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FLOOD RISK ASSESSMENT AND MANAGEMENT: REVIEW OF CONCEPTS, DEFINITIONS AND METHODS

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Flood risk assessment and management: review of concepts, definitions and methods

The article brings a brief overview of the current concepts, definitions and methods of flood risk assessment and management. The modern concept of flood risk assessment is based on combination of flood hazard, probability and potential negative consequences of floods for human health, economic activities, the environment and cultural heritage. An assessment of flood hazard is focused on the estimate of annual maximum discharges for different nonexceedance probabilities and establishment of the corresponding flooding area and specific parameters of flood (water level, flow velocity, etc.). Analysis of expected negative consequences of floods is based on the concept of vulnerability of social, economic and environmental systems. Methodological aspects of hazard dependent vulnerability and hazard independent vulnerability assessment are also briefly outlined. Two approaches are analysed for optimal methodology combining flood hazard and vulnerability. The first expresses the absolute flood risk by the value of the overall average annual damage. The second lies in expression of flood risk in a relative way by an ordinal scale. The integrated flood management is based on the mix of strategy to reduce flooding, strategy to reduce vulnerability to floods and strategy to mitigate the negative consequences.

Key words: flood hazard, flood risk, vulnerability, flood risk management, multicriterion decision analysis

INTRODUCTION

The idea that emerged already in the 1970s that the negative and disastrous effects of natural phenomena (floods, droughts, earthquakes, volcanic eruptions, etc.) are not only attributable to natural phenomena itself, but may also result from the vulnerability of society and its infrastructure (cf. Schneiderbauer and Ehrlich 2004) progressively leads to a different approach to flood risk assessment and flood risk management. Wisner et al. (2004) emphasize that in evaluating disaster risk, the social production of vulnerability needs to be considered with at least the same importance that is devoted to understanding and addressing natural hazards. The critical views concerning the exclusive application of the engineering approach to flood defence through regulation of flood discharges by technical means have gradually led to formulation of a new approach to flood defence – integrated flood risk management, in which the flood vulnerability paradigm plays an important role (Brown and Damery 2002, Plate 2002 and Werrity 2006).

The aim of the paper is to present a brief overview of the current state-of-the-art of flood risk assessment and current principles of integrated flood risk management. The article is organized into the following sections: section 1 – flood risk: concepts and definitions, section 2 – brief overview of the research into flood risk components, section 3 – methods of flood risk assessment, section 4 – principles of integrated flood risk management.

FLOOD RISK: CONCEPTS AND DEFINITIONS

Flood risk research concerns multiple disciplines: hydrology, sociology, economics, geography and environmental science. Each of them approaches flood risk assessment from their own viewpoints and the result is variability of the expressed objective matter in terminology and methods of assessment and management.

Single-dimension concept

Quantification of the flood risk level requires definition of flood risk in an unambiguous way. Flood risk defined as the *probability* of the specified annual maximum discharge in any year is the core of hydrological research into flood risk. This definition corresponds to the general definitions of risk, where the risk and the natural phenomenon (hazard) are interpreted and used as synonyms (e.g. Alwang et al. 2001). The principles of probability are applied to quantify the risk that annual maximum discharge $Q_{\max}$ will not exceed the specified value q.

$$F(q) = P(Q_{\max} \leq q), \tag{1}$$

$F_{(q)}$ is the cumulative distribution function of the frequency distribution. Its inverse function, $q(F)$ expresses the annual maximum discharge of nonexceedance probability, F is usually of primary interest. The greater the risk, the greater the nonexceedance probability. The concept of risk based only on the estimate of the quantil function $q(F)$ of frequency distribution is referred to as the *single scale conception* of flood risk (cf. DETR 2000). Flood risk level can be also expressed by the mean time (return period – T) that elapses before the maximum discharge of a certain volume q_T occurs.

Specification of the probability of maximum annual discharge occurrence and the corresponding scope of flooding is the basis for zonation of flood plains from the point of view of flood risk exposure. Delineation of flood exposure zones is relatively variable and depends on the purpose of flood exposure assessment (Kron and Willems 2002). The probability of occurrence of specified annual maximum discharge values is the primary basis for the assessment of safety standards for any engineering structure. Parameters of dams, protecting dikes and channel adjustment are designed to retain flood discharges with the specified probability (for instance P = 0.01, 0.001 or less). The traditional approach to flood defence lies in the safety standards of engineering structures.

Multidimensional concept

The basis of the new paradigm for preventive flood defence is the multidimensional approach to research of flood risk. Apart from probability of flood events it also takes into account potential adverse consequences of floods on human health, economic activities, the environment and cultural heritage. The definition:

"*Risk is the expected loss (of lives, persons injured, property damaged, and economic activity disrupted) due to a particular hazard for a given area and reference period*" (UN 1992)",

is the widely accepted way of expressing the multidimensional nature of the risk.

This conceptual and methodological framework of flood risk research is being developed as a link to all natural phenomena. As several sciences deal with research of flood risk, certain differences emerge in the formal expression of the above general definition of risk (cf. Thywissen 2006). The following ways of flood risk formalization have been described:

a) risk = hazard × vulnerability (UN 1992, UNDP 2004, Birkmann 2006),

b) risk = probability × negative consequences (Einstein 1988 and Meyer et al. 2007),

c) risk = f (hazard, vulnerability, deficiencies in preparedness) – Villagrán de León (2004),

d) risk = f (hazard, exposure, vulnerability, capacity and measures) – Bollin et al. (2003),

e) risk = f (hazard, vulnerability, exposure) – Crichton (1999), Hori et al. (2002) and ADRC (2005).

These formalizations of flood risk, in spite of some terminological disparity, contain two basic components: a) *natural phenomenon – flood hazard*; flood attributes determine the extent of exposure of objects of economic, social or environmental systems to flood and b) *concept of vulnerability*; analysing the attributes of objects of economic, social, and environmental systems from the point of view of their susceptibility to damage, resistance to the impact of a flood and capacity to recover to the state that existed before the flood event.

Some methodological aspects of assessing basic flood risk components and flood risk itself will be outlined in the next parts of paper.

BRIEF REVIEW OF THE STATE-OF-THE-ART RESEARCH ON FLOOD RISK COMPONENTS

Analysis of flood hazard

Analysis of flood hazard in general is focused on: a) estimating the annual maximum discharges for different exceedance probabilities, b) estimating the water levels for annual maximum discharges, c) establishing the area of flooded territory corresponding to water levels of annual maximum discharges with different exceedance probabilities.

A wide range of methods is used for estimating maximum discharges. They are divided into two basic groups: the first consists of precipitation-runoff models and the second is based on statistical procedures. The span of the structure of precipitation-runoff models is wide (cf. Sealthun and Oberlin 1993, Smith and Ward 1998, Beven 2000). The choice of an appropriate model depends on the spatial level for which the flood discharges are estimated. For instance, empirical formulas with very simple structure, such as a rational formula, regional formulas (e.g. Dub 1957) or regression equations are suitable for the national level.

By means of empirical formulas as a rule, the value of the annual maximum discharge is a function of the area of the basin and the basin's physical-geographical attributes. A more sophisticated way of transformation of rainfall into discharge is possible on the local level, for example by the method of unit hydrograph or by determinist models with spatially distributed or lumped parameters (cf. Beven 1985 and 2000, Blackie and Eeles 1985). These precipitation-runoff models simulate discharge values for time interval of the whole flood wave.

The basis of statistical methods is the probability theory. The distribution of annual maximum discharge probabilities or that of discharges exceeding the *a priori* set value is expressed by the distribution function (cf. Rao and Hamed 2000, Sealthun and Oberlin 1993 and FEH 2008). The distribution function is defined by parameters expressing the position, variability, skewness and curtosis of the probability distribution. The estimation of distribution function parameters is carried out by means of summed hydrological statistics of maximum annual discharges. Several methods can be applied: 1) method of traditional moments, 2) method of moments weighted by probability (Greenwood et al. 1979), 3) method of linear moments (Hosking 1990), and 4) method of maximum likelihood.

A reliable estimate of annual maximum discharges based on distribution functions requires long observations. However, the hydrological observations are only available from a limited number of gauges with relatively short observation period. Therefore, the estimate of annual maximum discharges mainly with low probability of occurence only from the data of gauging stations is not reliable. This is the reason why the discharge estimates with different probabilities for basins with short observation or without hydrological observation are carried out by the method of regional frequency analysis. The basic idea behind the regional frequency analysis is that when there is lack of discharge data for certain basin and there are other basins with similar attributes, better results can be achieved by analysing them together, instead of – so to speak – separately (cf. Wiltshire, 1985 and 1986, Burn 1988, Cunnane 1988, Hosking and Wallis 1993 and 1997, Burn and Goel 2000, Kohnová and Szolgay 2000 and 2002, Solín 2002, 2005 and 2006).

Two approaches are applied to modelling of water levels of flood discharges. The first is bound to real time and the water level is simulated for the set time intervals in the whole span of the flood wave. Simulation is based on application of 1D or 2D hydraulic models of unsteady flow expressed by Saint-Venant equations (cf. Fread 1985). Software products HEC-RAS, ISIS or Mike11 are used to solve the equations of unsteady 1D flow. LISFLOOD-FP, TELEMAC - 2D) software products (Bates and de Roo 2000, Horrit and Bates 2002), for instance offer solutions of more sophisticated 2D hydraulic models. The second type of modelling is not bound to real time and it does not simulate the water level in the whole span of a flood wave. It is rather focused on an estimate of the maximum water level for flood discharge of specified probability in profiles along the stream. The problem formulated in this way is a typical one solved by analysis of 1D steady flow applying the Manning equation (the slope area method) or energy conservation equation (step-backwater method), for details see, for example, Chow et al. (1988).

Accuracy of modelling itself and final delimitation of the flooded area is bound to the resolution level and accuracy of input data from which the digital elevation model (DEM) was created. The basic topographic source most frequently used for creation of DEM are usually digitized contours derived from maps at scales from 1:10 000 to 1:50 000 (Kron and Willems 2002, Rodda and Berger 2002 and JBA Consulting 2004), produced by the national cartographic and geodetic institutions. Use of Earth remote sensing techniques such as aerial photography or LIDAR (Light Detection and Ranging) technologies, which provide topographic data with significantly better vertical accuracy (+/-5 cm, or +/-10 cm) is limited to local or regional levels due to a relatively high costs.

For example, at national level (mostely for financial reasons), Sanders et al. (2005) recommend use of the IFSAR (Interferometric Synthetic Aperture Radar) technology, which provides topographic data with vertical accuracy +/- 5m (Space IFSAR), or 1m, +/- 0.50 m (Airborne IFSAR). However, using the DEM with lower vertical accuracy than 1 m for flood analysis and/or modelling is, at least, questionable even on the national level. Another problem considering raster DEM's (and consequently also TIN's derived from raster DEM's) is, that their surfaces are basically "smoothed" and therefore not very truthful representation of the real-world situation. This is a common issue, resulting from the nature of how interpolation algorithms, used to create these models, work. It is highly recommended to use a point cloud acquired photogrametrically, or by LIDAR to construct TIN DEM's, as they are referred as primary (or measured) DEM's. Also very important features, to be present in DEM, used to flood hazard modelling are terrain edges – natural or artificial (created by man). A channel is typically represented by terrain edges very well and especially in small basins, it can be of great help to have such information to identify it precisely. Terrain edges are also important when considering movement of water through a floodplain during the flood, as they can act as accelerators, direction-changers or natural barriers.

The state-of-the-art of vulnerability research

Definitions and concepts of vulnerability

The incentive to develop the concept of vulnerability to natural disasters has come from the social sciences in the 1970s as a response to the perception of disasters caused by natural hazards only through attributes of hazards themselves (Schneiderbauer and Ehrlich 2004). The concept of vulnerability underlines the idea that flood damage is a function of both – the magnitude of the flood and the vulnerability of the social, economic and environmental system. Some authors including Wisner et al. (2004) report that vulnerability refers only to people and they avoid using the word *vulnerable* regarding livelihoods, buildings, settlement locations or infrastructure and use instead terms such as unsafe, susceptible, fragile, hazardous, hazard-prone. Adger et al. (2004) also propose for expression of vulnerability of other than human systems to use the term inherent vulnerability instead of social vulnerability, which concerns the vulnerability of humans (human system) only.

The concept of vulnerability is now developed in the social, environmental and geographical sciences, which attribute it a special content in connection with the management of natural disasters and sustainable development. The literature brings different definitions and conceptual frameworks (e. g. Morrow 1999, Brown and Damery 2002, Tapsell et al. 2002, Cutter et al. 2003, Sarewitz et al. 2003, Turner et al. 2003, Adger et al. 2004, Green 2004, Schneiderbauer and Ehrlich 2004, Wisner et al. 2004 and Messner and Meyer 2005). Thywissen (2006), for instance, prepared a summarizing review of definitions of the term and Birkmann (2006) presented a certain systematization of views on vulnerability.

Vulnerability defined as:

”*Inherent characteristics of a system that create the potential for harm but are independent of the probabilistic of event risk of any particular hazard or extreme event*” (Sarawitz et al. 2003), represents the minimum common basis for the definition of vulnerability. Attributes expressing the inherent predisposition (potential) of economic, social and environmental systems to damage and loss (economic dimension of vulnerability) or in case of human system liability to drowning or injury are cores of the *susceptibility* concept. *The* social dimension of vulnerability is embodied in the concepts of *resistance* and *resilience,* which characterize a person or group in terms of their capacity to anticipate, cope with, resist and recover from the impact of a natural hazard (e.g. Blaikie et al 1994, Brown and Damery 2002 and Wisner et al. 2004). Meanwhile, the concept of susceptibility represents the passive (negative) component of vulnerability. Vulnerability increases with increasing susceptibility. On the other side, the concepts of *resistance* and *resilience* are active (positive) components of vulnerability and with increasing resistance and/or resilience, the vulnerability of systems decreases.

Approaches to vulnerability assessment

As a rule, two basic approaches are applied to vulnerability assessment. The first general way of vulnerability assessment expresses propensity to damage by floods, resistance to floods and capacity to recovery only in terms of properties of social, economic and environmental systems. For instance, earthen houses are generally considered more prone to damage by floods than brick houses. More damage is also expected in the case of single-floor houses than the multistoreyed ones. Likewise, older and less agile people find it more difficult to escape the effects of floods than younger people, etc. Well-to-do people with savings and those insured against flood damage or people with social capital are more capable of tackling the negative effects of floods than the poor, uninsured ones etc. General vulnerability assessment evaluates vulnerability regardless of the flood event occurrence; it does not contain the element of flood risk exposure; hence it is *hazard-independent* (Adger et al. 2004, Damm et al. 2010). In this context, vulnerability means a potential.

The concept of hazard independent vulnerability (potential) is applied to research, which compares the general level of vulnerability of spatial units. These spatial units can be, for instance, administrative units or delineated polygons based on various criteria. This, rapidly developing research current, referred to as “place based vulnerability” was presented by Cuter et al. (2003), Borden et al. (2007), Mayer et al. (2007), Simpson and Human (2008), Damm et al. (2010) and Solín (2012). It emphasizes that vulnerability associated with place is composed of the social, economic and environmental characteristics that make a place more susceptible to hazards and influence the ability to recover from them. Knowing the spatial variability of flood vulnerability is an important part of flood risk assessment on the national level, as well as for application of spatially differentiated approaches to flood defence strategy.

The second approach analyses vulnerability in relation to the particular attributes of the flood event, including flooding area, height of water level and flow speed. Therefore it is *hazard dependent*. In this case vulnerability expresses the size of expected negative effects caused by the concrete flood event with specific attributes:

"*Vulnerability is defined as the degree of loss to a given element at risk (or set of elements) resulting from given hazard at a given severity level*" (Coburn et al. 1994).

However, in the case of the hazard dependent vulnerability concept, the meaning of vulnerability is somewhat shifted from the position where it expresses the internal status of economic, social and environmental systems to the meaning that corresponds to the definitions of flood risk. The mutual overlapping of vulnerability and risk definitions is the source of confusion and misinterpretations – both of flood risk and vulnerability. However, Coburn et al. (1994) state that the risk combines the expected losses from all levels of hazard severity also taking into account their occurrence probability and this remark may contribute to a clearer discernment between flood risk and vulnerability.

Methodological aspects of hazard-independent vulnerability

Proxy variables

It is not possible to measure vulnerability directly. It can only be expressed by means of proxy variables (Adger et al. 2004 and Tate 2012). Variables that represent susceptibility should express the inner predisposition/potential of an economic system to damage, and loss, that of social system to occurrence of injuries, discomfort and stress and that of the environmental system to change of its quality. Variables representing resistance and resilience should express the capacity of a particular system to cope with a flood event and capacity to recover from a flood event, which means reaching the state as it was before the flood event.

The selection of vulnerability indicators is greatly influenced by the spatial research level (cf. Messner and Mayer 2005, Apel et al. 2009 and Fekete et al. 2010). Generally, the detail and spatial accuracy of information about vulnerability decreases with the increasing spatial dimension from the local to regional and national levels. The data sources for vulnerability research on the national and regional levels are those from census, national statistics and land cover maps. The data for vulnerability assessment on local levels are obtained from enquiries (questionnaire survey) and detailed field research.

Selection of vulnerability indicators can be carried out either by deductive or inductive means. The deductive approach is based on the logically reasoned dependence between indicators and negative effects (Tapsell et al. 2002, Simpson and Human 2008, Meyer et al. 2009 and Damm et al. 2010). The inductive method of indicator selection is based on the reduction of the great number of variables using methods of principal components analysis, to several latent factors representing vulnerability (Cutter et al. 2003 and Borden et al. 2007). The deductive way requires a concrete specification of negative effects. They are, as a rule, divided into two basic categories: the direct and indirect, which are further broken up into tangible and intangible (cf. Smith and Ward 1998). For instance, the direct tangible flood damage expressible on the monetary basis is typical for the economic system. Socially negative effects of floods are prevailingly intangible, difficult to express in money and they include, for instance, the loss of irreplaceable items, stress induced by the flood itself, temporary evacuation of the home, disruption caused by the flood to the life of the individual households and to the community as a whole and the effect on health (Tapsell et al. 2002 and Floodsite 2005). The negative effects of a flood on the environmental system are also prevailingly intangible and include drinking water polluted by faeces and chemical substances and environmental degradation (erosion and accumulation of sediments).

Vulnerability indexes

Vulnerability indexes are established through combination of normalized variables that characterize vulnerability of economic, social and environmental systems. For instance, Borden et al. (2007) established the social vulnerability index (*SoVI*), the built environmental vulnerability index (*BEVI*) and the hazard vulnerability index (*HazV*I) of American cities based on the sum of factor score values of the corresponding principal components representing individual vulnerabilities. Cutter et al. (2003) established the social vulnerability index (*SoVI*) by summing up the factor score values of the corresponding principal components of social vulnerability. Tapsel et al. (2002) established the social flood vulnerability index (*SFVI*) from a combination of three social characteristics and four indicators of financial deprivation. Simpson and Human (2008) expressed the hazard vulnerability score of a census tract by multiplication of the exposure score by the hazard score. Exposure and hazard score values were set from summation of the population rank, property value rank, critical facilities rank, social vulnerability rank, hazardous material rank, and transportation rank. Hazard score rank is the result of area affected rank or occurrence rank. Social susceptibility index (*SSI*), established by Damm et al. (2010) is the simple sum of three indicators: fragility, socio-economic condition and regional condition.

Partial vulnerability indexes (economic vulnerability index, social vulnerability index, and environmental vulnerability index) are combined mainly by an additive method to give the overall vulnerability index. If there is no specific knowledge, the same effect (weight) of the partial indexes on the overall vulnerability index is usually presumed.

Methodological aspects of hazard dependent vulnerability

The quoted approach is applied mainly in vulnerability assessment of the economic system. In this case the expected damage caused by a flood to assets, infrastructure and economic activities can be expressed in terms of money. An illustration of the methodological procedure of hazard dependent vulnerability assessment is presented in Fig.1. The procedure consists of four steps analysing dependencies: 1) probability vs. discharge, 2) discharge vs. water level, 3) water level vs. flood damage, 4) flood damage vs. probability.

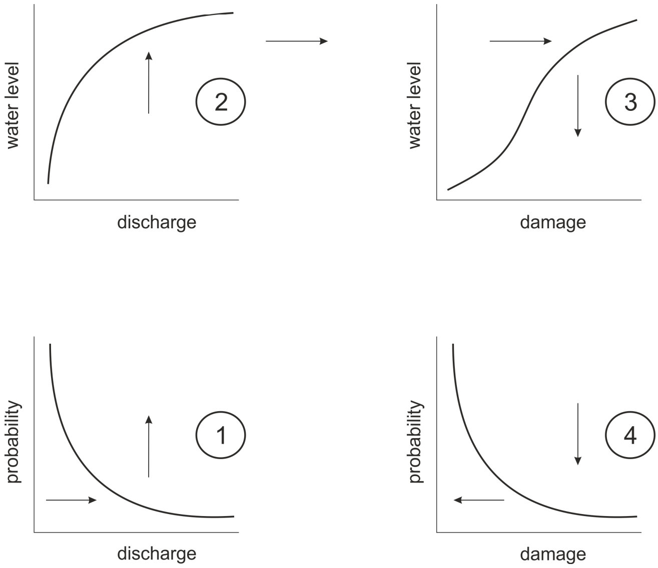

Fig. 1. Illustration of the methodology for hazard dependent vulnerability

Expected size of tangible damage (step 3) can be set using the *relative or absolute damage function* (Kang et al. 2005 and Floodsite 2006). The relative damage functions express the portion of damage to total property value and the absolute damage functions express the absolute amount of damage to property. In both cases, damage functions express the degree of damage to property more in dependence on the water level and less on the speed of water flow (e.g., Middelman-Fernandes 2010). An absolute damage function is derived either on the basis of real flood damage data or based on synthetic data (standardised typical property types (Floodsite 2006)). Exactness of data acquisition for derivation of damage functions has the result that the quoted approach is applied mostly on the local level (Herath 2003 and Büchele et al. 2006). The relative damage function expresses percentage damage to property; therefore the total value of property is needed in the process.

Many economic data are not available on the local level. Supplementing information, such as land cover/land use map, share/number of those employed in economic sectors is therefore used to spatially disaggregate economic data from the national level, to the level of spatial units (cf. Mayer et al 2009). For a detailed review of disaggregation methods see Madajová (2010). The one often used is dasymmetric mapping (Chen et al. 2004).

METHODS OF FLOOD RISK ASSESSMENT

Methodological aspects of flood hazard and vulnerability assessment were briefly analysed in the previous part. This part contains a brief introduction to methods of mutual combination of flood hazard and vulnerability components to express flood risk. There are two groups of methods for setting the level of flood risk. The first group consists of methods expressing flood risk in an absolute way, for example, by expected damage value in €, while the second group includes the method expressing the flood risk in a relative way by an ordinal scale.

Expression of flood risk in an absolute way

Assessment of flood risk in an absolute way combines the expected losses from all levels of hazard severity also taking into account their probability (Coburn et al. 1994). It means that flood risk is represented by the area under the damage-probability curve (Fig. 2).

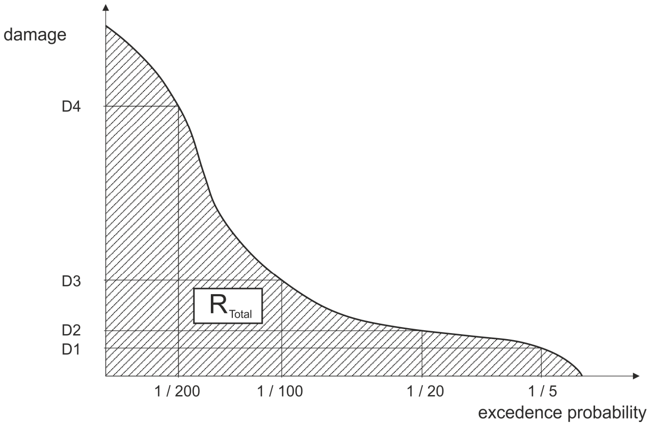

Fig. 2. Damage-probability curve (FLOODsite 2006)

The size of this area expresses the overall *average annual damage*. The expected monetary value of overall average annual damage ($E[X]$) on the discrete scale is set by summation:

$$E[X] = \sum_{i=1}^{l} p_i x_i, \tag{2}$$

where p_i is flood event frequency probability, x_i is amount of damage caused by flood event expressed for instance in €.

The average annual damage is the basic quantitative characteristic of flood risk to the economic system. It is the indispensable source for the assessment of financial effectiveness of particular flood defence measures via the cost-benefit analysis. However and Haimes (2009) and Merz et al. (2009) emphasize that application of average annual damage as an indicator of flood risk for the assessment of flood defence measure efficiency is quite problematic.

According to Haimes (2009, p. 328), use of the expected (average) annual damage value as the only criterion of risk estimate, is the principal source of chaos in interpretation of flood risk and wrong management conclusions and decisions. In fact, computation of the expected medial value makes great negative effects that occur with small probability commensurable with small negative effects, which occur with great probability. It means that on the one side the same value of flood risk can express great negative effects with small probability and the small negative effects with great probability on the other, because they participate in the expected average annual flood risk value with the same weight. Hence, to base flood risk management on the *average annual damage* of flood risk does not lead to prudent decisions. It is because the flood risk associated with a flood event with small probability and extensive negative consequences is perceived with much more apprehension than the flood event with great probability and small negative effects. Flood risk management should take this different perception of flood risk into account. This also is the reason why the author introduced the concept of ”*conditional expectation*“ as a supplementary measure of flood risk assessment. A conditional expectation is defined as: *“the expected value of a random variable given that this value lies within some prespecified probability range“* (Haimes 2009, p. 334). The axis of probability as a rule is divided based on two values of exceedance probability $1–\alpha_1$ a $1–\alpha_2$, with negative consequences β_1 and β_2 respectively, into three parts:

– high exceedance probability for an extreme event and small negative consequences

$$f_2(.) = E\left[X \mid X \le \beta_1\right], \tag{3}$$

– medium exceedance probability for an extreme event and moderate negative consequences

$$f_3(.) = E\left[X \mid \beta_1 \le X \le \beta_2\right], \tag{4}$$

– small exceedance probability for an extreme event and great negative consequences

$$f_4(.) = E\left[X \mid X > \beta_2\right]. \tag{5}$$

It means that apart from the traditional expected medial values three additional measures of risk have been created $E\ [X \mid X \le \beta_1]$, $E\ [X \mid \beta_1 \le X \le \beta_2]$ and $E\ [X \mid X \le \beta_2]$.

Merz et al. (2009) analysed the proportion of high probability/low damage and low probability/high damage in the overall value of average annual damage using the example of three case studies. The results showed that the low probability/high damage floods contribute only to a small degree to average annual damage and should therefore be of small importance in flood risk decision. On the other side, they also point out that flood mitigation measures are often initiated as a consequence of low probability/high damage floods. They explain this mismatch by the perception of risk. The concept of average annual damage assumes that decision makers and people are risk-neutral, but this assumption, however, is not valid because people tend to be risk-averse. As authors stress, people tend to dread events with large adverse consequences, even if their probability is very small and consequently their damage expectation is very small, too.

Expression of flood risk in a relative way

In spite of some progress achieved in the methods of financial estimation of social and environmental systems (cf. Parikh and Parikh 1998 and Bouma et al. 2005) there are some problems connected with the financial expression of social and environmental consequences (cf. Cochrane 2004 and Rose 2004). This is the reason why instead of expressing flood risk in an absolute way it is expressed relatively – on the ordinal scale, namely dimensionless values of the vulnerability or negative consequences of economic, social and environmental systems are aggregated and than ranked into classes expressing high, moderate or low level of risk. This process is the core of the spatial multicriterion decision analysis (MCDA) and was applied in connection with flood risk assessment for instance by Raaijmakers et al. (2008) and Meyer et al. (2009).

The spatial MCDA is a relatively new and rapidly advancing method that develops with the development of the GIS systems (cf. Malczewski 1999 and 2006). The aim of the MCDA is to establish the overall order of alternatives from the most preferred to the least preferred one. In terms of the nature of the decision-making space (*discrete and continuous*), there are two types of the MCDA: multiattribute decision-making (MADM) and multiobjective decision-making (MODM). The MADM solves a problem by choosing the best alternatives from the set of given alternatives. In MODM the number of alternatives is not explicitly defined, therefore it is indefinite. MODM searches for optimal alternatives regarding the objective function (Malczewski 1999). While MODM is predominantly "tied" to vector-based GIS and design/search operations, MADM is pretty much the opposite – mostly used in raster-based GIS and evaluation/choice decision operations. In the case of assessing the flood risk of a given set of spatial units which means assessment of different areas regarding their flood risk status and finding the best strategies and measures to reduce flood risk to an appropriate level the MADM approach is preferred (Meyer et al. 2007 and 2009). Figure 3 shows the scheme of the MADM application.

The process of flood risk assessment by the MADM approach consists of three main steps: standardization of variables representing given criteria, weighing of variables and aggregation of weighed values of these variables.

Standardization is transformation of original variables expressed by various physical units to dimensionless units by mathematical operations, while the relationships, intervals and spans of values are preserved. Standardization of variables is carried out by several methods such as the *linear transformation* or by the *value/utility function*. Linear transformation is division of the original value of variable by either its maximum score; or by the range of its values – difference between maximum and minimum value of the variable. There are two variants for doing this. The first one, so-called *benefit*, is usually used when, the higher value of a variable means the given area is more prone to be risky (e.g. ratio of elderly people in area – the higher the ratio is, the greater the risk of that area should be). The second one – *cost* – is used when the higher value of the variable means the risk should be lower. This is done by subtracting the standardized value from 1. Typical examples for using this variation are attributes defining the resistance or resilience of spatial units – the higher resistance or resilience, the lower the risk of a certain area should be (e.g. ratio households with insurance against floods – the more households insured, the greater is the chance that they can recover after a flood more easily). Standardization by the value/utility curve of function ($f(x)$) definitely sets its standardized value ($y = f(x)$) for the particular attribute. The key step is the acquisition of the correct and sufficiently accurate function (e.g. midvalue approach).

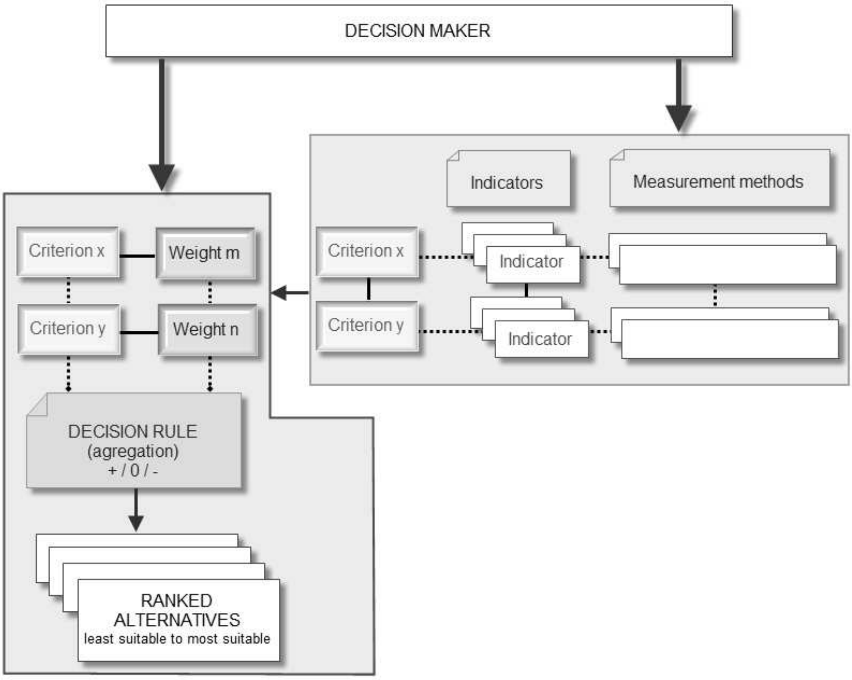

Fig. 3. Scheme of the multi-attribute decision-making (MADM) approach (Macharis 2004)

Weighting expresses the size of effects of the individual variables on the overall level of flood risk. This is a crucial and very delicate step of MCA because even a slight change of overall weights can later transform into relatively important change of the analysis outcome. Establishment of weights can be carried out by several methods: ranking, rating, pairwise comparison, swing weight approach, group decisions and also as one of the steps from the AHP process (for more details see, e.g. Malczewski 1999 and Meyer et al. 2007). The common feature of all methods is that the weights are standardized and their sum equals 1.

Aggregation of weighed values of individual variables constitutes the core of the MADM. Aggregated values establish the overall level of flood risk in spatial units. Clustering algorithms are various. They can be based on comparatively simple decision-making rules (dominance strategy and disjunctive approach) or other more sophisticated ones (different additive models, analytic hierarchy process – AHP, ideal point method and others). For the detailed description of individual algorithms see Malczewski (1999) and Meyer et al. (2007).

PRINCIPLES OF INTEGRATED FLOOD RISK MANAGEMENT

According APFM (2004) integrated flood management should address the following five key elements: 1) management of the water cycle as a whole; 2) integration of land and water management; 3) adoption of a best mix of strategies; 4) ensuring a participatory approach; 5) adoption of integrated hazard management approaches. The ideas of the new approach have resounded at the World Conference on Disaster Reduction (Hyogo, Japan in 2005) and also appeared in the UN/ISDR (2007) document from this conference. Building the resilience of nations and communities to disasters is emphasized by the application of five priorities: 1) ensure that disaster risk reduction is a national and local priority with a strong institutional basis for implementation; 2) identify, assess, and monitor disaster risks, and enhance early warning; 3) use knowledge, innovation, and education to build a culture of safety and resilience at all levels; 4) reduce the underlying risk factors, and 5) strengthen disaster preparedness for an effective response at all levels.

Flood risk definitions show that flood risk management can be based on three basic flood defence strategies:

- flood management strategy with the objective of reducing flooding,
- flood management strategy with the objective of reducing vulnerability,
- flood management strategy with the objective of mitigating the negative consequences.

Particular measures are bound to each flood management strategy (Tab. 1). The proposal of optimal flood defence strategies may be either a combination of several flood defence strategies or a dominant application of a single strategy. The rationale behind the share in which strategies are combined is knowledge of the spatial variability of flood risk and its structure. A different level of flood risk also requires application of a different flood management strategy or combination of strategies.

It is very important to evaluate the effects of strategies and their measures on the lowering of flood risk level and their overall efficiency. The above-mentioned MADM approach and the cost/benefit analysis (CBA) are applied to the assessment of efficiency of flood risk management strategies and measures. However, these two tools yield different outputs. Brouwer and van Ek (2004) emphasize that the results obtained by the quoted methods are not comparable to each other because of several reasons. The principal reason is that “the outcome of CBA can be interpreted in terms of the effect of a single alternative on overall economic welfare, whereas the outcome of MCA cannot. The outcome of MCA allows one to decide whether one alternative is preferred over and above another alternative, based on the pre-selected and weighted criteria. Hence, CBA can be applied to one alternative only, while MCA requires at least two alternatives.“

Tab. 1. Strategies and options for flood management (APFM 2004)

Strategy	Option
Reducing flooding	Dams and reservoirs Dikes, levees and flood embankments High flow diversions Basin management Channel improvements
Reducing susceptibility to damage	Flood plain regulation Development and redevelopment policies Design and location facilities Housing and building codes Flood-proofing
Mitigating the Impacts of flooding	Flood forecasting and warning Information and education Disaster preparedness Post flood recovery Flood insurance
Preserving the natural resources of flood plains	Flood plain zoning and regulation

FINAL REMARKS

The first remark concerns flood hazard assessment which is exclusively based on establishment of the probability that the specified maximum discharge causing flooding would not be exceeded. However, such an assessment is a considerably limiting one because it only takes into account the type of floods caused by the natural overflow if the volume of a flood wave is bigger than the channel capacity of a particular stream. But an overflow may also take place if the volume of the flood wave is smaller than the channel capacity under the effect of local hazard factors (improper dumps next to streams, solid wastes in channels, tapering of the discharge stream profile, blocking of culverts, blocking of passages under bridges etc.) causing impoundment and overflow. Such flood events often occur in upstream basins. The concept of expressing flood hazard via probability does not consider flood events caused by, for instance, concentration of overland flow if the rain intensity exceeds the soil infiltration capacity. High speed of water causes comparatively large flood damage out of floodplains. Brown and Damery (2002) report that 40% of flood damage in the UK occurs outside floodplains. Likewise, analysis of insured events caused by floods in Slovakia in 2002-2011 indicates that as much as 20-40% of flood damage was not connected with an overflowing stream. The probability concept of flood hazard also fails to take into account floods caused by ice blocking a stream and flooding due to increased groundwater level (inner floods).

The above critical notes concerning the prevailing current trend of flood hazard assessment have perhaps made space for formulation of an alternative concept of flood hazard. In its core is the property of a basin referred to as the *flood predisposition of the basin* (Weingartner et al. 2003) or *flood potential* determined by either systemic or random physical attributes of the basin (Minár et al. 2005 and Solín 2008 and 2011.

The flood predisposition of basins appears, for instance, in flood events frequency. In basins with a high flood predisposition (high level of flood hazard), frequency of flood events is expected to be much higher than in basins with a low flood predisposition (low flood hazard). Spatial variability in flood predisposition or flood potential would clearly be manifested in the case of upstream basins, which are less heterogeneous than big basins in terms of physical attributes (Solín 2008 and 2011).

The second remark concerns the efficiency of the *ex ante* assessment of flood risk based on the average annual damage first of all regarding flood risk on the national and regional levels. Application of the probability concept as part of the flood hazard assessment in the framework of these spatial levels due to the use of less accurate input data and the necessity to apply simplifying steps in hydraulic modelling of water table levels yields imprecise maps. The character of such maps is informative only. A very coarse estimate of flooded area and expected flood damage can be deduced using such maps. They provide rough information for the government on how large the total amount of loss for the nation and the economy would be or they serve as a basis for allocation of compensation payments to flood victims (FLOODsite 2006). However, they are useless for the operative management of flood risk or the choice of optimal flood defence strategies of integrated flood risk management on the national, regional and local levels and the assessment of cost/benefit effectiveness of the proposed flood defence measures. The results of flood risk assessment by combination of flood hazard and vulnerability expressed in terms of the potential provide a wider and more efficient knowledge basis for formulation of the optimal flood defence strategy (which means establishment of the ratio between strategies for reduced flooding, reduced vulnerability and mitigation of negative consequences) for individual flood risk classes precisely in connection with the flood risk management in small mountainous countries with frequent occurrence of floods in headwater basins (Solín 2008).

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HODNOTENIE POVODŇOVÉHO RIZIKA A JEHO MANAŽMENTU: PREHĽAD KONCEPTOV, DEFINÍCII A METÓD

Kritické názory na výlučné uplatňovanie inžinierskeho prístupu k protipovodňovej ochrane viedli postupne k sformovaniu nového prístupu k ochrane pred povodňami – k integrovanému manažmentu povodňového rizika. Nová paradigma protipovodňovej ochrany si vyžaduje aj nový prístup k hodnoteniu povodňového rizika. Cieľom príspevku je podať stručný prehľad súčasného stavu hodnotenia povodňového rizika a základných princípov jeho integrovaného manažmentu. Článok je rozdelený do piatich častí: Prvá sa zaoberá koncepciami a definíciami povodňového rizika, v druhej časti sa analyzujú metódy hodnotenia základných komponentov povodňového rizika. Tretia časť je venovaná metodologickým aspektom stanovenia úrovne povodňového rizika. V štvrtej sú načrtnuté základné princípy integrovaného manažmentu povodňového rizika a v záverečnej časti sú uvedené vlastné postrehy k súčasnému stavu hodnotenia povodňového rizika.

V literatúre sa stretávame s dvoma základnými koncepciami povodňového rizika, a to s jednorozmernou a viacrozmernou koncepciou. V rámci prvej koncepcie je povodňové riziko funkciou len samotného povodňového javu a je definované ako pravdepodobnosť s akou maximálny ročný prietok $Q_{\max}$ neprekročí špecifikovanú hodnotu q. Naproti tomu viacrozmerná koncepcia povodňového rizika vychádza z definície rizika, ktorá predstavuje očakávané straty na životoch, zranenie osôb, poškodenie majetku a prerušenie ekonomických aktivít v dôsledku prírodného javu. Táto definícia zdôrazňuje myšlienku, že negatívne a katastrofické dôsledky prírodných javov nie je možné pripísať len na vrub samotných prírodných javov, ale že sú aj dôsledkom zraniteľnosti spoločnosti.

Základom hodnotenia povodňového rizika je analýza povodňového javu a zraniteľnosti ekonomického, sociálneho a environmentálneho systému územia. Analýza povodňového javu je zameraná na: a) na odhad hodnôt ročných maximálnych prietokov pre rôzne pravdepodobnosti výskytu , b) odhad výšok hladín zodpovedajúcich ročným maximálnym prietokom rozdielnej pravdepodobnosti výskytu a stanovenie rozsahu zaplaveného územia. Prehľadným spôsobom sú načrtnuté základné metodologické postupy riešenia uvedených problémov. Pokiaľ ide o hodnotenie zraniteľnosti, sú spravidla uplatňované dva základné prístupy. V rámci prvého prístupu hodnotenie zraniteľnosti vyjadruje náchylnosť na poškodenie a schopnosť vyrovnať sa s negatívnymi účinkami povodní s ohľadom na atribúty objektov ekonomického, sociálneho a environmentálneho systému územia. Vo všeobecnosti tento prístup vyjadruje zraniteľnosť bez ohľadu na atribúty povodňovej udalosti a je v podstate nezávislý od povodňového javu. V súvislosti s hodnotením zraniteľnosti sú analyzované metodologické aspekty výberu premenných reprezentujúcich ekonomický, sociálny a environmentálny systém a stanovené indexy zraniteľnosti. Druhý prístup analyzuje zraniteľnosť vo vzťahu k atribútom povodňového javu, napr. k zaplavenej ploche, k výške hladiny alebo k rýchlosti prúdenia, čiže je závislý na povodňovej udalosti. V tomto prípade zraniteľnosť vyjadruje negatívne dôsledky konkrétnej povodňovej udalosti na monetárnej báze. Ilustrácia metodologického postupu hodnotenia zraniteľnosti je na obr. 1.

Samotné hodnotenie povodňového rizika, t. j. stanovenie jeho úrovne, je výsledkom vzájomnej kombinácie povodňového javu a zraniteľnosti. Analyzované sú dva základné prístupy hodnotenia: kvantitatívny a kvalitatívny. Prvý prístup vyjadruje úroveň povodňového rizika na základe stanovenia výšky priemernej ročnej škody, ktorú reprezentuje veľkosť plochy pod krivkou vyjadrujúcou vzťah medzi škodou a pravdepodobnosťou jej výskytu (obr. 2). Niektorí autori však upozorňujú na to, že aplikácia hodnoty priemernej ročnej škody ako jediného indikátora povodňového rizika je problematická v prípade hodnotenia efektívnosti protipovodňových opatrení. Problémy, ktoré vznikajú pri finančnom vyjadrení negatívnych dôsledkov povodní na sociálnom a environmentálnom systéme spôsobujú, že sa k stanoveniu úrovne povodňového rizika pristupuje kvalitatívnym spôsobom na základe ordinálnej škály. Bezrozmerné hodnoty zraniteľnosti alebo negatívnych povodňových dôsledkov na ekonomickom, sociálnom a environmentálnom systéme sú agregované a rozdelené do tried charakterizujúcich nízku, strednú a vysokú úroveň povodňového rizika. Tento proces je jadrom metódy, ktorá sa nazýva priestorová multikriteriálna analýza.

Integrovaný manažment povodňového rizika obsahuje päť kľúčových krokov: 1) manažovanie hydrologického cyklu ako celku, 2) zjednotenie manažmentu vodných zdrojov a krajiny, 3) prijatie optimálnej protipovodňovej stratégie, ktorá je kombináciou viacerých stratégií, 4) zapojenie všetkých dotknutých subjektov do rozhodovacieho procesu o optimálnej protipovodňovej stratégii, 5) prijatie integrovaného prístupu k manažmentu prírodných javov ako celku.

V záverečných poznámkach je poukázané na to, že hodnotenie povodňového javu, založené len na stanovení pravdepodobnosti, že nebude prekročená špecifikovaná hodnota maximálneho ročného prietoku, sa obmedzuje len na jeden typ povodňových situácií, ktoré vznikajú v dôsledku prirodzeného vybreženia hladiny z koryta rieky. Nezohľadňuje však celý rad ďalších povodňových situácií, ktoré sú spôsobené upchatím koryta rieky ľadmi alebo vzdutím hladiny v dôsledku upachtia mostných priepustov. Uvedený koncept taktiež nezohľadňuje povodne v dôsledku vzniku povrchového odtoku mimo nivných území pri vysokej intenzite dažďa, ktorá prevyšuje infiltračnú kapacitu pôdy, alebo povodne spôsobené výstupom podzemných vôd na povrch pôdy.

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