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# FLOOD RISK ASSESSMENT IN THE MOST ENDANGERED WATERSHEDS IN SLOVAK REPUBLIC

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**Abstract.** In recent years, the growth of population and diffusion of settlements over flood vulnerable areas have increased the impact of the floods worldwide. Natural disasters such as floods have constituted a major problem in many countries. Floods have caused immense economic and social losses, mainly as a result of unplanned urbanization, uncontrolled population density and not strictly inspected construction by authorities. Floods can anywhere and anytime have disastrous consequences, so it is desperately important to place emphasis on early warning and adequate protection against flooding. Flood damages that arose on watercourses and hydraulic structures on the territory of the Slovak Republic have been huge. The most affected is eastern Slovakia, where the most complex situation has been in Bodrog and Hornad river basins in the recent years, mainly in 2010. The paper presents flood risk assessment and management in these territories in context within Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. During the last decades extreme meteorological and hydrological phenomena became more frequent and more destructive. The return period for extreme hydrological phenomena, such as floods, is a common criterion employed in the design of hydraulic structures.

**Keywords:** floods, flood risk, risk assessment, watershed, likelihood.

## 1. Introduction

Floods are natural phenomena which cannot be prevented. Floods have the potential to cause fatalities, displacement of people and damage to the environment. Some human activities (such as increasing human settlements and economic assets in floodplains and the reduction of the natural water retention by land use) and climate change contribute to an increase in the likelihood and adverse impacts of flood events (Directive 2007/60/EC).

In the last decade, Slovakia is increasingly affected by floods. These floods have been recorded in substantial material damage and there are exceptional cases of loss of human life. Floods constantly point to the fact that the society is very vulnerable to flooding. In the last 13 years have caused floods in Slovakia, the loss of at the least 56 lives and affected more than 2500 villages and towns; only in the year 2010 the floods damages were calculated to 695,1 milion eur. Scope and extremity of flood episodes point to the need to build a comprehensive proposal eventually completion of flood protection measures in potential flood areas. Proposal for flood protection measures are fully devoted to the management of flood risk (Šlezingr 2009). The main objectives of management are determined the by Directive of the European Parliament and Council Directive 2007/60/EC on the assessment and management of flood risks. To assess the degree of flood protection and appropriate measures are currently applied data collection and evaluation and assessment of their confidence by the methods of risk analysis, which consists of flood risk assessment in the watersheds, so that the risk to determine the potential of this area (Zeleňáková 2010).

The risk assessment process provides a way to develop, organize and present scientific information so that it is relevant to environmental decisions. The aims of assessment are to introduce a sound science-based assessment method to people working in watersheds; and to point out how using the methodology makes environmental assessment data more useful to managers (Zeleňáková 2009).

Risk analysis can take many forms, from informal methods of risk ranking and risk matrices to fully quantified analysis. In the context of flood risk, in which many of the salient variables are continuous rather than discrete events and system responses are nonlinear, it is widely accepted that dependable risk analysis must incorporate some quantified representation of the main processes that contribute to flood risk, namely flood-generating mechanisms, the processes by which floods materialize at point where they can cause harm and the main processes of consequential damage.  The concepts and structure of flood risk analysis have now become so widely accepted around the world that it is easy to forget that essentially deterministic approaches, based on the estimation of a design flood and identification of flood defence designs to resist that flood, have persisted, in many places until rather recently (Hall 2010).

The main objective of this paper is to assess flood risk in river basins in the eastern Slovakia for the purposes of flood risk management. The paper deals with addressing the issue of risk assessment of floods in river valleys in the eastern Slovakia and the objective is to characterize the flood risks in the area (Zeleňáková 2009).

## 2. Materials and methods

Flood risk means the combination of the probability of flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event (Directive 2007/60/EC). Based on available or readily derivable information, such as records and studies on long term developments, in particular impacts of climate change on the occurrence of floods, a preliminary flood risk assessment shall be undertaken to provide an assessment of potential risks. The assessment shall include a description of the floods which have occurred in the past and which had significant adverse impacts on human health, the environment, cultural heritage and economic activity and for which the likelihood of similar future events is still relevant, including their flood extent and conveyance routes and an assessment of the adverse impacts they have entailed (Zeleňáková 2010).

According to 2007/60/EC every member state should prepare and publish the flood risk management plans, in which the flood risk management strategies are described, before 22 December 2015. It is recognized that flood hazard and flood risk maps contain essential information to prepare these plans. Therefore, the member states have to finalize a preliminary flood risk assessment before 22 December 2011 and flood maps before 22 December 2013 (ECE 2010).

Above mentioned requests were taken into consideration to fulfill the aims of this paper. Background for the methodology of the flood risk assessment watershed (basin) is the (general) process of environmental risk assessment. The process of the risk assessment is accomplished by evaluating the likelihood that adverse environmental effects may occur as a result of exposure to stressors (Zeleňáková 2009).

The risk characterization should interpret the major risks and the environmental significance of the findings. Created thematic maps, simplified scoring systems, clearly defined evaluative criteria and limiting the numbers of stressors and effects addressed all help to assess effectively and show the suitability of using ArcGIS software wherever it is necessary to make quick and effective decisions in emergency relief efforts for flood protection needs. Graphs are one of the best analytical tools for describing relationships between investigated attributes and impacts. Summary tables are an effective approach to display the most meaningful information in one condensed exhibit. Other benefits of using this process in watershed assessment are also evident.

The most dangered area by floods in Slovakia is its eastern part, particularly in the Bodrog and Hornád (Fig1). The morphological type of terrain in Hornád river valley (Fig1) is dominated by rolling hills, highlands and lower highlands. The southern sub-basin is part of a plane and Slovak Kras and is formed by moderately higher highlands. Geological structure of the territory determines the hydro-geological conditions of the basin. Sub-basin of the Hornád valley can be assigned to areas with a strong predominance of impervious, respectively poorly permeable rocks with moderate to low permeability. Well-drained rocks with high permeability are only in Spiš and Gemer areas and in Slovak Kras near Košice.

Territory of Bodrog – Cirocha, Laborec, Latorica, Ondava, Topľa and Uh rivers (Fig1) basin is located in two orographic subassemblies, which are the Carpathians and Pannonian Basin. The morphological type of the relief is predominantly plane in the southern part, hilly in the northern part. Bodrog river valley has varied climatic conditions. Precipitations are highly differentiated. The highest annual totals are mainly at east border mountains and Vihorlat where rainfall totals is about of 1.000 mm. Decrease of total precipitation is quite intense direct to the south - annual totals fall to below 800 mm. Lowland part of the Michalovce - Lastomír and Medzibodrožie belong to among the driest in the eastern region (550 mm rainfall per year).

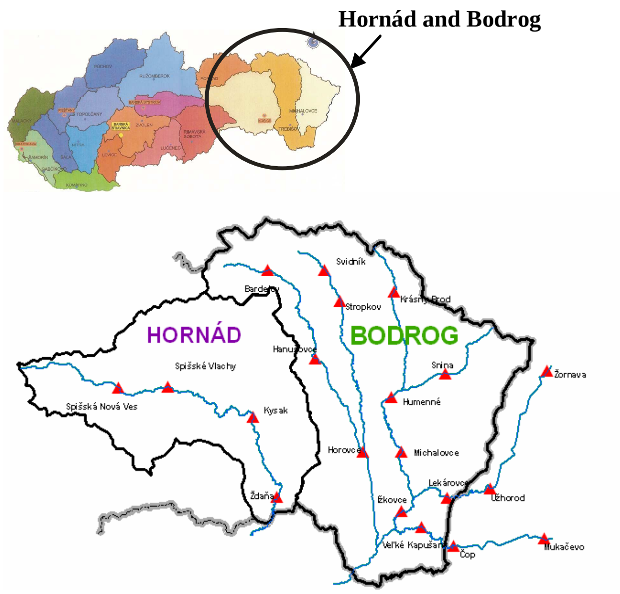


**Fig 1.** Hornád and Bodrog river watershed

Flood risk assessment includes gathering available information about the watershed, its valuable resources potentially at risk, stressors and exposure opportunities, and environmental effects are a practical starting point.

## 3. Results

Act No. 7/2010 of Slovak republic on the flood protection states three grades of flood according to the water level in the stream. The levels differ for the different river stations (Tab.1).

**Table 1.** Number of flood grade in river stations

| Watershed | River | River station | Number of I. FG Water level (cm) | Number of II. FG Water level (cm) | Number of III. FG Water level (cm) |
|---|---|---|---|---|---|
| Hornád | Hornád | Ždaňa | 190 | 280 | 380 |
| | | Kysak | 200 | 290 | 350 |
| | | Sp. Vlachy | 250 | 300 | 330 |
| | | S.N.Ves | 250 | 300 | 350 |
| Bodrog | Cirocha | Snina | 200 | 250 | 300 |
| | Laborec | Ižkovce | 700 | 750 | 800 |
| | | Michalovce | 500 | 600 | 700 |
| | | Humenné | 250 | 300 | 400 |
| | | K. Brod | 150 | 200 | 230 |
| | Latorica | Veľké | 500 | 600 | 750 |
| | | Čop | 400 | 470 | 600 |
| | | Mukačevo | 450 | 520 | 570 |
| | Ondava | Horovce | 400 | 500 | 600 |
| | | Stropkov | 220 | 250 | 280 |
| | | Svidník | 200 | 250 | 300 |
| | Topľa | Hanušovce | 150 | 200 | 250 |
| | | Bardejov | 250 | 300 | 350 |
| | Uh | Lekárovce | 600 | 700 | 800 |
| | | Užhorod | 100 | 130 | 150 |
| | | Žornava | 70 | 110 | 150 |

The twenty river stations in the Hornád, Cirocha, Laborec, Latorica, Ondava, Topľa and Uh streams with the height in centimetres for the different flood grades (FG) have been assessed. For the purposes of preliminary flood risk assessment daily data of water levels in the river stations for nine years period were assessed. The data were provided by Slovak Water Management Enterprise, s.e. Košice.

The flood risk assessment includes the likelihood and significance of adverse effects that have been evaluated according to the occurrence of flood grades (I. or II. or III.). Table 2 presents the average number (for the year) in the nine-year period of flood grade occurrence in each river station.

**Table 2.** Number of flood days at river stations

| Watershed | River | River station | Number of I. FG | Number of II. FG | Number of III. FG |
|---|---|---|---|---|---|
| Hornád | Hornád | Ždaňa | 34 | 2 | 1 |
| | | Kysak | 16 | 2 | 1 |
| | | Sp.Vlachy | 2 | 0 | 0 |
| | | S.N.Ves | 0 | 0 | 0 |
| Bodrog | Cirocha | Snina | 0 | 0 | 0 |
| | Laborec | Ižkovce | 1 | 1 | 0 |
| | | Michalovce | 1 | 0 | 0 |
| | | Humenné | 1 | 0 | 0 |
| | | K. Brod | 0 | 0 | 0 |
| | Latorica | Veľké | 39 | 23 | 2 |
| | | Čop | 26 | 38 | 21 |
| | | Mukačevo | 0 | 0 | 0 |
| | Ondava | Horovce | 1 | 1 | 0 |
| | | Stropkov | 1 | 1 | 0 |
| | | Svidník | 0 | 0 | 0 |
| | Topľa | Hanušovce | 2 | 1 | 0 |
| | | Bardejov | 1 | 0 | 0 |
| | Uh | Lekárovce | 1 | 1 | 0 |
| | | Užhorod | 0 | 0 | 0 |
| | | Žornava | 1 | 0 | 0 |

Risk was counted from eqn (1):

$$R_i = \sum_{i=1}^{n} (L_i \times C_i) = (L_1 \times C_1) + (L_2 + C_2) + (L_3 + C_3), \qquad (1)$$

where: R – risk, $L_i$ – likelihood (occurrence of flood grade – I, FG = 1, II. FG = 2, III. FG = 3), $C_i$ – consequences (number of flood grades).

Risk description concludes the characterization phase with the preparation of an environmental risk summary and the interpretation of environmental significance (Table 3). Interpreting environmental significance translates possible risk estimates into a discussion of their consequences for the watershed.

**Table 3.** Risk acceptability and its significance

| Risk rate | Risk acceptability | Scale of risk | Significance of flood risk in watershed |
|---|---|---|---|
| 1 | acceptable | 1 – 10 | Risks in watersheds are acceptable – current practice |
| 2 | moderate | 11 – 20 | Risks in watersheds are moderate – condition of continual monitoring |
| 3 | undesirable | 21 – 30 | Risks in watersheds are undesirable – flood protection |
| 4 | unacceptеble | 31 and more | Risks in watersheds are unacceptable – immediate flood protection |

Table 4 and figure 2 represents the acceptability (risk rate) of flood risks for each of the Hornád, Cirocha, Laborec, Latorica, Ondava, Topľa and Uh rivers watersheds zones.

**Table 4**. Flood risk

| Watershed | Partial watershed | River station | Risk – quantitative assessment | Flood risk rate - acceptability |
|---|---|---|---|---|
| Hornád | *Hornád pod Olšavou* | Ždaňa | 41 | 4 - unacceptable |
| | *Hornád - Kysák* | Kysak | 23 | 3 - undesirable |
| | *Hornád nad Hnilcom* | Sp.Vlachy | 2 | 1 - acceptable |
| | *Hornád pod Brúsnikom* | S.N.Ves | 0 | 1 - acceptable |
| Bodrog | *Cirocha - Snina* | Snina | 0 | 1 - acceptable |
| | *Laborec pod Dušou* | Ižkovce | 3 | 1 - acceptable |
| | *Laborec - Michalovce* | Michalovce | 1 | 1 - acceptable |
| | *Laborec - Humenné* | Humenné | 1 | 1 - acceptable |
| | *Laborec - K. Brod* | K. Brod | 0 | 1 - acceptable |
| | *Latorica – V. Kapušany* | Veľké Kapušany | 91 | 4 - unacceptable |
| | *Latorica - Čop* | Čop | 165 | 4 - unacceptable |
| | *Latorica - Mukačevo* | Mukačevo | 0 | 1 - acceptable |
| | *Ondava - Horovce* | Horovce | 3 | 1 - acceptable |
| | *Ondava - Stropkov* | Stropkov | 3 | 1 - acceptable |
| | *Ondava - Svidník* | Svidník | 0 | 1 - acceptable |
| | *Topľa – Hanušovce nad* | Hanušovce | 4 | 1 - acceptable |
| | *Topľa - Bardejov* | Bardejov | 1 | 1 - acceptable |
| | *Uh - Lekárovce* | Lekárovce | 3 | 1 - acceptable |
| | *Uh - Užhorod* | Užhorod | 0 | 1 - acceptable |
| | *Uh - Žornava* | Žomava | 1 | 1 - acceptable |

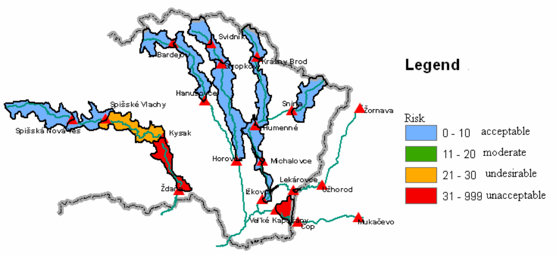


**Fig 2.** Map of flood risk

The results from preliminary flood risk assessment in the Hornád and Bodrog watersheds shows that unacceptable flood risks are in the lower parts of the Hornád river watershed (Ždaňa and Kysak) where its tributaries flow into and in the river stations Veľké Kapušany and Čop of the Laborec river watershed (Table 3).

## 4. Conclusion

Flooding is a complex phenomenon and several generating mechanisms can be involved, such as istense and/or long-lasting precipitation, snowmelt, dike or dam break, ice jam/landslide, outburst of glacial lake. Climate-driven changes in future flood frequency are projected to be complex, depending on the generating mechanism, e.g.; increasing flood magnitudes where floods result of heavy rainfall and decreasing magnitudes where floods are generated by spring snowmelt (Kundzewicz 2010).

People must learn to live with floods in the future. The value of the property threatening flooding is increasing. Therefore, attention must focus on the whole society to prevent and protect itself from big water to reduce or damage minimized.

Generally, watershed environmental risk assessment provides tools and information that may be used in managing flood risks [4]. Flood risk management in a narrow sense is the process of managing an existing flood risk situation. In a wider sense, it includes the planning of a system, which will reduce the flood risk. These two aspects of flood risk management will be considered separately (Thicken 2006). Preliminary flood risk assessment is focusing on the likelihood of adverse effects of floods as a basic philosophy for making environmental decisions related to flood measurements in the watershed. The results of preliminary flood risk assessment in the Hornád and Bodrog watersheds is the identification of unacceptable flood risks in the lower part of the Hornád stream and Latorica stream in the Eastern Slovak Lowland. This part of Slovakia is frequently exposed to floods.

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## References

Act no. 7/2010 of Slovak republic of 2 December 2009 on the flood protection.

Direcitve 2007/60/EC of the European parliament and of the Council of 23 October 2007 on the assessment and management of flood risks.

European Commission. Environment. *Flood risk management*. [online]. 2010. Available on the Internet: <http://ec.europa.eu/environment/water/flood_risk/index.htm>.

Hall, J. 2010. Journal of flood risk management, *Journal of flood risk management* 3(1), 2010.

Kundzewicz, W. Z.; *et al.* 2010. Assessing river flood risk and adaptation in Europe – review of projections for the future. Mitig Adapt Strateg Glob Change. DOI 10.1007/s11027-010-9213-6.Šlezingr, M. 2009. Reasons of the revitalization of watercourses, *Journal of Civil Engineering* 4(1): 69–80.

Thicken, A.; *et al.* 2006. Methods for flood risk assessment: Concepts and challenges, in *International Workshop on flash floods in urban areas*: 4–6 September 2006, Muscat-Sultanate of Oman.

Zeleňáková, M. 2010. Geographical approach to flood risk analysis, in *Proc. from International scientific conference: People, buildings and environment 2010*. Brno: Akademické nakladatelství CERM, s.r.o. 442–447.

Zeleňáková, M. 2009. Preliminary flood risk assessment in the Hornád watershed, in *River Basin Management 5:* Fifth International conference on River Basin Management including all aspects of Hydrology, Ecology, Environmental, Management, Flood plains and Wetlands. 7–9 September 2009, Ramla Bay Resort, Malta. Southampton : Wessex Institute of Technology, 15–24.