from climatologic stations if they are available. It is also possible to derive actual evapotranspiration from potential evapotranspiration (there are a lot of equations based on climatologic data).

Surface runoff from the catchment – the most common used method is the Unit hydrograph (UH) and various modifications (Clark´s, Snyder´s, SCS). Principe of this method is described in the literature (e.g. Chow et al. 1988). User can also use other methods based on kinematic wave model or finite difference method.

Subsurface flow in the unsaturated zone – it is mostly the most important component of runoff concentration. Several methods are available, e.g. SCS CN method (Soil Conservation Service Curve Number), which is used for runoff volume computation in dependence on hydrological parameters of the soil, initial condition (saturation) or soil land use (see e.g. Mack 1995). Some other methods are Green-Ampt method or SMA (Soil Moisture Accounting). Other methods are based on simple or complicated approaches starting with simple two layers model, gravity model and finishing with model based on solution of Richard´s equations.

Base flow – in dependence on concrete model, mostly applied are methods based on linear cascade model (see O´Connor, 1976), exponential decrease (Chow et al. 1988) or constant runoff. Common are also 2D or 3D base flow models based on the finite difference method.

Open-channel flow – rainfall-runoff models apply methods together often called hydrologic routing. There are e.g. Muskingum-Cunge method, Lag model, kinematic wave model or transport diffusion equation. These methods are mainly based on a solution of basic equations of open-channel flow – continuity and momentum equations. There are together known as St. Venant´s equations (see e.g. Feldman 2000).

Water control facilities – in R-R model are also some possibilities for modelling water control facilities, such as reservoirs, polders or diversion.

4. Characteristic of some rainfall-runoff models

4.1. MIKE-SHE

Rainfall-runoff model MIKE-SHE of Danish firm DHI (Danish Hydraulic Institute) belongs to a group of conceptual distributed or semi-distributed models. It consists of several components computing a volume and distribution of water during particular phases of runoff process:

- Precipitation – serves as an input data. Both liquid and compact.
- Evapotranspiration, included interception (input data)
- Surface flow – based on 2D finite difference method.
- Channel flow – 1D routing model MIKE11 is applied. This model provides several methods, such as Muskingum, Transport Diffusion Equation or method based on solution of St. Venant´s equations.
- Subsurface flow in unsaturated zone – simple two-layer model, gravity flow model or on Richard´s equation based model are available.
- Base flow – MIKE-SHE contains 2D and 3D base flow model based on the finite differences method.

For the soil model a database including soil hydrology characteristic (porosity, hydraulic conductivity, etc.) was created. Also two extensions of ESRI software ArcView 3.x or ArcGIS 9.1 were created. These extensions work with the input data. First, *Geomodel* (for ArcGIS 9.1) serve for geological characteristics interpretation. Second, *DaisyGIS* is a conceptual model (for ArcView 3.x) for description of all important processes bounded on agricultural ecosystem (water, heat or nutrients transport).

In the model both manual and automatic calibration is possible. For automatic calibration the tool AUTOCAL was developed. This tool allows optimisation according to initial and border conditions.

4.2. HEC – HMS

Model HEC-HMS (Hydrologic Engineering Centre – Hydrologic Modelling System) is a continuator of model HEC-1 developing since 60s by the US Army. It is mainly lumped model. Its great advantage is that fact, that it is a freeware, also in Internet available. The basic components are following:

- Runoff-volume models – includes some methods, such as SCS CN (Soil Conservation Service Curve Number), Green-Ampt or SMA (Soil Moisture Accounting).
- Direct-runoff models – for direct runoff computation a Unit Hydrograph method (UH) or its various modifications is used. (Clark´s, Snyder´s, SCS). For user a method of kinematic wave is also available.
- Baseflow models – a user can choose, for instance, linear reservoir model, exponential decrease, or constant runoff model.
- Routing models – there are Muskingum-Cung model, Lag model, kinematic wave model or their modifications available.
- Others models – in special cases there are also possible to simulate the reservoirs, weirs, etc.

For HEC-HMS model an extension of ArcView 3.x called HEC-GeoHMS was also created. This extension is able to derive some basic hydrological characteristics of the basin – watersheds, water flow directions, flow accumulations, slopes, etc.

With HMS both manual and automatic calibration of parameters is possible. Regarding the type of a model (suitable for catchments up to 500 km^2) the calibration takes place on short flood events.

4.3. NASIM

Rainfall-runoff model NASIM (Niederschlag-Abfluss Simulation Model) made by German firm Hydrotec is developing since 80s and belongs to a group of conceptual, deterministic, semi-distributed models. The basic components are following:

- Rainfall generation (Belastungsbildung) – for differentiation of liquid and compact precipitation a combined method "Temperature Index/Snow Compaction" is applied.
- Space distribution of precipitation (Belastungsverteilung) – conversion of point values to area precipitation.
- Runoff components separation (Belastungsaufteilung) – quantification of runoff components (interception, evapotranspiration, accumulation in depressions, infiltration, percolation).
- Runoff concentration (Abflusskonzentration) – water flow in unsaturated (interflow) and saturated (baseflow) zone of the soil profile is by linear or nonlinear cascade model described. For surface runoff a method based on Unit hydrograph was created.

- Channel flow (Wellentransport) – by channel flow description an adjusted Kalinin-Miljukov method is applied.

For data analysis some extensions for ArcView 3.x were created. Most important are extensions "Zfl" and "Verschneidung". First makes time-area function of the catchment. Second works up basic characteristic of the catchment. Useful are also extensions for results interpretation. Together with model a software Time-View for time series visualization and interpretation was made.

For model calibration, only a program unit for manual calibration was developed. By calibration, the biggest change is mostly registered by those parameters, which express hydrological properties of the soil – vertical and horizontal hydraulic conductivity, porosity, infiltration rate, etc. (Jeníček 2005). In the future, also an automatic calibration will be applied.

4.4. SAC – SMA (Sacramento)

Sacramento-Soil Moisture Accounting, a part of the model technique library of the NWSRFS system (National Weather Service River Forecast System), is developing since 70s by a US National Weather Service (NWS; Burnash 1995). In Czechia is this model a part of the model techniques library of the Aqualog forecast system. Aqualog is used in the Czech Hydrometeorological Institute (CHMI) as a forecast system of the Vltava and Elbe Rivers basins. Every catchment is divided into several zones, which are connected into a reservoirs system. Basis of these zones are upper and lower zone. Upper zone contains tension and free water, lower zone contains primary free and tension water and supplementary free and tension water). Excess water flows away in a form of several types of runoff:

- direct runoff
- surface runoff
- subsurface runoff (interflow)
- primary base flow
- supplementary base flow.

Whereas Sacramento is a soil moisture model the most important data are soil data – hydraulic conductivity, porosity, etc.

Sacramento supports both manual and automatic calibration. Together 24 parameters can be calibrated, which can be classified according to a particular zone.

4.5. HBV

Hydrologic model HBV is developing since the beginning of 70s in the Swedish Meteorological and Hydrological Institute (Bergström 1995). It is a part of the modelling system IHMS (Integrated Hydrological Modelling System). Although this model is not so used in Czechia, abroad is very often applied. Typical components are:

- snow Unit – computation is base on simple degree-day method
- soil Moisture Unit – main computation component of runoff concentration
- runoff Origin Unit – base on the Unit Hydrograph method
- reservoir Unit.

In HBV model a manual calibration is used. For most of time-series a day step of calibration is used, for evapotranspiration time-series a month step is applied. For the calibration period, information about discharges in outlet profile is needed.

5. Conclusion

From this article is clear, that for modelling of rainfall-runoff processes many methods are available. These methods are possible to use by solution of various types of hydrological tasks, such as operational hydrology, flood or drought protection or pollution transport modelling. One of the first steps by the project solution is a choice of the model, which will be suitable for concrete hydrological task. The user should take into account some criterions and claims to a model according to the data which model needs, type of hydrological problem (if model is needed for operative forecast or modelling of catastrophic scenarios, for instance), size of a catchment, connection to GIS or other software for collecting, analysing or presentation of the data and results. The user should also know if data which model needs are available for the catchment. Also previous references, support and of course a price are very important. For more extensive catchments (over 100 km^2) could be also a connection with a routing model for flood wave progress simulation useful. In department of physical geography and geoecology was after consideration of all described factors models MIKE-SHE together with MIKE 11 and HEC-HMS together with HEC-RAS chosen. It is also studied the possibility of using Czech hydrodynamic model Hydrocheck and the R-R model WMS.

References:

BEAR, J. (1972): Dynamics of fluids in porous media. American Elsevier publishing, New York, 764 p.

BECKER, A., SERBAN, P. (1990): Hydrological models for water – resources system design and operation. Operational Hydrology Report No. 34, WMO, Geneva, 80 p.

BERGSTRÖM, S (1995): The HBV Model. In: Singh, V. P. (ed.): Computer models of watershed hydrology. Water Resourse Publications, Highland Ranch, pp. 443–476.

BEVEN, K.J. (1996): A discussion of distributed hydrological modelling. In: Abbott, M. B., Refsgaard, J. C. (1996): Distributed hydrological modelling. Kluwer, Dordrecht, pp. 255–279.

BEVEN, K. J. (2001): Rainfall-Runoff Modelling, The Primer. John Wiley & Sons, Chichester, 360 p.

BLÖSCHL G., GRAYSON R. (2002): Flächendetaillierte Niederschlag-Abfluss Modellierung. In: Wiener Mitteilungen – Band 164 – Niederschlag-Abfluss Modellierung – Simulation und Prognose, Technische Universität Wien, pp. 33–55.

BUCHTELE, J. (2002): Úvod k metodám a modelům hydrologických předpovědí. In: Patera, A. et al.: Povodně: prognózy, vodní toky a krajina. ČVUT, Praha, pp. 33–35.

BURNASH, R. J. C. (1995): The NWS River Forecast System – catchment modeling. In: Singh, V. P. (ed.): Computer Models of Watershed Hydrology. Water Resourse Publications, Highland Ranch, pp. 311–366.

CLARKE, R. T. (1973): Mathematical models in hydrology. Irrigation and Drainage paper No. 19, FAO, Rome.

CHOW, V. T., MAIDMENT, D. R., MAYS, L. W. (1988): Applied hydrology. McGraw-Hill, New York.

DAŇHELKA, J., KREJČÍ, J., ŠÁLEK, M., ŠERCL, P., ZEZULÁK, J. (2002): Posouzení vhodnosti aplikace srážko-odtokových modelů s ohledem na simulaci povodňových stavů pro lokality na území ČR. ČZÚ, Praha, 214 p.

FELDMAN, A. D. (ed., 2000): Hydrologic Modeling System HEC-HMS – Technical Reference Manual. US Army Corps of Engineers, Washington, 149 p.

FLEMING, G. (1979): Deterministic models in hydrology. Irrigation and Drainage paper, 32, FAO, Rome, 80 p.

JENÍČEK, M. (2005): Aplikace matematického modelu NASIM pro simulaci srážko-odtokových poměrů v povodí Černé vody. Thesis. PřF UK, 104 p.

KULHAVÝ, Z., KOVÁŘ, P. (2002): Využití modelů hydrologické bilance pro malá povodí. VÚMOP, Praha, 123 p.
LANGHAMMER, J. et al. (2006): Změny krajiny jako ovlivňující faktor průběhu a projevů extrémních povodní. PřF UK, Praha, 209 p.
MACK, M. J. (1995): HER – Hydrologic evaluation of runoff; The Soil Conservation Service Curve Number technique as an interactive computer model. Computers & Geosciences, Vol. 21, Issue 8, pp. 929–935.
O'CONNOR, K. M. (1976): A discrete linear cascade model for hydrology. Journal of Hydrology, 29, pp. 203–242.
REFSGAARD, J. C., STORM, B. (1996): Construction, calibration and validation of hydrological models. In: Abbott M. B., Refsgaard J. C.: Distributed hydrological modelling. Kluwer, Dordrecht, pp. 41–54.
ŘIČICOVÁ, P., KREJČÍ, J. (2002): Využití hydrologických modelů a perspektivy jejich rozvoje u nás. In: Počasí – moderní předpovědní metody, prevence a snižování následků katastrof, ČHMÚ, Praha, pp. 36–41.
SMITH, M. B., KOREN, V. I., WELLS, E., WANG, D., ZHANG, Z. (2000): Evaluation of the advantages of the continuous SAC-SMA model over an event API model. 15th Conference on Hydrology 9.1–4.1.2000, Long Beach, CA.
SMITH, M. B., KOREN, V. I., ZHANG, Z., REED, S. M., PAN, J-J., MOREDA, F. (2004): Runoff response to spatial variability of precipitation: an analysis of observed data. Journal of Hydrology, 298, pp 267–286.
STARÝ, M. (2004): Užití umělých neuronových sítí v aplikované hydrologii – zkrácená verze habilitační práce. VÚT, Brno, 40 s.
WMO-No. 168 (1983): Guide to hydrological practices, Volume II – Analysis, Forecasting and other application. WMO, Geneva.

Shrnutí

MODELOVÁNÍ SRÁŽKO-ODTOKOVÝCH PROCESŮ NA MALÝCH A STŘEDNĚ VELKÝCH POVODÍCH

Matematická reprezentace srážko-odtokového procesu má dlouhou historii, ale teprve zhruba od 80. let minulého století se díky postupnému rozvoji počítačových technologií stává významným nástrojem hydrologů a vodohospodářů, ať už pro operativní předpověď nebo pro návrhové účely.

Cílem příspěvku je podat základní informace o přístupech ke srážko-odtokovému modelování, jednotlivých metodách a také charakterizovat některé nejčastěji používané modely, jako jsou MIKE-SHE, HEC-HMS, NASIM, Sacramento a HBV.

Problematikou využití hydrologických a jednorozměrných hydraulických modelů se v současné době zabývá řada autorů. Z českých jsou to například Buchtele (2002), Daňhelka a kol. (2002); Kulhavý, Kovář (2002); Řičicová, Krejčí (2002) nebo Starý (2004). Hlavní těžiště výzkumu a vývoje všech typů hydrologických modelů spočívá v zahraničí, především v pracích Bevena (1996, 2001); Bergströma (1995); Blöschla, Graysona (2002); Refsgaarda, Storma (1996); Smithe a kol. (2000, 2004) a dalších, kteří aplikovali nejrůznější hydrologické modely a výrazně tím přispěli k vývoji metod popisující srážko-odtokový proces. Tyto práce dokazují, že důraz je kladen především na přesnější zpracování srážkových polí jako vstupu do modelu (hlavně v podobě radarových odhadů). Významný prostor je také věnován postupům kalibrace modelu, především pak procesu automatické optimalizace vstupních parametrů. Zásadní je také vývoj metod popisujících proudění v nenasycené zóně půdního profilu (model půdní vlhkosti). Významným příspěvkem do problematiky jak hydrologických, tak hydraulických modelů byl projekt DMIP (Distributed Model Intercomparison Project), který si dal za cíl srovnání několika srážko-odtokových modelů a jejich přístupů. Výsledky byly publikovány v Journal of Hydrology, 298 (říjen 2004). Mnoho z těchto i dřívějších přístupů je zahrnuto v metodikách a doporučeních WMO (World Meteorological Organisation), například Becker, Serban (1990) nebo WMO (1983).

Použití matematických modelů je možné rozdělit do tří hlavních kategorií podle charakteru daného úkolu. První oblast využití je operativní hydrologie, druhou oblast tvoří jednak dlouhodobější řešení protipovodňové ochrany a také řešení nejrůznějších vodohospodářských staveb. Pod třetí kategorií využití hydrologického modelu se skrývají možnosti dalšího vývoje modelu, výzkum jednotlivých komponent srážko-odtokového procesu a jejich přesnější popis.

Výstupy z hydrologického modelu mohou sloužit jako vstupní veličiny dalších modelů (například modelů šíření znečištění ve vodním prostředí) a naopak mohou mít hydrologické modely návaznost na jiné projekty, například odhad vlivu klimatických změn na srážko-odtokové poměry v povodí.

Obecnou charakteristikou většiny modelů je rozdělení povodí na několik, většinou vertikálně uspořádaných zón, které jsou počítány konceptem lineární nádrže. Jedná se o následující komponenty:

Srážky (dešťové i sněhové) – jde o vstupní data ve formě časových řad ze srážkoměrných stanic. Pro výpočet sněhových dat bylo vyvinuto množství metod.

Evaporace, včetně intercepce – aktuální evapotranspirace a intercepce bývá počítána z časových řad, pokud jsou uživatelem zadány.

Povrchový odtok z povodí – nejčastěji je využíván jednotkový hydrogram (Unit Hydrograph). Uživatel také může využít model kinematické vlny nebo metodu konečných diferencí.

Podpovrchový odtok v nenasycené zóně půdního profilu – často se jedná o nejdůležitější komponentu koncentrace odtoku. K dispozici bývá více metod například metoda SCS CN křivek (Soil Conservation Service Curve Number). Jiné metody jsou například Green-Ampt metoda nebo SMA (Soil Moisture Accounting). Další metody jsou založeny na jednodušších i poměrně složitých postupech od dvouvrstvého modelu, přes gravitační model proudění, až po model založený na řešení Richardsovy rovnice.

Podzemní odtok – v závislosti na konkrétním modelu jsou často používanými metodami model lineární nádrže, exponenciálního poklesu nebo konstantního odtoku. Obvyklý je také 2D a 3D model proudění podzemní vody založený na metodě konečných diferencí.

Odtok v korytě – rozšířenými modely jsou například Muskingum-Cunge, Lag model, model kinematické vlny nebo transportní difuzní rovnice. Tyto metody jsou založeny na řešení rovnice kontinuity a momentové rovnice (St. Venantovy rovnice).

Z uvedeného přehledu je zřejmé, že k modelování srážko-odtokových procesů je k dispozici celá řada přístupů, které je možné použít pro řešení úkolů spojených s problematikou povodní. Důležitý je výběr vhodného modelu. Ten musí odpovídat charakteru projektu, tedy účelu zpracování. Je potřeba také dopředu vědět, jsou-li data, která model vyžaduje, dostupná. Pro řešení projektů na středně velkých povodích (nad cca 100 km^2) je již vhodné propojení srážko-odtokového modelu s podrobnějším korytovým modelem. Při zpracování dat a interpretaci výsledků je žádoucí také schopnost komunikace modelu, či modelového systému s geoinformačními systémy. Aplikace hydrologického modelu je většinou finančně i časově velmi náročný proces a je tedy nutné zvážit zda se investované peníze a čas nakonec vyplatí.

Obr. 1 – Obecná struktura hydrologického modelu

(Author is with Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology, Albertov 6, 128 43 Praha 2, Czechia; e-mail: jenicek@natur.cuni.cz.)

Arrived to the editorial board on August 28, 2006

GEOGRAFIE – SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI
ROK 2006 • ČÍSLO 3 • ROČNÍK 111

TOMÁŠ CHUMAN, ZDENĚK LIPSKÝ, TOMÁŠ MATĚJČEK

SUCCESSION OF VEGETATION IN ALLUVIAL FLOODPLAINS AFTER EXTREME FLOODS

T. Chuman, Z. Lipský, T. Matějček: *Succession of vegetation in alluvial floodplains after extreme floods.* – Geografie–Sborník ČGS, 111, 3, pp. 314–328 (2006). – The paper deals with the topic of vegetation changes and successional developments as well as spread of invasive species in alluvial plains after extreme floods. The issue has become topical in Czechia after several extreme floods concentrated in the last 10 years. The paper is based on the search of the Czech and foreign literature as well as authors own experience and research after catastrophic summer floods in 1997 and 2002 in Czechia. The attention is paid to processes and mechanisms of vegetation succession and regeneration after floods. Floods are functioning as important natural disturbances increasing both geodiversity and biodiversity in the riverine landscapes. Different successional stages as well as variable habitats create a varied mosaic of vegetation and cause high species and ecosystem biodiversity in floodplains. On the other hand the disturbance regime of floods is particularly favorable also for invasive species that spread rapidly through floodplain. While future spatial distribution and spread of invasive species is difficult to forecast, the processes of succession and regeneration of vegetation after floods as well as changes in species composition of communities are predictable and confirm basic ecological principles.
KEY WORDS: floods – floodplains – vegetation – succession – invasive species.

The presented research was funded by the Research Plan MSM 0021620831 "Geographical Systems and Risk Processes in Context of Global Changes and European Integration" of the Czech Ministry of Education and Research Project VaV-SM/2/57/05 "Long-term changes of river ecosystems in floodplains affected by extreme floods" of the Ministry of Environment of the Czech Republic which is fully appreciated by the authors.

1. Introduction

Floodplains represent complex, naturally fragmented ecosystems dependent on the influence of natural disturbance regimes (like floods, erosion and sedimentation), climatic factors and/or ways of present as well as historical land use not only in the floodplain but in the whole catchment. Therefore alluvial floodplains along water courses serve as an excellent example of the geographical continuum (Kolejka 2003). In addition, they belong to the youngest, the most dynamic and changeable segments of the landscape. Fast and extensive changes in alluvial floodplains concern both natural and cultural (land use changes and management) processes. The extreme rate and intensity of geomorphological processes like erosion, transport and sedimentation are accompanied by biotic processes of succession, colonization and migration. Floodplains are used as extremely important biocorridors by plant and animal species for their movement and migration but also as spaces where invasive species are spreading in the landscape. Their distribution is generally facilitated by natural as well as

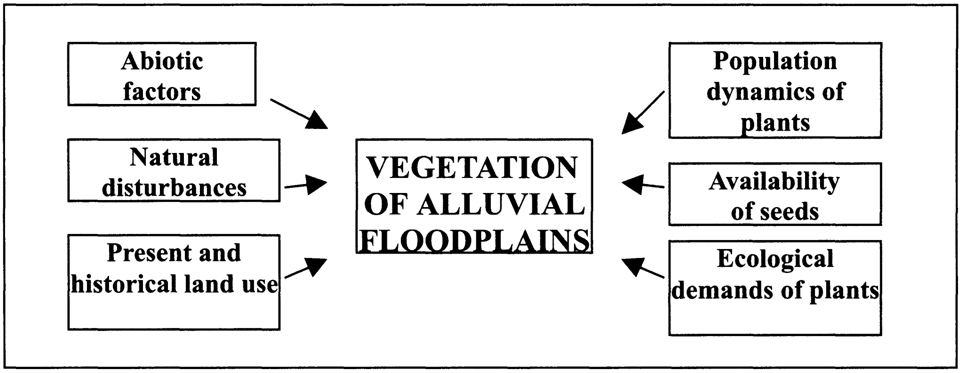

Fig. 1 – Factors influencing vegetation in floodplains

anthropogenic disturbances, which erode the ecosystems, disturb their continuity and create new habitats often occupied by invasive species. Large-scale disturbances like floods are an important factor driving the dynamics of the whole floodplain ecosystem.

Catastrophic floods in July 1997 in Moravia and in August 2002 in Bohemia started up many case studies investigating vegetation changes and developments in alluvial plains after floods (Blažková 2003; Koutecký 2000; Kovář 1998; Kovář et al. 2002a; Lacina et al. 1998 etc.). Floodplains as areas periodically disturbed by erosion and sedimentation represent a kind of large-scale field laboratories making possible to follow up processes of natural succession, colonization on new created and disturbed surfaces, changes in species composition of communities and other ecological processes in the landscape.

2. Vegetation of alluvial plains and roots of its high geo/biodiversity

The state and development of vegetation in alluvial floodplains depend, beside the processes and factors mentioned above, on seeds and spores availability, population dynamics of species and their ecological demands. Relations among the dynamics of the water course, its hydrological parameters and dynamics of the development of vegetation in alluvial plains have been proved by many research activities carried out in different geographical conditions covering diverse water regimes throughout the world (Salo et al. 1986 – Amasonia; Marston et al. 1995 – Western Europe; Hupp, Osterkamp 1996 – United States; Townsend 2001 – United States and Western Europe; Petit, Froend 2001 – Australia; Thoms et al. 2005 – Australia; Schnitzler et al. 2005 – Western Europe and United States; Meyer 2001 – United States and others).

In alluvial plains along water courses, where periodical floods occur, the vegetation cover is composed of a mosaic of transient stages from more to less stable formations. The extent and proportion of areas with specific vegetation stages are a result of flood frequency and kinetic energy of every flood (fig. 1).

In lowlands of the temperate zone, regardless of the human influence, the vegetation in alluvial plains along water courses most likely develops from herbaceous vegetation of early successional stages on young fluvial deposits across stages of shrub vegetation to inundated floodplain forests representing final climax community. Because regular yearly floods have only small kinetic energy in this part of alluvial plain under forest vegetation, no significant morphological changes take place on the surface of the floodplain. Montane and submontane rivers power with significantly higher kinetic energy. Large amounts of matters like gravel and stone are yearly transported in their alluvial plains which lead to mechanical defects and injuries of plant individuals; some individuals are buried under the layer of the young sediment deposits. Succession of vegetation is not only one-sided in such dynamic environment and a varied mosaic of habitats with different successional stages of vegetation is formed here. Single successional stages are periodically disturbed and new succession is initiated. It is a reason why mature or even climax successional stages with old trees are not occured here. The absence of trees in alluvial plains along rivers with often occurring and heavy floods is mentioned by Kenyon, Rutherfuer (1999) and Petit, Froend (2001) from Australian rivers or by Meyer (2001) from the Yellowstone National Park. In spite of geographical differences among studied areas, the results confirm the fact the intensive changes of the river channel and floodplain inhibit the growth of tree species in the area affected by the disturbance regime.

Native floodplain forests have been limited by man activities in their original extent and changed into agricultural lands. Primary woody vegetation has been replaced by herbaceous vegetation of alluvial meadows. The meadows represent the vegetation of permanent grasslands created by regular agricultural activities (grazing or mowing grass) on localities with regularly repeated floods and high level of groundwater. Alluvial meadows with many rare species are an important factor increasing biodiversity of the landscape. High biodiversity of plants in alluvial floodplains is a significant feature especially in landscapes with mineral poor grounds where species rich vegetation contrasts with species poor vegetation in the surroundings.

The biodiversity of alluvial vegetation, both floodplain forests and alluvial meadows, is a reflection of different geographical, ecological and historical factors (Salo et al. 1986; Amoros et al. 1987; Schnitzler et al. 2005). According to Krahulec (1996), the factors of biodiversity can be divided in to following groups:

I. Geographical factors are demonstrated especially in phytogeographical differences amongst single regions which are characterized by a specific species composition. The species composition is conditioned by geographical factors namely the altitude (above sea level), slope inclination and orientation (influence on shading, frequency and length of climatic inversions, soil moisture and air humidity) and geological characteristics. Morphological diversity of the surface of the alluvial plain plays an extremely important role increasing the biodiversity as well. It concerns especially various terrain depressions and incised meanders which increase geodiversity of the environment in floodplains and cause the existence of different successional stages of vegetation. Diversity of vegetation is further supported by active dynamics of the water course and floods creating, disturbing and remodelling existing fluvial forms of relief and supporting such a creation of a heterogeneous mosaic of different habitats (Krahulec 1996; Amoros et al. 1987; Salo et al. 1986). Even very low altitudinal differences cause large differences in the frequency of flooding of the surface. On the other hand, according to Marston (1995), extreme floods and extremely high dynamics of water course, which is typical for wild mountain rivers, can effectively disturb successional stages of vegetation and inhibit successional development and that way decrease the biodiversity. Marston (1995) demonstrates these effects on the example of the river Snake in the Grand Teton National Park but we can find similar situations in Europe for example in the Alps as well. Common knowledge of landscape ecology concerning the different role of small and big disturbances in the landscape and their influence on biodiversity (Forman, Godron 1993) is so confirmed.

II. Frequency, intensity and duration of floods have influence on processes of erosion and accumulation, transport of seeds and spores and elimination of species which do not tolerate long-term flooding. Physiological mechanisms allowing plants to survive during long-term flooding belong to the most important adaptions we can find in the vegetable kingdom. Some species have even adapted their phenological phases to regular floods. So Australian species *Eucalyptus camaldulensis, Melaleuca leucadendra* and *Eucalyptus rudis* or some species of the genera *Salix* and *Populus* in the North America have timed to discharge seeds just in the flood period. Seeds have assured optimal moisture regime and minimum competition of other species this way (Pettit, Froend 2001). But these adaptations are possible only at species growing on regularly flooded sites. Intensity of floods, especially the force of water flow, erosion and accumulation have also influence on creation of new open surfaces without vegetation which are colonisated by species not able to survive in a closed stand. Transport of seeds and spores is very important factor influencing the species composition of vegetation on these new surfaces.

III. Species biodiversity is negatively influenced by dominants. Communities without significant dominants are richer and more varied as to species composition in comparison with communities with one dominant species. On the other hand, the existence of more monodominant stands contributes to higher diversity among communities (Krahulec 1996).

IV. Occurence of large mammals contributes to higher biodiversity in alluvial plains along rivers as well. On the example of beaver is demonstrated how mammals increase the general diversity of sites on local level. Rather drier sections are concentrated under beaver dam while wet habitats with swamp vegetation are above the dam and the best conditions for heliophilous species are created in the area of the dam (Krahulec 1996).

V. Historical factors, namely increasing *anthropogenic pressure* on the landscape: deforestation changing water regime, frequency and intensity of floods, regulation of water courses, construction of dams, mill-races and other artificial channels, frequency and time of grass mowing, fertilizing, tillage, drainage, ground water withdrawal etc.

3. Floodplain vegetation and its reaction to extreme floods

As mentioned above floods are natural and important disturbances that drive the whole floodplain ecosystem. Floods eliminate species that are not adapted to flooding in terms of lack of oxygen and mechanical destruction by transported material. On the other hand floods support less competitive species and are essential for native floodplain vegetation.

Duration and timing together with flood energy are crucial ecological factors controlling floodplain vegetation. Floods during non-growing season affect floodplain vegetation less severely than floods during growing season. Moreover floods during growing season bring a large amount of seeds and affect the spread of species along the stream.

Extreme floods can negatively influence also floodplain vegetation that is adapted to every year flooding. According to Townsend (2001) variation in flood energy and flood duration even the occurrence of extreme floods are likely to be important ecological factors controlling floodplain vegetation. In case of any alteration to hydrological regime of a particular stream, such as river regulation, the number of floods decreases and floodplain vegetation is becoming less diverse in favor of more competitive species due to more stable and less humid environment. These vegetation communities are afterwards less likely or unable to survive sudden extreme flood therefore the effect of extreme flood is more damaging and the regeneration of vegetation is slower.

In Czechia the vegetation succession and changes of species composition were studied after extreme floods in the Orlice river floodplain by Kopecký already in 1965. The following articles were published after extreme floods in 1997 in the Orlice river floodplain (Kovář 1998; Koppová 2001; Janoušková 2001), Morava river floodplain (Koutecký 2000, 2003), Bečva river floodplain (Lacina et al. 1998) and after extreme floods in 2002 in the Berounka river floodplain (Blažková 2003) and in several floodplains in South Bohemia (Vaněček 2005). The published results together with our own field research of vegetation dynamics after floods can be summarized and divided into three thematic groups:

- regeneration of floodplain vegetation
- vegetation succession on new sites and on agricultural land abandoned due to floods
- the spread of invasive species in the floodplain.

3.1. Regeneration of floodplain vegetation

Kopecký (1969) as well as Balátová-Tučková (1996) and Koutecký (2000, 2003) studied the regeneration of herbaceous floodplain vegetation after extreme floods. They identically concluded that regeneration of floodplain vegetation affected by floods is completed within 2 years depending on the flood impact. According to Koutecký (2000, 2003) even after long term flooding when almost all herbs died down in the Morava river floodplain in 1997, the regeneration was completed within 2 years. Woody plant species were less affected by the 1997 flood except *Euonymus europaeus* and *Sambucus nigra* which died down as well. One month after water regression 28 species were already recorded, regenerating from underground organs or from the present seed bank e.g. *Alopecurus pratensis, Carex gracilis, Carex riparia, Dactylis glomerata, Elytrigia repens, Iris pseudacorus, Juncus effusus, Lysimachia nummularia, Lysimachia vulgaris, Lythrum salicaria, Phalaris arundinacea, Polygonum amphibium, Potentilla anserina, Potentilla reptans, Rorippa sylvestris, Rumex crispus, Sanguisorba officinalis* and there was also a massive occurrence of seedlings of *Plantago lanceolata*. Woody plant species seedlings except *Fraxinus excelsior* were absent. Three month after flooding vegetation cover increased up to 60 %. Vegetation was still absent in deep depressions where water stagnated longer time. The following growing season the vegetation cover in these depressions reached half of the vegetation cover in the surroundings and the next year there was no notable difference in vegetation cover.

Kovář et al. (2002b) also concluded that the regeneration of floodplain vegetation after extreme floods was successful even on places that were buried under layer of sediments. Geophytes were especially successful followed by *Alopecurus pratensis*, *Poa pratensis*, *Rumex acetosa*, *Rumex obtusifolius*, *Symphytum officinale*, *Plantago lanceolata*.

Generally the regeneration of native floodplain vegetation is fast since species have evolved life strategies that enable them to quickly colonize large areas. The ability of certain species to regenerate depends mainly on the depth of flood water, duration of flooding and thickness of sediment. Flood induced dynamics within vegetation communities creates series of patches with following characteristics:

- the vegetation community does not change, the flood causes only fluctuation in overall vegetation cover
- the vegetation community does not change, the flood causes only fluctuation in vegetation cover of dominant species
- the temporal change in composition of the vegetation community but the development leads towards previous state
- the long term change in composition of the vegetation community.

3.2. Vegetation succession on new sites and on agricultural land abandoned due to floods

On newly deposited sediment the composition of species is dependent upon several factors. Primarily it is dependent upon the seed bank brought and deposited together with the sediment but also on the seed bank buried underneath. The succession is afterwards controlled mainly by abiotic factors such as the type of sediment in terms of coarseness, insolation, the amount of organic matter and also the microclimate. The vegetation succession may be also influenced by the layer of nutrient rich fluvisols under sediments that can be easily accessible to plant roots.

The diversity of seed bank contained in the sediment reflects the timing of flooding. According to Kovář at al. (2002b) the diversity of seed bank is recognizable already one month after flooding during the growing season. Kovář et al. (2002a) and Janoušková (2001) also concluded that the seed bank was not large in deposits and there was no difference between sand and gravel despite the sandy sediments were previously thought to contain richer seed bank. The most common species of the deposits were *Urtica dioica*, *Stellaria media*, *Artemisia vulgaris*, *Chenopodium album*, *Chenopodium polyspermum*, generally species producing high number of seeds. There also occurred new species, after the floods, previously absent it the Orlice river floodplain e.g. *Melandrium rubrum*, *Aster novi-belgii*, *Sedum hispanicum*, *Rudbeckia laciniata* or *Veronica filiformis*. Patches covered by sediments represent places with minimal space and light competition, therefore these conditions enable establishment of less competitive species.

Blažková (2003) studied the vegetation succession on deposits in the Berounka river floodplain after the floods in 2002. Massive gravel sediments were without vegetation even two month after water regression compared to gravel sediments with layer of sand underneath where species from the alliance *Bidention* and mainly ruderal plant species had already been present. The most common young seedlings were *Galium aparine*, *Stelaria media*, *Carduus crispus*, *Barbarea vulgaris* and *Rumex obtusifolius*. Sandy and less coarse gravel sediments were the most vegetated sediments two month after floods. The most common species were *Sinapis alba* and *Triticum aestivum* that were brought from the surrounding agricultural fields with the sediments.

Loamy sediments were deposited only in higher parts of the floodplain. They did not cause any damage to the present vegetation but they enriched the sites with nutrients and moisture, moreover enriched the seedbank with several species e.g. *Potentilla supina*, *Veronica beccabunga*, *Filaginella uliginosa.*

Blažková (2003) also recorded vegetation of erosive cuts that occurred only in those parts of floodplains converted to arable land. The most common species were *Equisetum arvense* and ruderal plants.

Generally we can summarize the knowledge about vegetation succession on sediment as follows:

- annual plants are the first colonists followed by plants expanding from sides
- there is a higher biodiversity on new sediments compared to the surroundings e.g. Blažková (2003) recorded 50 species within a 25m2 plot
- there can occur plant species long time absent in the floodplain or mountain and submountain species can occur in the lowland
- the sediments can support expansion of invasive species or support less competitive species
- the full canopy closure occurs after 2 years on sandy sediments, and after 4 years on gravel sediments; the difference is due to different amount of organic matter and different moisture regime
- the regular rhythm of more extensive floods maintains the sediments in early successional stages.

Kovář (1998) and Kovář et al. (2002a) studied the succession of vegetation after floods in 1997 in the Morava river floodplain. The agricultural land abandoned due to the floods was dominated by invasive plant species e.g. *Solidago gigantea, Impatiens glandulifera* and woody plant species e.g. *Salix triandra, Salix purpurea, Salix caprea, Alnus glutinosa.* The willows colonized mainly depressions while alder mainly more coarse sediments. The common woody plant species were also *Betula pendula, Populus tremula, Acer pseudoplatanus.* Five years after floods the mosaic of herbal, shrub and potentially forest stages of succession were present. The same conclusions brought also the research in the Bečva river floodplain after the floods in 1997. The 1997 flood renewed ecological conditions suitable for floodplain forest that was destroyed during former channel modifications. The similar succession stages were identified also in several other floodplains affected by the 1997 flood e.g. the rivers Desná, Branná and Krupá.

3.3. Spreading of invasive species in floodplains

The areas affected by fluvial disturbance offer possibility to be colonized by invasive neophytes (introduced species that rapidly occupy new areas). There are more reasons for successful spreading of invasive neophytes in river floodplains. These are the most important of them:

– floodplain is an extraordinary dynamic and overburdened area

– river is something like „transport trunk“ of material and energy flows in the landscape; it makes opportunity for rapid spread of introduced species diaspores

– there is an extraordinary concentration of human settlement and economic activities; the spread of invasive species is supported especially by transport and agricultural activities

– floodplains are often degraded due to an extraordinary high level of anthropogenic pressures

– there is regular disturbance of these areas by floods
– floodplain soils are very nourishing.

The most important invasive plants in floodplains and river bank vegetation in Czechia are *Reynoutria japonica, R. sachalinensis* and *R.* × *bohemica*, *Solidago gigantea*, *S. canadensis*, *Helianthus tuberosus*, *Impatiens glandulifera* and others. This species can be important competitors for native species and they can form large monocultural areas. For example, more than 1 % from the total area of Přerov town region (Central Moravia) is covered by invasive species, especially in Bečva river floodplain (Dohnal 2005).

These species can also change their own habitat. For example, the rootage of *Reynoutria* can destabilize and destroy river banks. Other species can hybridize with natives. This process can make native species disappear. Another interesting example from floodplains in Czechia is *Populus* × *canadensis*. It is a hybrid of native *Populus nigra* and *Populus deltoides*, which was introduced there. Although it was rather frequent in history, the pure form of *Populus nigra ssp. nigra* is very rare now. There are only about 200 individuals in Czechia now (for further information see Benetka 1997).

The spreading of invasive species in certain sections of floodplains affected by floods was in Czechia studied for example by Kopecký (1967), Lacina et al. (1998), Kovář et al. (2002a), Kovář (2002) and Blažková (2003).

A large expansion of *Impatiens glandulifera* and *Solidago sp.* was observed in Moravia after floods and a large expansion of *Bunias orientalis* and *Impatiens glandulifer*a in the Tichá Orlice river floodplain. *Impatiens glandulifer*a appeared in the Orlice river floodplain in 1970´s and 1980´s. Indian balsam became dominant species of river bank vegetation during this time period and after floods in July 1997 it rapidly occupied all the floodplain area. It was spreading from fresh fluvial sediments to the upper and drier grassland, forest edges and it also occupied partly the sunny forest borders out of floodplain. The spreading was not so successful in coherent areas of *Urtica dioica*. *Bunias orientalis* was found to be successful competitor to perennial coherent vegetation. It normally produces seeds there and it is able to regenerate from underground organs (Kovář et al. 2002b).

On the other hand, Lacina et al. (1998) presents rather different results from the Bečva river floodplain. There were scatterly observed invasive neophytes only during initial succession states, in spite of their long term previous presence in neighbor river bank vegetation before floods. *Reynoutria japonica, Helianthus tuberosus* and *Impatiens glandulifera* were found only on newly established habitats after floods having formed scattered isles there (Lacina et al. 1998).

The population of *Impatiens glandulifera* in Berounka river floodplain was quite reduced by floods in July 2002. There were found only 2 individuals there after these floods, but the seeds of Indian balsam were distributed by water along the entire river. On the other hand, *Echynocystis lobata* did not lose its position after the floods. *Reynoutria japonica* was after the floods successful too and there was found a great number of regenerating individuals there in October 2002 (Blažková 2003).

Kopecký (1967) observed rapid spreading of *Solidago sp.* and *Impatiens glandulifera* on the central and lower section of the Bečva river. This species were spreading there due to regulation of the river and devastation of natural river bank phytocoenosis.

There was observed a low number of invasive neophytes, especially of *Reynoutria sp.*, *Impatiens glandulifera* and *Solidago sp.* in the floodplains of the rivers Blanice and Volyňka in the south of Bohemia, in comparation with the situation in the floodplains of both the Orlice river and rivers in the north of Moravia. However, this difference had already been there before the floods.

The massive spreading *Impatiens glandulifera* was already observed in floodplains of both Tichá and Divoká Orlice rivers in 1990´s. (Lipský et al. 1993). This species spreads rapidly in floodplains of the other rivers (for example, Sázava, Svratka and its tributaries under the Vír Lake. It has been spreading also in the parts that have not been affected by floods during last decades.

Helianthus tuberosus spreads especially in Moravian river floodplains. Two thirds of areas affected by invasive neophytes in Přerov town region were formed by this species (Dohnal 2005).

The situation of different biotopes in the central Labe floodplain (between towns Kolín and Čelákovice) was studied in 2004 (Matějček 2004). Since there were no great floods in this part of Labe river floodplain in last decades, it is interesting to compare it with the river floodplains affected by great floods during last years. There was observed relatively lower occurence of *Reynoutria sp.* and *Impatiens gladulifera* in the Labe floodplain if we compare it with the other rivers in the Czech Republic, but the abundance of *Solidago sp.* is rather high. *Impatiens parviflora* were observed to be very common in floodplain forests, it was often dominant species of bottom layer. High number of invasive species was observed in exhausted send quarries. In addition to current invasive species mentioned before there was also observed rather high occurrence of *Erigeron annuus.*

Of course, the spreading of invasive species is not a problem only of the Czech rivers. There were, for example, observed *Reynoutria japonica*, *Solidago gigantea*, *Acer negundo*) and *Robinia pseudacacia* in the Rhôna river floodplain (Schnitzler et al. 2005). The most important invasive species of river floodplains in Ireland are *Impatiens gladulifera*, *Reynoutria japonica* and especially rhododendrons (most often it is a hybrid of *Rhododendron ponticum* and *Rhododendron catawbiense* (Pilcher, Hall 2001).

4. Conclusion

Extreme floods are an integral part of floodplain ecosystem and a significant driver influencing its dynamics and the whole development. They disturb existing habitats, create new ones and support a varied mosaic of different habitats with different successional stages of vegetation. Floodplain vegetation is adapted to floods as repeated stress factor and after floods the vegetation is capable to regenerate. In general the ability to regenerate is dependent upon flood duration and flood water depth. On localities where new morphological landforms like gravel beds and sand deposits were formed the spontaneous succession is initiated. Therefore vegetation communities create a series of patches made up transitions between more or less stable stands in the floodplain. Different successional stages as well as variable habitats in floodplains are functioning as factors increasing ecosystem and species biodiversity. According to the basic landscape ecological principle on the role of disturbances in the landscape (Forman, Godron 1993), repeated floods necessitate an increased geo/biodiversity in the riverine landscape.

Because of the close dependence on natural flooding regimes, floodplains are particularly vulnerable ecosystems and any anthropogenic alterations of hydrology and vegetation can modify the ecosystem in a significant way. Moreover floodplains were proofed to be important sources of biodiversity in the landscape. Factors controlling the diversity, species composition and development of the vegetation can be divided into 5 groups: geographical factors (especially morphological and geological conditions); flood duration, frequency, intensity and timing; dominant species in vegetation; disturbances caused by large mammals and floodplain history in the sense of anthropogenic alterations.

Disturbance regime of floods and erosion of existing vegetation communities offer, on the other hand, an excellent possibility for the disturbed sites to be colonized by invasive neophytes that spread rapidly through floodplain. Field research carried out on more Czech and Moravian rivers after catastrophic summer floods in July 1997 and August 2002 confirmed big differences in occurring invasive plant species in different areas. While future spatial distribution and spread of invasive species is difficult to forecast, the processes of succession and regeneration of vegetation after floods are well predictable.

References:

AMOROS, C. et al. (1987): The reversible process concept applied to the environmental management of large river systems. Environmental Management, 11, pp. 607–617.

BALÁTOVÁ-TULÁČKOVÁ, E. (1996): K ekologii zaplavovaných luk kontinentálně laděných oblastí. Příroda, 4, AOPK, Praha, pp. 69–76.

BAILEY, P. B. (1995): Understanding large river-floodplain ecosystems. Biological Science, 45, pp. 153–158.

BENETKA, V. (1997): Program na záchranu genofondu topolu černého v České republice. Ochrana přírody, 52, No. 6, pp. 178–180.

BLAŽKOVÁ, D. (1996): Aluviální louky řeky Berounky. Příroda, 4, AOPK, Praha, pp. 125–129.

BLAŽKOVÁ, D. (2003): Pobřežní vegetace řeky Berounky dva měsíce po povodni v srpnu 2002. Bohemia centralis, 26, Praha, pp. 35–44.

BROOKS, A. P., BRIERLY, G. J., MILLAR, R. G. (2003): The long-term control of vegetation and woody debris on channel and floodplain evolution: insights from a paired catchment study in southeastern Australia. Geomorphology, 51, pp. 7–29.

DOHNAL, J. (2005): Evidence výskytu neofytů na území Přerova a návrh na jejich likvidaci. Absolventská práce. VOŠ zahradnická, Mělník, 57 p.

FORMAN, R. T. T, GODRON, M. (1993): Krajinná ekologie. Academia, Praha, 586 p.

HADINCOVÁ, V. (1996): Vodní retenční kapacita půd nivních luk. Příroda, 4, pp. 53–66.

HOLOUBEK, I., DUŠEK, L. et al. (1998): Identifikace rizik pro životní prostředí. Projekt IDRIS. Výzkumná zpráva MR/340/1/96 depon. in knih. CENIA.

HUPP, C. R. (1992): Riparian vegetation recovery patterns following stream channelization: a geomorphic perspective. Ecology, 73, pp. 1209–1226.

HUPP, C. R., OSTRKAMP, W. R. (1996): Riparian vegetation and fluvial geomorphic processes. Geomorphology, 14, pp. 277–295.

JANOUŠKOVÁ, P. (2001): Ekologický význam náplavů v říční nivě. Thesis. Depon. in Knih. kat. bot. PřF UK, Praha.

KENYON, CH., RUTHERFORD, I. D. (1999): Preliminary evidence for pollen as an indicator of recent floodplain accumulation rates and vegetation changes: The Barmah-Millewa forest, SE Australia. Environmental Management, 24, No. 3, pp. 359–367.

KOLEJKA, J. (2003): Geoekologické aspekty zmírňování povodňových škod. Geografie–Sborník ČGS, 108, No. 3, pp. 1–13.

KOPECKÝ, K. (1969): Změny druhového složení některých fytocenos v inundaci dolního toku Orlice po záplavách v roce 1965. Preslia, 4, pp. 284–296.

KOPPOVÁ, J. (2001): Znovuosidlování náplavů vegetací na aluviálních loukách. Thesis. Depon. in Knih. kat. bot. PřF UK, Praha.

KOUTECKÝ, P. (2000): Regenerace luk v nivě Moravy po katastrofální povodni v roce 1997. Thesis. Depon. in knih. kat. bot. PřF UK, Praha.

KOUTECKÝ, P. (2003): Změny vegetace aluviálních luk po povodních (jižní Morava). Zprávy ČBS, 38, pp. 111–115.

KOVÁŘ, P. (1998): Povodňové náplavy: otevřený biologický prostor. Živa, 84, No. 5, p. 203–204.
KOVÁŘ, P. (2002): Ekologická synchronie: paralelní koridory v krajině a rostliny (Případová studie: Bunias orientalis L. v polokulturní krajině říční nivy). In: Maděra P. (ed.): Ekologické sítě. Sborník příspěvků z mezinárodní konference 23.–24.11.2001 v Brně, Geobiocenologické spisy, sv. 6, MZLU v Brně a Mze Praha, pp. 14–18.
KOVÁŘ, P. (2003): Transplantovaná synantropizace: rostliny a nová stanoviště vložená do krajiny. Zprávy ČBS, 38, pp. 17–26.
KOVÁŘ, P. et al. (2002a): Ekologický význam vegetační sukcese v říční nivě po extrémních záplavách. Souhrn dosažených výsledků, Projekt GAUK126/2000/B/BIO, PřF UK, Praha.
KOVÁŘ, P. et al. (2002b): Vegetační sukcese v nivě řeky pět let po záplavě. Živa, 88, No. 6, pp. 253–257.
KRAHULEC, F. (1996): Příčiny druhové diverzity aluviálních luk a možnosti jejich obnovy. In: Příroda, 4, AOPK, Praha, pp. 155–162.
KVĚT, J. (1996): Obecné ekologické funkce nivních luk. Příroda, 4, AOPK, Praha, pp. 21–23.
LACINA, J. (2002): Katastrofické přírodní jevy a jejich odezva v ochraně přírody a krajiny. In: Tvář naší země. Krajina domova. Díl 5. Ochrana krajiny. Studio JB, Praha, pp. 37–43.
LACINA, J. et al. (1998): Sledování sukcese, vegetace a vývoje říčního koryta ve vybraných profilech Bečvy mezi Osekem n. B. a Valašským Meziříčím. Výzkumná zpráva, Ústav geoniky AV ČR, Brno, 61 p.
LANGHAMMER, J. et al. (2006): Změny krajiny jako ovlivňující faktor průběhu a projevů extrémních povodní. PřF Uk, Praha, 209 p.
LIPSKÝ, Z. et al. (1993): Ekologická studie Orlice. ÚAE VŠZ, Kostelec n. Č. l. Studie pro Povodí Labe.
LOŽEK, V. (2003): Povodně a život nivy. Bohemia centralis, 26, Praha, pp. 9–24.
MARSTON, R. A. el al. (1995): Channel metamorphosis, floodplain disturbance and vegetation development: Ain River, France. Geomorphology, 13, pp. 121–131.
MATĚJČEK, T. (2004): Invazní druhy rostlin v nivě středního Labe. In: Měkotová, J., Štěrba, O. (eds.): Sborník z konference Říční krajina, PřF UP, Olomouc, pp. 162–167.
MEYER, G. (2001): Recent large-magnitude floods and their impact on valley floor environments of northeastern Yellowstone. Geomorphology, 40, pp. 271–290.
PETIT, N. E., FROEND, R. H. (2001): Variability in flood disturbance and the impact on riparian tree recruitment in two contrasting river systems, Wetland Ecology and Management, 9, pp. 13–25.
PETŘÍČEK, V. (1998): Povodně v nivách a náprava jejich účinků na krajinu. Živa, 84, No. 4, pp. 154–156.
PILCHER, J., HALL, V. (2001): Flora Hibernica. The wild flowers, plants and trees of Ireland. The Collins Press, Cork, 203 p.
RYCHNOVSKÁ, M. (1992): Funkčnost a vzájemné vztahy polopřirozených a umělých ekosystémů v říční nivě. CHKO Litovelské Pomoraví. Výzkumná zpráva F1.14/01 depon. in Knih. CENIA.
RYCHNOVSKÁ, M. (1996): Ekosystémové funkce nivních luk. In: Příroda, 4, AOPK, Praha, pp. 25–33.
SALO, J. el al. (1986): River dynamics and the diversity of Amazon lowland forest. Nature, 332, pp. 254–258.
SCHNITZLER, A., HALE, B. W., ALSUM, E. (2005): Biodiversity of floodplain forests in Europe and eastern North America: a comparative study of the Rhine and Mississippi Valleys. Biodiversity and Conservation, 14, pp. 97–117.
TOWNSEND, P. A. (2001): Relationship between vegetation patterns and hydroperiod on the Roanroke River floodplain, North Carolina. Plant Ecology, 156, pp. 43–58.
VANĚČEK, Z. (2005): Sukcese vegetace na říčních náplavech vzniklých po povodni v srpnu 2002. Bakalářská práce depon. in Knih. kat. bot. BF JU, České Budějovice.

Shrnutí

SUKCESE VEGETACE V ALUVIÁLNÍCH ZÁPLAVOVÝCH ÚZEMÍCH PO EXTRÉMNÍCH POVODNÍCH

Extrémní povodně jsou neoddělitelnou součástí nivních ekosystémů a jsou významnou řídící silou, která ovlivňuje dynamiku a celý vývoj říčních niv. Disturbanční režim povodní

vede k vytváření nových stanovišť, na nichž probíhají intenzivní procesy ekologické sukcese a kolonizace. Povodně tak přispívají k rozrůznění ekosystémů a tím i ke zvyšování biotické pestrosti společenstev v údolní nivě. Nivy řek představují složitý přirozeně fragmentovaný ekosystém, jehož stav v sobě vstřebává a odráží vliv historických i současných přírodních disturbancí (záplavy, eroze, sedimentace), klimatických faktorů a managementu. Mimořádná rychlost a intenzita geomorfologických procesů eroze, transportu a sedimentace je doprovázena procesy sukcese, kolonizace a migrace druhů. Tuto vlastnost si ponechávají i nivy v kulturní krajině pozměněné a využívané člověkem. Nivy tak slouží jako významné koridory pro pohyb rostlinných a živočišných organismů a také jako prostory šíření invazních druhů v krajině. K jejich šíření obecně přispívají disturbance, které způsobují narušení ekosystémů a vytvářejí nová stanoviště, jež jsou často obsazována invazními druhy. Vegetace niv je navíc závislá na dostupnosti diaspor, populační dynamice druhů a jejich ekologických nárocích.

Katastrofální povodně, které se v posledních 10 letech opakovaně vyskytly na rozsáhlých územích Česka, byly impulsem pro celou řadu případových studií, zabývajících se sledováním změn vegetace v územích postižených záplavou a sedimentací. Údolní nivy jako periodicky narušovaná území tak představují jakési terénní laboratoře, v nichž lze sledovat průběh sukcese, osídlování nově vzniklého nebo narušeného prostředí, změny v druhovém složení společenstev a další ekologické procesy v krajině. Tematické zaměření dosavadních výzkumů lze rozdělit do 3 skupin:

– regenerace původní vegetace po narušení způsobeném povodní
– sukcese na nově vytvořených stanovištích
– šíření invazních druhů rostlin v údolní nivě.

Nivní vegetace má vyvinutou řadu adaptačních mechanismů a dokáže na působení disturbancí způsobených povodní spontánně reagovat. Záplavy eliminují výskyt druhů, které k nim nejsou přizpůsobeny, podporují druhy přizpůsobené a umožňují i existenci některých konkurenčně slabších druhů. Schopnost regenerace vegetace po záplavách závisí především na délce trvání povodně a na jejich extremitě (výšce maximálního vodního stavu). Tam, kde v důsledku povodní vznikly nové geomorfologické tvary (např. štěrkopískové akumulace), dochází ke spontánní sukcesi. Vytváří se tak pestrá mozaika vegetace v různých sukcesních stádiích.

Vývoj nivní vegetace, její prostorové rozmístění a druhovou diverzitu ovlivňují nejrůznější faktory, které je možno rozdělit do pěti skupin: geografické faktory (především geologické a geomorfologické podmínky); frekvence, intenzita a délka trvání záplav; dominantní druhy; disturbance způsobené působením velkých savců a historický vývoj nivy, především její antropogenní ovlivnění.

Pravidelné disturbance a vznik nových stanovišť však na druhou stranu vytvářejí podmínky pro šíření invazních druhů, které může být příčinou poklesu početnosti populací druhů domácích. Významným praktickým problémem je navíc špatná předvídatelnost působení invazních druhů v nově obsazených ekosystémech. V údolních nivách řek a jejich břehových porostech se v uplynulých desetiletích rozšířily zejména křídlatky (*Reynoutria japonica, R. sachalinensis* a *R. x bohemica*), zlatobýly (*Solidago gigantea* a *S. canadensis*), slunečnice hlíznatá (*Helianthus tuberosus*), netýkavka žláznatá (*Impatiens glandulifera*) a některé další. Mezi jednotlivými řekami postiženými katastrofálními záplavami však existují ve výskytu invazních druhů významné rozdíly.

Výsledky výzkumů prováděných na mnoha českých, moravských a slezských řekách postižených katastrofálními povodněmi v červenci 1997 a v srpnu 2002 přinesly zajímavé poznatky o průběhu sukcese a kolonizace na narušených nebo nově vytvořených stanovištích. Potvrdily také rozdíly v charakteru a průběhu těchto procesů mezi vodními toky horských a podhorských či nížinatých oblastí, které vyplývají zřejmě z rozdílného charakteru sedimentace v údolní nivě i z rozdílů v okolní krajině, v množství a typu genetického materiálu apod. Další výzkumy v modelových územích by měly přispět k vysvětlení těchto rozdílů a zákonitostí.

Obr. 1 – Faktory ovlivňující vegetaci v záplavových územích

(Authors are with Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology, Department of Social Geography and Regional Development, Albertov 6, 128 43 Praha 2, Czechia; e-mail: chumant@natur.cuni.cz, lipsky@natur.cuni.cz, tomatej@natur.cuni.cz.)

Arrived to the editorial board on August 28, 2006

GEOGRAFIE – SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI
ROK 2006 • ČÍSLO 3 • ROČNÍK 111

RAFAEL BAENA ESCUDERO, INMACULADA GUERRERO AMADOR,
BOHUMÍR JANSKÝ

COMPARATIVE ANALYSIS OF THE FLOODS IN PRAGUE (CZECHIA) AND IN SEVILLE (SPAIN): SEEN FROM THE GEOGRAPHICAL VIEWPOINT

R. Baena Escudero, I. Guerrero Amador, B. Janský: *Comparative analysis of the floods in Prague (Czechia) and Seville (Spain): seen from the geographical viewpoint.* – Geografie–Sborník ČGS, 111, 3, pp. 326–340 (2006). – The urbanization pressure upon the areas originally endangered by floods has increased, creating a new imbalance between the city and the river. The relationship to the various strategies that are being used to prevent the predictable flood risk in Prague and Seville, constitute the main topics of the following article. Authors analyze two very different drainage systems – the Vltava river in Czechia with temprate snow-rain climate versus the Guadalquivir river in the south of Spain with subtropical rain climate. The general hydrological properties will be compared as well as the highly different morphohydrology of the specific flood areas close to the cities of Seville and Prague.
KEY WORDS: flood risk – hydrology – Vltava river – Guadalquivir river – comparative analysis – historical floods – flood protection strategies..

The presented research was funded by the Research Plan MSM 0021620831 "Geographical Systems and Risk Processes in Context of Global Changes and European Integration" of the Czech Ministry of Education and Research Project VaV-SM/2/57/05 "Long-term changes of river ecosystems in floodplains affected by extreme floods" of the Ministry of Environment of the Czech Republic which is fully appreciated by the authors.

1. Introduction, goal and methods

During the last two decades in the Czechia and Spain, important changes to the social system have taken place. These resulted, among other things, in new approaches by public administration to natural systems in general and to the rivers in particular. The rivers represent clear examples of complex ecosystems deeply altered by human activity. Undoubtedly they are of considerable economical, sociocultural and ecological importance for the cities built on their shores (Garzon et al. 1990; Martinez et al. 1991; Peiry, Nouguier 1994; Klingeman et al. 1994; García y Baena 1997). Despite the traditional as well as current danger of floods with catastrophical consequences, the areas immediately along the shores of a river are not always included in territorial planning. Thus, a conflicting borderline area between the socio-economical and natural spheres has been created. Factors that influence the river-basins and their surroundings became the top priority in the fight against floods. This, to a larger extent, explains why river streams in cities are so artificial and at the same time almost marginal, without much importance. Regardless of our feelings about it: we had succeeded in reducing the frequency and volume of floodings leading to increased safety for human activities. At the same time, urbanization pressure upon the areas originally endangered by floods has also increased, creating a new imbalance between the city and the river. In such an imbalanced system, the risk of potentially dangerous hydrological events, now extreme ones, is growing again.

The relationships between the above mentioned elements and especially the relationship to the various strategies that are being used to prevent the predictable flood risk in Prague and Seville, constitute the main topics of the following article. It is based upon two key assumptions for the arrangement of the city landscape located directly ashore a river. The first principle is that floods are not disasters. They are natural events reacting to extreme but natural processes in the river systems. That is why flooding lowlands and similar morphological shapes exist (Ward 1978, Mateu 1990, Díaz y Baena 1999). Therefore, it is the interference of humans and their settlement on the shores of rivers, that causes and increases the flood risk (Parker, Penning-Rowsell 1982; Baena y García 1995; Langhammer 2003). The second principle says that we have to approach a risk that has been created in this manner as a problem between the interaction of society and the environment. Variable factors of time and area are included, depending on other participating forces. This second principle also depends on the level of socio-technological development, on the city's spatial and infrastructural needs (Guerrero y Baena 1996), or from the climate change and the corresponding river reaction in regard to water volume and sedimentation (Schum 1977, García y Baena 1997).

To illustrate these ideas, this article analyzes two drainage systems, very different due to location: 1. the Vltava river, representing the headwaters, of the Elbe river basin in Czechia and 2. the Guadalquivir river, the main collection stream in the south of Spain. The second major difference is the climate – temperate continental climate versus Mediterranean climate – and the third consists of hydrological properties – temperate snow-rain climate versus subtropical rain climate. In this article, the general hydrological properties will be compared as well as the highly different morphohydrology of the specific flood areas close to the cities of Seville and Prague. We will analyze the distribution and volume reached by floods in these two cases, their consequences resulting from identified morphohydrological elements, and construction projects realized within their immediate surroundings.

The publicly accessible hydrological data has been acquired from UNESCO (1971–1985). Additional data valid for floods has been added – provided by Vanney (1970), Drain et al. (1971) and Guerrero y Baena (1998) in the case of the Guadalquivir river and Janský (2004), Daňhelka (2004) as well as Baena et al. (2004) for the Vltava river. The physiography of each of the city's position in relation to the development of the geometrical variables of the river bed and its stability or instability has been acquired by geomorphological terrain investigation and by the use of satellite ortho-images.

2. Hydrology of the rivers Vltava and Guadalquivir

The amount of rainfall registered in Czechia during August 2002 was undoubtedly an exceptional situation given the geographical size of the

Tab. 1 – Hydrological properties of the Vltava and Guadalquivir rivers

River	Profile	Area of River basin (km^2)	Discharge (m^3/s)	Qmax average	Qmin average (m^3/s)	Coef. var. annual	Discharge 100 (m^3/s)	Discharge 500–1000 (m^3/s)	P (mm)	T July (°C)
Vltava	Praha	26 730	148	662	50	0.30	4 020	5 200	525	< 20°
Guadalquivir	Alcalá	49 900	185	1 306	32	13.8	8 000	11 000	585	> 20°

afflicted area (100 000 km^2), the persistence of raining (August 6th to 15th, 2002) and it's intensity throughout all of Central Europe. Such a meteorological occurrence is caused by continual progress of occlusion fronts strengthened by the presence of warm and damp air streams acting together with the influence of mountains. All this created a certain phenomenon similar to the extreme autumn rains in Mediterranean Spain or to the continuous storms from the South-West in the lowland of the Guadalquivir river. Here, rainfall values, higher than the above mentioned ones in Central Europe, cause floods of a larger extent, although in a smaller area and with a lesser danger to the society. The reason for this is probably that centuries of adaptation have made the human ecosystems at least partially prepared and more able to protect itself from the dramatic consequences (Gil Olcina, Morales 1989).

This event from the summer of the year 2002 and now also from the summer of 2005, assumes revision of the general planning of stream regulation in the temperate climate zone. Especially for the rivers with rare fluctuations within one year (0,3 for Vltava, 0,2 for Rhein, etc. ... compared to 13,8 for the Guadalquivir river) and reduced flood stage (1 500 m^3/s average, 3 700 m^3/s for hundred-year water of the Vltava river) in relation to the maximum annual flow rate (Qmax.= 697 m^3/s). Particularly in comparison with Mediterranean rivers such as Guadalquivir (Table 1), which is being considered a large stream, given the up to seven-times difference between it's coefficient attained by the maximum average flow rate and the sixty-times larger flow rate value during the millennial water such as on 1. January 1968. This millennial flow rate is estimated to have been about 12 000 m^3/s, with 63 000 victims and 6 000 houses as well as the majority of wall paintings destroyed, it is the largest catastrophe of it's kind in the history of Europe (Drain et al. 1971, Bosch 1988, Albentosa 1989).

In comparison, the values exceeding 5 000 m^3/s measured at the Vltava river in the summer, corresponding to values for ten-year floods at Guadalquivir (Vanney 1997), have raised great agitation regarding their causes. The influence of climatic changes, incorrect landscape usage or non-functioning Central European structural protection systems, for example insufficient shore dams and reservoir systems for the regulation of the main stream, are being discussed. The solution – surface geometry of the potentially flooded area has to be judged from the hydrogeomorphological and historical viewpoints – probably still lays in distant future for many rivers and is literally impossible for the problematic ones.

2.1 Important floods on the Vltava river and their characteristics

The Vltava river can be characterized by snow-rain mode with spring melting and intense orographical showers during the summer. A series of

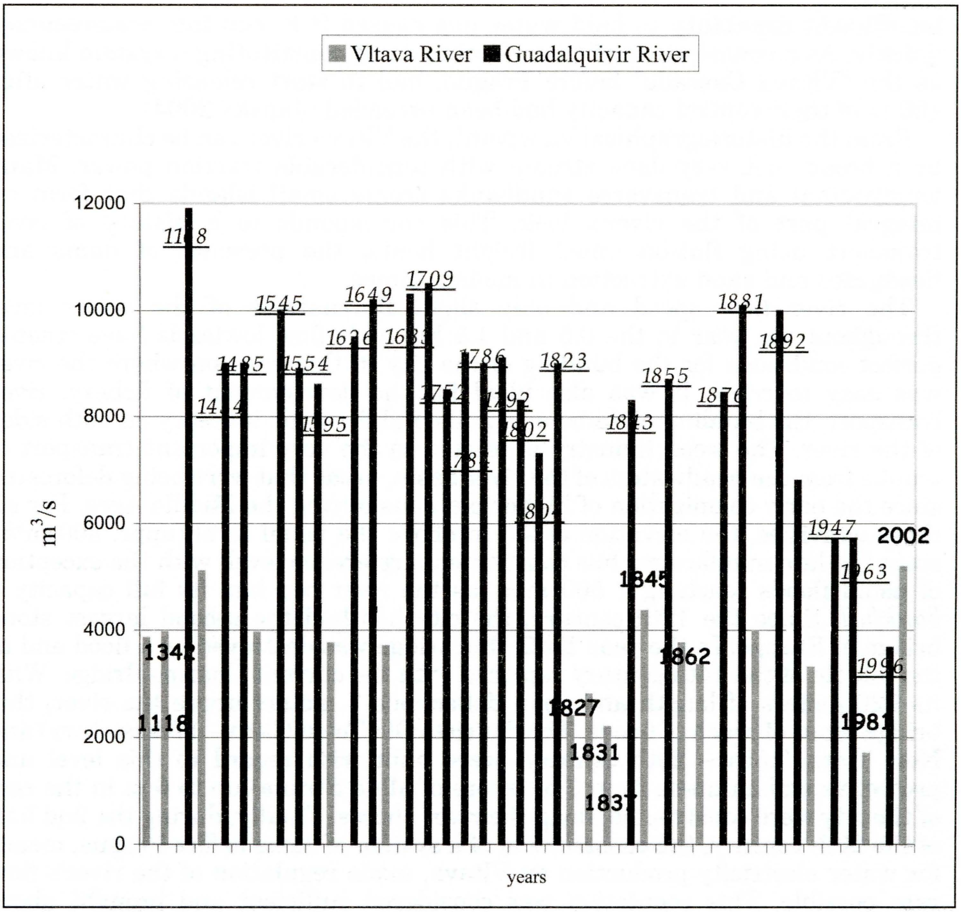

Fig. 1 – Main floods in the history of the city of Prague (Vltava River) and Seville (Guadalquivir River)

exceptional floods in the history of the Vltava river in Prague since 1827 shows a tendency common for European rivers; reduction in the number of exceptional floods during the last two centuries (Petts et al. 1989) with the largest number of floods in the second half of the 19th century (Fig. 1), especially in the winter period, which has during the last fifty years become warmer, with a lesser amount of snow.

The most destructive floods ever registered have been single cases, such as in March of the year 1845 (4 360 m^3/s or 7.07 m height above the usual water level in Prague), in the year 1890 (3 860 m^3/s and 6.42 m height), where three bridges were destroyed, and in the middle of the 20th century in the year 1940 (3 300 m^3/s). Unexpected river flow in August 2002, with a flow rate of 5 160 m^3/s and a height never reached before, 7.82 m, represents a serious warning about the disturbance of geomorphic limits in the river system of this region. The fact that this catastrophe occurred in summer, in a period with the lowest expected rainfall volume, highlights its significance as within only 10 days, the rainfall had reached 40 to 60 % of the total annual rainfall for the South Bohemian area. The other serious fact to note is that the landscape's insufficient capability to hold water has caused it to run into watercourses quickly. As a consequence of this, all nine dams constituting a system known as the "Vltava Cascade" before Prague, had to start releasing water after 100 % of their control capacity had been exceeded (Janský 2004).

From the historiographical viewpoint, the Vltava river can be characterized by a broad, not very deep stream with considerable traction power. Many longitudinal and transverse sandbanks create small islands that form an integral part of the river's look. This corresponds to a history of river transport using flat-bottomed freight boats, the presence of dams and floodgates and sand extraction in modern times.

The river flow speed and only slight fluctuations of the water level throughout the year in the 0.5 and 1.5 km wide flow lowlands have created perfect conditions for the building of the city in this position where the river was easy to cross. It was also ideal for the development of fishery, river transport, the building of dams and mills and for wood industry on both sides of the river. The wood industry is related to the very important transport of trunks from the headwaters of the river basin, areas that were being deforested since the early colonization of higher plateaus during the Middle Ages. For all these activities, the elevation of 2.5 m above the usual level (appr. 300 m^3/s) since the late middle ages has constituted a reference level, with the exception of usual floods reaching 1 500 m^3/s, as the river bed had its full capacity – *bankfull*. Since the 12th century, the city has had the second largest stone bridge in Europe. In the year 1342, this bridge was destroyed by a flood and in the middle of the 14th century replaced with the current Charles Bridge. With its 520 meters of length and span deflections 7 meters above the river, this bridge is out of reach of floods. The districts Old Town (14th – 17th century) and New Town (18th – 20th century) were built with regard to this level and protective embankmets from 3 m (shore of Malá Strana) up to 6 m in the rest of the city were constructed along the river shores. Finally, during the 2nd half of the 20th century, the construction of a system of dams before Prague, meant for water electricity production on Vltava, made regulation of the river's flow rate possible. This regulation was considered sufficient and brought about enormous integration of urban elements into the river landscape.

2.2 Important floods on the Guadalquivir river and their characteristics

In the case of Seville, the river's morphogenesis originally included the complete space without grass topography, with a low elevation above sea level (between 6 and 13 m). At the right and left edge, it is demarcated by slopes that were created above the last Quaternary irrigation fields, on marly and sandy basis, which creates the Aljarafe slope. It is a lowland, on the average 5 km wide, with the Guadalquivir river flowing through the middle, with low longitudinal fall (0.045 %), of meander-like shape, with frequent aquosity fluctuations during different parts of the year. Minimums occur in September (32 m^3/s) and maximums in spring (300–400 m^3/s), not exceeding the full capacity of the river bed estimated to be about 900 m^3/s (Vanney 1970).

From the hydrological viewpoint, this wide space was great for natural drainage needs, with average flow coefficient, estuary dynamics in the Seville area, high time irregularities and great floods, catastrophic for human activity on the river's shores. These floods generally reach from 1 500 up to 12 000 m^3/s (thousand-year water). Until the middle of the last century, they were regulated by the functioning of numerous branches and vacant meanders located in the lowland.

From the values measured in Seville's harbor that show the height reached by floods (Fig. 1), an increase in the number of floods towards the end of the 18th century and in the second half of the 19th century is visible. The floods in the 19th century strongly exceeded the usual level: in the year 1892 (more than 10 m), repeated after 100 years, or in the years 1168 and 1709, with maximum flooding in 500–1000 years and a level rise of 11 to 12 m. The last important flood at the Guadalquivir river, before the completion of the hydroelectric plants in the eighties, happened in February 1963. With 5 700 m^3/s, it caused considerable damage to the inhabitants of the lowland between Córdoba and the swamps. These are now probably the maximum values that can be expected, because of the regulation stage ensured by dams in the river's drainage basin.

In the past, the city has tried to adapt to these exceptional events by using various settling strategies. In Romanic times settlement in the lowland was important for agriculture and the possibility to use the river for ship transport. Buildings were situated 10–12 m above the river, with the exception of harbor buildings which were placed at the side branches of the Guadalquivir river. During the Middle Ages and in the modern times, the increasing number of inhabitants has led to the occupation of a part of the flood lowland. Since the 12th century, the people here defended against the river using broad and high Almohad walls. In floods, Seville remained isolated from the rest of the area for weeks. The city's surroundings behind walls (Triana, Macarena, San Bernardo), or inside walls, were stricken because of rain water. Such was the situation until the end of the 18th century. At that time, insufficient river depth for ship passage and frequent floods prevented normal functioning of harbor activities. So people began work on the following large protective projects:

1. The building of embankments, 10 and 11 m high, along the river stream in the harbor area. At first at the edge of the historical centre (18th–19th century.) and later also in the Triana suburb. At the same time, the first solid bridges were built (the Triana bridge 1852; the San Telmo bridge 1931) both 12 meters above water.
2. The river was straightened, the meanders shortened and the main stream behind the city of Seville was deepened (18th–20th century). The river's axis was shortened by more than 40 km and its bed was deepened considerably, so that drainage capacity increased.
3. Artificial moving of the river towards the west, outside the city (Corta de Tablada in the year 1926, Canal de Alfonso XIII, silt deposition at the Chapina and Los Gordales shores), while harbor activity inside the city remained in the inner harbor controlled by a lock. Higher protective walls, above the thousand-year water level, were added.
4. The regulation of a large part of the stream in the river basin by the building of many dams at Guadalquivir (Alcalá del Río, Cantillana, Puente Sifón, Peñaflor) and it's main affluents with 18 functional spillway dams and a capacity of 1 500 Hm^3 in the first half of the 20th century; the 25 additional dams have quadrupled the total capacity since the year 1960, so that the theoretical values necessary for general hydrological control were achieved.
5. Finally, the realization of the last of the corridors (La Cartuja) meant definite removal of the functional river from the immediate vicinity of the city through the sluicing of shores in the San Jerónimo and Triana

quarters. These measures extended the usable space meant for the World Exhibition in the year.

The result is that the functional river flows outside the city in a designated water channel, into which the water is being drained. All this, together with long droughts in the 80s and 90s has created a false belief that all flood risks have been removed, both by the authorities as well as the public. Doubts were cast on this as a flood of smaller volume but larger height caused by limited space for water spreading came in winter of the year 1996.

3. The flood at the Vltava river in the year 2002 and it's consequences for the city of Prague

From the geomorphological point of view, the river section of Vltava in Prague corresponds to the meandric model, with a low sinusoid, wide stream of medium fall and mixed bottom (gravel and sand), which passes through a flood lowland limited by hill slops. This fact makes wide spreading of the flood maximums impossible. Instead, convergence and divergence of flood streams happens, depending on whether the river section is straight or incurvated, with natural or artificial obstructions.

As mentioned previously, the movement of continuous fronts from the Mediterranean sea in the summer of 2002 caused rainfall in the whole area of Central Europe and especially in South, West and Central Bohemia. Here, the rainfall volume from both fronts was so large that it reached 1.87 km^3 in the river basin of Vltava in the first wave (August 7th–8th, 2002) and 2.77 km^3 in the second wave (August 11th–12th). As a consequence of this, the river basin was completely saturated. This led to the exceeding of the retention capacity of the river's dam system by 8 %. After their opening, a flow rate of 5 160 m^3/s, with estimated return once in 500 to 1 000 let was created. The flood reached this point on August 14th at 12:00 (Fig. 2), with a maximum of 7.82 m in relation to the normal water surface. This is 1.4 m more than during the hundred-year water in the year 1890. The water remained outside the water bed for 9 days, compared to 6 days in 1890. The consequences were disastrous for Prague and its surroundings. Inhabitants

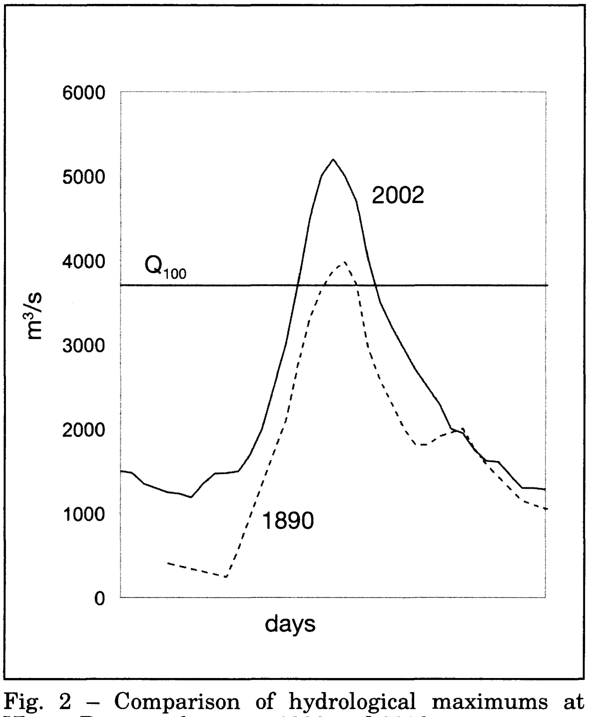

Fig. 2 – Comparison of hydrological maximums at Vltava River in the years 1890 and 2002

including tourists had to be evacuated. Damages and losses were estimated to amount to EUR 2.5 billion.

In the area between Vyšehrad and Sedlec, different behavior of floods and differences in the damages caused, depend on the functionality of the following morphohydrological sections that can be distinguished from the South to the North.

3.1 Section Vyšehrad – Letenské sady

In this section, the stream is straight, with considerable deviations in width and terrain breaks in the profile that correspond to the location of islands. The stream has shores well-defined by historical protective walls, with the exception of areas with old mills, side islands or water energy usage (Kampa, foot bridge...). This has created a discrepancy in the water activity. The water is more active at the left shore (Vojanovy), while the jesep-walls or *point bars* in Josefov remain completely inactive because of the presence of the historical centre. In this section, the river has increased drainage capacity in the case of extreme floods, reduced only by the incurvation and meander between Josefov and Letenská. This region corresponds to the historical river sector of great historical value, dominated by the Charles Bridge and river islands such as Střelecký, Dětský and Slovanský, clearly integrated between the city and river landscape. This area is a very important focal point for tourism because of its characteristic open space. It connects the historical core with the castle and cathedral with amazing views of the city and many possibilities for entertainment and recreation. The consequences of the flood were partially reduced by the building of mobile dams up to 1.5 m. However, these could not prevent the flooding of the underground subway system, so that city transport was paralyzed (more than 1 million subway users a day) and huge damage was incurred (10 % of the total damage) to machinery, the electric system and because of the evacuation and closing of the closest stations.

3.2 Section Karlín – Holešovice

Consists of the large Holešovice meander, which geomorphologically presented the main area for the spreading of the maximum water level values at the Vltava river, after the water crossed the narrowing in the previous part. In this section, stream divergence occurs. This has considerable influence upon the sedimentation of side *point bars* in Holešovice and the verticals in *concave bench* in Karlín. In addition, in the form of sand and mud (overbank deposits) in the mound presented by the old Rohanský island or in the form of clay (*channel-fill deposits*) in the vacant meander area in Karlín. In this section, the largest number of natural changes happened in the Holocene period including side potholes in the meander, widening and creation of the point bars at the right shore as well as *neck cut off* and stream vacation. Later changes were of antropical origin, related to the founding of harbors in Libeň and Holešovice or to the urban development of Karlín. As a consequence of this, great changes in the behavior of floor streams occured. These are now forced to hit the river's right shore. This has caused great damage during the last floods. This happens because of the continuing urbanization of the wide point bars in Holešovice. As their natural size is reduced, they make the passage of flood streams difficult, so that these deviate to the right shore. Then, the vacant stream in Karlín regains importance. Here we find the largest damage in the city, with the water level reaching its top value (2 m above street level). This densely populated historical quarter had to be evacuated completely during the flood and the largest number of houses destroyed occured here. Numerous buildings above the point bars of Holešovice belonging to the top standard service and office complex (Rivercity Praga 2003) were endangered and are now evaluating the suitability of their position because of these risks.

3.3 Section Trója – Bubeneč

Consists of an old branch of sedimentation decantation, with a peaceful stream outside shores, meeting again after Bubeneč. Today, because of the construction measures happening in the previous section, this is the only area for the flood spill in the city of Prague. This is the nearest flood lowland, the target of a still-growing flood pressure. Highly endangered is the Pelc – Tyrolka area, downstream of the most intense flows from Libeň and Maniny. The flooding of the Prague ZOO in the Trója area was especially dramatic, more than 1 000 animals were evacuated and equipment near the river destroyed.

4. Flood protection at the Guadalquivir river in Seville: space divided between the nature and the city

Just like in the case of Prague, in Seville the Guadalquivir river and its flood lowland is the main geographical point of the city, one of the most important socioeconomic, natural, cultural and historical elements. Here the flood dynamic, because of its higher historical frequency and volume, has been the leading factor for the creation and development of the river space where the city is located and where the river presents the main spatial discontinuity. It is a territory where two large morphogenetic systems meet and encounter each other: on one hand the river system as a natural system with important risk factors in it's dynamics (the moving of meanders, leaving shores, floods, river conflux), and on the other hand the city, founded thanks to the river, which has during history overcome this dependence and has caused the largest disturbances man can bring about in their efforts to make maximum use of the territory.

Regarding the river, we have already mentioned its Mediterranean properties, characterized by irregularities, and the related fight against floods since the end of the 18th century with the help of large hydraulic construction projects that dominate today's lowland. These measures succeeded in achieving drastic reduction in the flood phenomenons and at the same time allowed the number of human inhabitants in this flow lowland to grow considerably. The river's spillage space for the case of extreme floods has been reduced to less than 25 % of the original value. This lead to potentially higher water levels and a potential for extreme events.

It is now obvious that the flood in December 1996 with 3 670 m^3/s and a height of more than 7 m meant complete filling of the water corridor passing

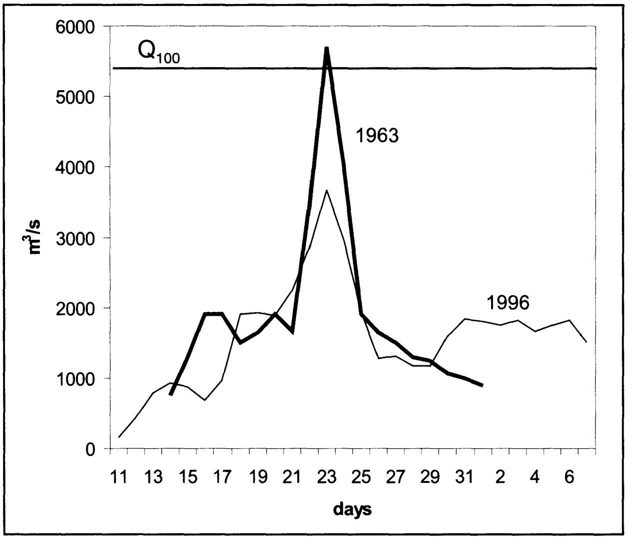

Fig. 3 – Comparison of the hydrological maximum of the Guadalquivir River in the years 1963 and 1996

through the Western part of the city. This was a flood of the second grade that occurred after a long dry period of six years and ended in the fall and winter of the year 1996 by 260 mm of rainfall within three months. These enduring rains were enough to saturate the river basin surface, to fill the dams completely and cause a flood comparable to the flood from the year 1963. In Alcalá del Río, the water reached a flow rate of 5 700 m^3/s. This was the last exceptional flood of the 20th century. In both cases, the flood followed forced openings of the dams of the regulation system (Fig. 3). In the year 1996, the rising and falling was regulated more by the release of water from spillway dams upstream than by the intensity of rainfall. Regarding the city, no considerable damage has happened, besides damages to agriculture, irrigation devices and some roads. We can say that the flood-protection system designed in the previous century, which sets the look of the Guadalquivir river near Seville, does work. It consists of two streams relatively close to each other, independent of each other and with clearly divided function.

4.1 Historical river; today inland harbor

The inland harbour is the best-known region of the city and industry river. Its bed from San Jerónimo up to Los Gordales consists largely of the original river and also of the artificial channel dug during the Iberoamerican Exhibition in the year 1929, which now creates an inland harbor. In it's surrounding, we find the original face of a functioning flood lowland, now covered by city activity and buildings. We can only get to see the original version by performing archeological work on the ground designed for the construction of buildings or for the installation of infrastructure. This space is located at the edge of the river's morphogenesis and it's only disadvantages are the rising of the piesometric level of the alluvial water, which floods basements and garages, or the impossibility of rain water drainage. This isolation has finally allowed the river's integration into the city between fluctuations, with definite historical, recreational and visual importance. At the same time, this solution is good for the harbor function of the river, which is moving more and more towards the south, along the Alfonso XIII. channel, where the lock is the only mobile outlet of the protective system at the city's circumference.

4.2 Functional river; hydraulic channel for the removal of flood water

A lesser-known part of the river, with a half-natural stream or 'living' river passes through the western part of the city, enclosed by the protective system of walls theoretically higher than the thousand-year water. The river's dynamics are influenced by the sea and also by the fluctuation aquosity caused by the time of the year and compensated by the large regulation capacity of numerous dams in the river basin. This is a changed area at the edge of the city, with only the need of minimum restoration of the natural environment of the shores to allow the inhabitants to use it for leisure and enjoy its natural potential. It's for good reason that the last city ground not covered by buildings can be found here. This ground still performs an important morphohydrological role in the spreading of the river's level during the exceptional floods. It includes such exceptional places as the La Isla Quijano Island and Playas de Tercia in the north or La Dehesa de Tablada in the south. There is strong urban pressure, especially on the Tablada islands. The land there has been purchased by a real estate agency and the authorities pursue it's overbuilding.

In any case, both streams with their shores represent the main and last open space factors of the Guadalquivir river on the city level as well as on the level of the metropolitan surroundings. For this reason, they should enjoy a lot of interest of public authorities to ensure their preservation. It would also be useful to utilize urban planning to preserve these shores as a green connecting corridor. The highways crossing the streams could be transferred to high viaducts crossing the lowland, so that territorial fragmentation of the area, which prevents it's integration into the city, would end.

4. Conclusions

From the morphological and hydrological viewpoint, the comparison of the city of Prague flooded in summer 2002 and the flood lowland of the Guadalquivir river in Seville again shows that it is the presence of humans and their activities on the floodable shores that causes natural events of this type, of catastrophic and exceptional character. We have to admit that situations such as the flow rate of 5 160 m^3/s at the Vltava river and 5 700 m^3/s at Guadalquivir can reoccur, especially if we take into account the origin of the imbalance and changes in river systems and their main control factor – the climate.

It would be necessary to evaluate the behavior of both rivers using integration strategies, not only structural, economically demanding ones as is the case of Seville. This means that the river area has to be planned and organized with regard to the natural morphohydrological dynamics that are typical for the river "free river space"" and not the other way around. However, if the society has already ignored these warnings once, as our examples show, the reduction of these dynamic and instable areas to a minimum brings about an increased danger, which has to be accepted in spite of economic costs and material and human losses.

In the case of the Vltava river passing through Prague, there is a lack of structural investments of the volume found in Seville. These have until now not been known in Central Europe. It would be necessary to take into account that the protection of a certain river section for its historical and cultural value, as in the case of the section Vyšehrad – Letenské sady means to designate a natural space for the spreading of possible extreme floods downstream. With the help of project work, passing of the spilled river over the point bars in Holešovice would be made possible. A construction project would have to be limited there. Then, the spilled river would get back to the original vacant basin in the far-away lowland of Karlín. Further areas identified in this article as the closest flood lowland should only be used for purposes compatible with the possibility of high frequency of floods. So, we would no doubt avoid moving the problem to other parts of the river stream. With such plans, the Czech government has decided to introduce a flood protection programme, which includes the building of small dams in the river basin, thus increasing the regulation capacity. At the level of Vltava's city section, protection by raising the embankments in Karlín and by emergency plans prepared in cooperation with various authorities is being considered.

In case of the Guadalquivir river passing through Seville, the maximum level of structural measures would on the contrary require the current unstable balance between city and river presented by the lowland to be maintained. For this, the existing closest lowland next to the half-natural channel of the Guadalquivir river has to be preserved. The efforts to occupy it have to be suppressed and the creation of cross-obstructions of the road infrastructure kept to a minimum. For this, political willpower would be necessary, which would look after the precise observance of the existing extensive legislation framework: Directiva Marco de Aguas 2000/60/CEE (Water Directive), Ley de Aguas (Water Act), Ley de Costas (Shores Act), Ley de Ordenación Urbanística de Andalucía (Andalusia Urban Order Act), Ley de Protección Ambiental (Environment Protection Act), Planes Hidrológicos de Cuenca (Hydrological River Basin Plans), Directiva Hábitat (Natural Environment Directive), Ley de Espacios Protegidos (Protected Area Directive), Planes Generales de Ordenación Urbana (General Urban Order Plans), Ordenanzas Municipales (City Order), etc... and also the competency framework (River Basin Organisms, Department of the Environment; Environmental Committee, Environment Council; State Harbors, Development Department; Public Works Department; Environment Committee and Council, etc...).

Finally, the future administration of these risk area has to be guaranteed and they have to be protected with appropriate cooperation of the authorities. Such cooperation could be realized through the creation of an association for decision making and management, through international directives and treaties or by both. Definite change can be made in the concept of interference with river streams. These interferences should no longer only observe hydrological and structural objectives (building of additional protective walls, dams, reservoirs, river bed straightening, sewage systems, etc ...). Other methods, respecting the environment, should be preferred. The development should be harmonized with the preservation of the environment, so that the highest possible durability and sustainability can be guaranteed.

References:

ALBENTOSA, L. (1989): Las aguas continentales de la Espańa peninsular. El Clima y las aguas. Con la colab. De J. M. Rubio. Ed. Síntesis, Madrid, No. 4, pp. 141–240.

BAENA, R., GARCÍA, B. (1995): Repercusiones de la intervención antrópica contemporánea sobre la llanura aluvial del Guadalquivir aguas arriba de Seville. Cambios Regionales a finales del siglo XX. Ed. A.G.E-Univ. de Salamanca. Salamanca, pp. 9–14.

BAENA, R., GARCÍA, B., GUERRERO, I., HARTVICH, F., LEICHT, B., MARCHIOL, L. (2004): Floods 2002 in Prague: reflections, lessons and ideas. Geografie–Sborník ČGS, 109, No. 2, ČGS, Praha, pp. 170–180.

BROOKES, A., SHIELDS, F. D. (1996): River channel restoration: guiding principles for sustainables projects. Wiley, Chichester, 438 p.

BOSCH, J. (1988): La Seville Islámica, 712–1242. Colecc. HȘ. Univ. de Seville, Seville, No. 92, 417 p.

DAŇHELKA, J. (2004): August 2002 flood in the Czech Republic: meteorilogical causes and hydrological response. Geografie– Sborník ČGS, 109, No. 2, ČGS, Praha, pp. 84–92.

DÍAZ, F, BAENA, R. (1999): La restauración geomorfológica del río Guadiamar. International Seminary Corredores ecológicos y restauración de ríos. Seville, Junta de Andalucía, 78 p.

DRAIN, M., LHÉNHAFF, R., VANNEY, J. R. (1971): Le Bas Guadalquivir. Introduction géographique. Casa de Velásquez. Ed. Boccars, Paris, No. 1, 124 p.

GARCÍA, B., BAENA, R. (1997): Cambios históricos en la hidrología del Guadalquivir y su repercusión en el meandro de Tocina (Seville). En Rodríguez, J. (ed.): Cuaternario Ibérico, (AEQUA), Seville. pp. 368–371.

GUERRERO, I., BAENA, R. (1996): La inundación del Guadalquivir en diciembre de 1996 (sector Alcolea del Río-Cantillana, Seville). En: Investigaciones recientes de la Geomorfología espańola, Geoforma Ediciones, p 25–37.

GARZON, G., ALONSO, A., LÓPEZ, J., ARCHE, A. (1990): Desbordamientos en el río Jarama (provincia de Madrid) e interferencia humana en la llanura de inundación. IV Reunión Nac. Geol. Ambiental y Ordenación del Territorio. Gijón, p. 259–270.

GIL OLCINA, A., MORALES, A. (1989): Avenidas fluviales e inundaciones en la cuenca del Mediterráneo. Instituto Universitario de Geografía, Alicante, 586 p.

JANSKÝ, B. (2004): Strategie di difensa per Praga (Strategie ochrany Prahy). In.: Governare l´acqua – Difensa del territorio, qualitŕ, tutela, servizi, emergence regionali e confronti europii. Europa e Regione 54 (Collana di studi, maggi e documentazioni). IRSE (Instituto Regionale Studi Europei, Friuli Venezia Giulia. Edizioni Concordia Sette, Italia, pp. 61–71.

LANGHAMMER, J. (2003): Antropogenic Transformation of River Network in the Otava River Basin. Acta Universitatis Carolinae – Geographica, XXXVIII, No. 2, UK, Praha, pp. 139–155.

MARTÍNEZ, R.; GÓMEZ, A., GARCÍA, J. M. (1991): Ajustes fluviales derivados de cambios de usos del suelo en el Pirineo Aragonés. Cuaternario y Geomorfología, 5, p. 91–105.

MATEU, J. (1990): Avenidas y riesgos de inundación en los sistemas fluviales mediterráneos de la Península Ibérica. Rev. Asociación de Geógrafos Espańoles, 10, 2Ș época. Madrid, 103 p.

MASACHS, V. (1954): Las aguas. Geografía de Espańa y Portugal. Ed. Montaner y Simón. Barcelona, t. 2, pp. 80–142.

NIJLAND, H. J., CALS, M. J. R., eds. (2000): River restoration in Europe. Practical approaches. Conference on river restoration the Netherlands. Ed. RIZA Wageningen, 343 p.

KLINGEMAN, P. C.; BRAVARD, J. P., GIULIANI, Y. (1994): Les impacts morphodynamiques sur un cours d´eau soumis ŕ un aménagement hydroélectrique ŕ derivation: le Rhône en Chautagne (france). Revue de Géographie de Lyon. 69, No. 1, pp. 73–87.

PARKER, D. J., PENNING-ROWSELL, E. C. (1982): Flood risk in the Urban Environment. Geography and the urban Environment. V Jonh Wiley and Son, Chichester, p. 201–239.

PEIRY, J. L., NOUGUIER, F. (1994): Le Drac dans l´aglomeration de Grenoble: premičre evaluation des changenments géomorphologiques contemporains. Revue de Géographie Alpine, 82, No. 2, pp. 77–96.

SCHUMM, S. A (1977): The fluvial system. John Wiley and Sons, London, 338 p.

UNESCO (1971–1985): Discharge of selected rivers of the World, III. UNESCO Press, Paris.
VANNEY, J. R. (1970): L´hidrologie du bas Guadalquivir. C.S.I.C. Madrid, 176 p.
WARD, R (1978): Floods. A geographical perspective, London, MacMilan, 224 p.

Shrnutí

SROVNÁVACÍ ANALÝZA POVODNÍ V PRAZE (ČESKO) A V SEVILLE (ŠPANĚLSKO): POSUZOVÁNO Z GEOGRAFICKÉHO HLEDISKA

Řeky představují příklad komplexního ekosystému hluboce pozměněného rozmanitými aktivitami člověka. Současně mají pro města ležící na jejich březích značný význam ekologický, sociokulturní a ekonomický. Území v bezprostředním okolí toků nebývá však často integrováno do územního rozvoje měst vzhledem k nebezpečí záplav s katastrofálními následky. Záplavové území představuje tak konfliktní prostor mezi přírodní a socioekonomickou sférou. Přesto v územích ohrožovaných povodněmi roste urbanizační tlak, podmiňující vznik nevyvážené situace mezi řekou a městem. V takovém prostředí se zvyšuje riziko potenciálně nebezpečných extrémních hydrologických jevů.

Předmětem článku je diskuze různých strategií protipovodňové ochrany, které jsou využívány k prevenci předvídatelných povodňových rizik pro území Prahy a Sevilly. Pro ilustraci těchto idejí zvolili autoři analýzu dvou velmi odlišných povodí – Vltavy, reprezentující středoevropský tok v mírném kontinentálním klimatu s typickým fluviálně – niválním režimem odtoku, s maximy průtoku v době jarního tání sněhu a Guadalquiviru, jako hlavního kolektoru jižního Španělska, s charakteristickým klimatem mediteránního typu a fluviálním odtokovým režimem se zimními průtokovými maximy.

Z hydrologického a morfologického hlediska je na základě porovnání povodně v Praze v roce 2002 a srovnatelně velkých povodní na řece Guadalquivir v Seville (např. v letech 1963 a 1996) patrné, že především existence člověka a jeho aktivit v záplavovém území dává povodním katastrofický a mimořádný charakter. Je třeba připustit, že povodně takové velikosti a charakteru (5 160 m^3/s na Vltavě resp. 5 700 m^3/s na Guadalquiviru) se mohou opakovat, tím spíše, když uvážíme, co je hlavní příčinou nestability – tzn. změny obou fluviálních systémů a jejich hlavní kontrolní faktor, tj. podnebí.

Jde především o to, abychom u obou řek našli východiska k realizaci integrálních strategií, tedy nejen strukturálních opatření vyžadujících vysoké finanční náklady, jako je tomu v případě Sevilly. V záplavovém území podél toků bychom měli plánovat a územní strukturu uspořádat tak, aby se přizpůsobila přírodní hydrologické a morfologické dynamice a ne naopak. Řece bychom tedy měli ponechat její přirozený volný prostor. Zkušenosti však ukazují, že společnost ignorovala tyto zásady a redukce nestabilních záplavových území přinesla výrazný růst ekonomických nákladů, materiálních škod i obětí na životech.

V případě Vltavy v Praze chybějí vysoké strukturální investice v té podobě a objemu, jak byly vynaloženy v Seville, což je dosud neobvyklé i v jiných městech střední Evropy. Dá se přitom předpokládat, že se protipovodňová ochrana soustředí především na úsek Vltavy mezi Vyšehradem a Letenskými sady vzhledem k vysoké historické a kulturní hodnotě tohoto území. To předpokládá ovšem úzkou vazbu na výše i níže ležící záplavová území, která přispějí díky plánovaným rozlivům ke snížení piků budoucích mimořádných povodňových vln. Jednou z takových možností je např. obnovení funkce starého opuštěného ramene Vltavy v Karlíně. V každém případě lze konstatvat, že zajištění ochrany v historické části města přenáší problémy protipovodňové ochrany do jiných inundačních území.

V programu „Prevence před povodněmi“, schváleného českou vládou, se mimo intravilány obcí počítá s výstavbou polderů a malých vodních nádrží, které zvýší kapacitu regulace toků. Na území Prahy byly podél břehů Vltavy vymezeny zóny vysokého povodňového rizika a schváleny nouzové plány navzájem koordinované různými orgány státní správy. V některých úsecích toku, především na pravém břehu podél Karlína a na levém břehu kolem Holešovic, byly dobudovány protipovodňové stěny.

V případě řeky Guadalquivir na průtoku Sevillou bylo provedeno větší množství strukturálních opatření, které zachovaly současnou rovnováhu v rámci nestabilního systému řeka – město. Do budoucna se plánuje ochrana rozlehlé nížiny nad městem , která bude vodohospodářsky propojena s umělým kanálem Guadalquiviru. To zabrání obsazení říční nivy rozmanitou novou infrastrukturou. K tomu bude však zapotřebí politické vůle a dodržování patřičných legislativních norem.

Obr. 1 – Hlavní povodně v historii měst Praha (Vltava) a Seville (Guadalquivir)
Obr. 2 – Srovnání hydrologického maxima na Vltavě v letech 1890 a 2002
Obr. 3 – Srovnání hydrologického maxima na Guadalquivir v letech 1963 a 1996

R. Baena Escudero and I. Guerrero Amador are with University of Seville, Faculty of Geography and History, Department of Physical Geography and Regional Geographical Anylyses. B. Janský is with Charles University in Prague, Faculty of Science, Department of Physical Geography and Geoecology, Albertov 6, 128 43 Praha 2, Czechia; e-mail: jansky.b@seznam.cz, baena@us.es, inmaguer@us.es.)

Arrived to the editorial board on August 28, 2006

GEOGRAFIE

SBORNÍK ČESKÉ GEOGRAFICKÉ SPOLEČNOSTI

Ročník 111, číslo 3, vyšlo v prosinci 2006

Vydává Česká geografická společnost. Redakce: Albertov 6, 128 43 Praha 2, tel. 221995511, e-mail: jancak@natur.cuni.cz. Rozšiřuje, informace podává, jednotlivá čísla prodává a objednávky vyřizuje RNDr. Dana Fialová, Ph.D., katedra sociální geografie a regionálního rozvoje Přírodovědecké fakulty UK, Albertov 6, 128 43 Praha 2, tel. 221951397, fax: 224919778, e-mail: danafi@natur.cuni.cz. – Tisk: tiskárna Sprint, Pšenčíkova 675, Praha 4. Sazba: PE-SET-PA, Fišerova 3325, Praha 4. – Vychází 4krát ročně. Cena jednotlivého je sešitu 150 Kč, celoroční předplatné pro rok 2005 je součástí členského příspěvku ČGS, a to v minimální výši pro řádné členy ČGS 500 Kč, pro členy společnosti důchodce a studenty 300 Kč a pro kolektivní členy 2 000 Kč. – Podávání novinových zásilek povoleno Ředitelstvím pošt Praha, č. j. 1149/92-NP ze dne 8. 10. 1992. – Zahraniční předplatné vyřizují: agentura KUBON-SAGNER, Buch export – import GmbH, D-80328 München, Deutschland, fax: ++(089)54218-218, e-mail: postmaster@kubon-sagner.de a agentura MYRIS TRADE LTD., P.O. box 2, 142 01 Praha, Česko, tel: ++4202/4752774, fax: ++4202/496595, e-mail: myris@login.cz. Objednávky vyřizované jinými agenturami nejsou v souladu se smluvními vztahy vydavatele a jsou šířeny nelegálně. – Rukopis tohoto čísla byl odevzdán k sazbě dne 28. 11. 2006.

---

47 303

ISSN 1212-0014

Cena 150,- Kč

POKYNY PRO AUTORY

Rukopis příspěvků předkládá autor v originále (u hlavních článků a rozhledů s 1 kopií) a v elektronické podobě (Word), věcně a jazykově správný. Rukopis musí být úplný, tj. se seznamem literatury (viz níže), obrázky, texty pod obrázky, u hlavních článků a rozhledů s anglickým abstraktem a shrnutím. Zveřejnění v jiném jazyce než českém podléhá schválení redakční rady.

Rozsah kompletního rukopisu je u hlavních článků a rozhledů maximálně 10–15 normostran (1 normostrana = 1800 znaků), jen výjimečně může být se souhlasem redakční rady větší. Pro ostatní rubriky se přijímají příspěvky v rozsahu do 3 stran, výjimečně ve zdůvodněných případech do 5 stran rukopisu.

Shrnutí a abstrakt (včetně klíčových slov) v angličtině připojí autor k příspěvkům pro rubriku Hlavní články a Rozhledy. Abstrakt má celkový rozsah max. 10 řádek (cca 600 znaků), shrnutí minimálně 1,5 strany, maximálně 3 strany včetně překladů textů pod obrázky. Text abstraktu a shrnutí dodá autor současně s rukopisem, a to v anglickém i českém znění. Redakce si vyhrazuje právo podrobit anglické texty jazykové revizi.

Seznam literatury musí být připojen k původním i referativním příspěvkům. Použité prameny seřazené abecedně podle příjmení autorů musí být úplné a přesné. Bibliografické citace musí odpovídat následujícím vzorům:

Citace z časopisu:

HÄUFLER, V. (1985): K socioekonomické typologii zemí a geografické regionalizaci Země. Sborník ČSGS, 90, č. 3, Academia, Praha, s. 135–143.

Citace knihy:

VITÁSEK, F. (1958): Fysický zeměpis, II. díl, Nakl. ČSAV, Praha, 603 s.

Citace z editovaného sborníku:

KORČÁK, J. (1985): Geografické aspekty ekologických problémů. In: Vystoupil, J. (ed.): Sborník prací k 90. narozeninám prof. Korčáka. GGÚ ČSAV, Brno, s. 29–46.

Odkaz v textu na jinou práci se provede uvedením autora a v závorce roku, kdy byla publikována. Např.: Vymezováním migračních regionů se zabývali Korčák (1961), později na něho navázali jiní (Hampl a kol. 1978).

Obrázky zpracované v digitální podobě je nutné dodat (souběžně s vytištěným originálem) i v elektronické podobě (formát .tif, .wmf, .eps, .ai, .cdr, .jpg). Perokresby musí být kresleny černou tuší na pauzovacím papíru na formátu nepřesahujícím výsledný formát po reprodukci o více než o třetinu. Předlohy větších formátů než A4 redakce nepřijímá. Xeroxové kopie lze použít jen při zachování zcela ostré černé kresby.

Fotografie zpracované v digitální podobě musí mít dostatečné rozlišení (300 dpi). Fotografie odevzdané v analogové podobě formátu min. 13×18 cm a max. 18×24 cm musí být technicky dokonalé a reprodukovatelné v černobílém provedení.

Texty pod obrázky musí obsahovat jejich původ (jméno autora, pramen, příp. odkud byly převzaty apod.).

Údaje o autorovi (event. spoluautorech), které autor připojí k rukopisu: adresa pracoviště, včetně PSČ, e-mailová adresa.

Všechny příspěvky procházejí recenzním řízením. Recenzenti jsou anonymní, redakce jejich posudky autorům neposkytuje. Autor obdrží výsledek recenzního řízení, kde je uvedeno, zda byl článek přijat bez úprav, odmítnut nebo jaké jsou k němu připomínky (v takovém případě jsou připojeny požadavky na konkrétní úpravy).

Honoráře autorské ani recenzní nejsou vypláceny.

Poděkování autora článku za finanční podporu grantové agentuře bude zveřejněno jen po zaslání finančního příspěvku ve výši minimálně 5000,- Kč na konto vydavatele.

Autorský výtisk se posílá autorům hlavních článků a rozhledů po vyjití příslušného čísla.

Separáty se zhotovují jen z hlavních článků a rozhledů pouze v elektronické podobě (soubor .pdf). Redakční rada si vyhrazuje právo na vyžádání poskytnout publikovaný příspěvek v elektronické podobě (soubor .pdf), a to členům ČGS pro studijní účely.

Příspěvky se zasílají na adresu: Redakce Geografie – Sborník ČGS, Albertov 6, 128 43 Praha 2, e-mail: jancak@natur.cuni.cz.

Příspěvky, které neodpovídají uvedeným pokynům, redakce nepřijímá.