USING GIS IN THE FLOOD MANAGEMENT – FLOOD MAPS (TROUBKY, CZECH REPUBLIC)

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ABSTRACT:
Floods are the most threatening natural phenomenon in the Czech Republic. Intensive floods in 1997 and 2002 called attention to insufficient solution of flood problem in the Czech Republic. Gradually, there appear changes in the conception of flood protection. It should not be focused only on technical measures as greater emphasis is now laid on multicriterial evaluation of floods. The inhabitants of endangered areas should be the main actors in flood protection. In order to involve them in the flood management process, it is necessary to inform them suitably about flood hazard and risks. Flood hazard maps and flood risk maps should be one of the fundamental instruments for the public. The contribution deals with the evaluation of their strong and weak points. The municipality of Troubky was selected as a model area for the application of the methodology of T. G. Masaryk Water Research Institute which is used for the flood hazard and risk mapping in the Czech Republic. The municipality was most severely affected by the flood in 1997, however, up to now there is no sufficient flood protection there. Created maps were subsequently discussed with local authorities and after suitable methodology changes they serve as a basis for local flood management.

Key-words: *Flood maps, Flood protection, GIS, Risk communication, Troubky.*

1. INTRODUCTION

Floods are a natural phenomenon which is known from the beginning of human civilization. Storms and floods are the most frequent natural disasters in Europe. Between 1980 and 2006, 77% of economic losses in Europe were caused namely by them (Bubeck, Botzen & Aerts, 2012). Flood situation in the recent past (for example in 1997, 2002 or 2006) caused changes in the conception of flood problem in the Czech Republic. Former dominance of extensive technical solutions of flood protection is gradually and slowly complemented by local measures and preventive measures. As foreign research shows (Motoyoshi, 2006; Bradford et al, 2012; Wachinger et al, 2012), only technical solutions of flood protection are not sustainable in the long run. Flood management must be approached in an integrated manner (Haidu & Nicoara, 2011).

One of the preventive instruments as introduced by the European Union by means of the Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks (hereinafter called „flood directive“) is the analysis of flood risks. This is, among others, carried out by the creation of maps of flood hazards and risks (in summary flood maps) according to the methodology of T. G. Masaryk Water Research Institute. These maps are created in GIS. In the future, the created maps should serve not only to water management experts and state administration but also to the public. Some authors (e.g. Hagemeier-Klose & Wagner, 2009) perceive flood maps as the first step to a successful risk communication. Therefore, it is necessary that the maps should be easily legible, interpretable and interesting for the

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public. The aim of this contribution is to evaluate the advantages and difficulties of the new instrument of flood protection taking the municipality of Troubky as an example.

2. AREA OF INTEREST

Troubky, a municipality in Přerov district which is situated in the vicinity of the confluence of the rivers Morava and Bečva, became the symbol of floods in 1997. The municipality is in the floodplain of the Bečva and floods occurred there in the past. Historical sources show that the municipality was protected by a system of levees before (Lapáček, 1998). The changes and modifications of Bečva river channel in the 20th century (ploughing of the levees, straightening of the flow) up to now negatively influence the passing of flood wave through the municipality (**Fig. 1**).

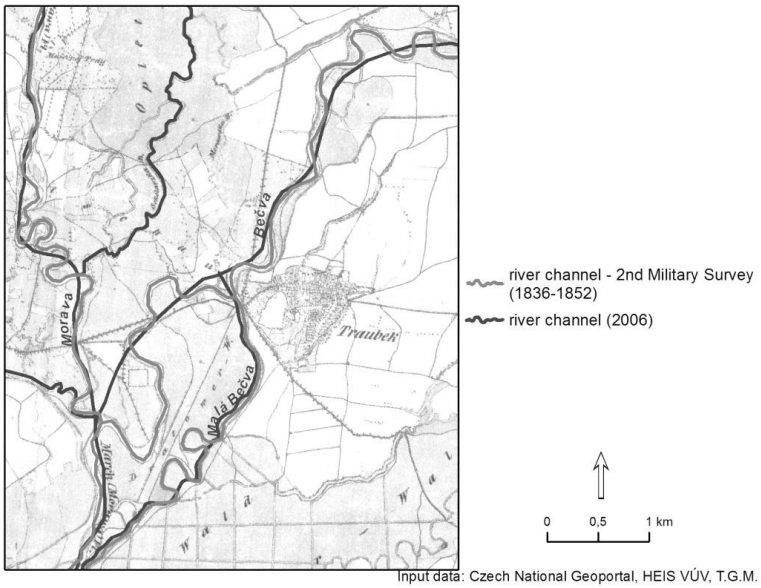

Fig. 1 Changes in Bečva river channel in the area of interest.

In 1997 9 people died as a result of the flood. Material damage was approximately 500 million Czech crowns. Half of the houses out of the total of 720 buildings had to be demolished as a result of waterlogging (Vaishar, 2000).

The flood in 2010 caused the damage of 400 million Czech crowns (Šunka, 2011). The intensity of flood was not equal to that of 1997, however, Troubky was one of the most affected municipalities again.

In spite of persisting flood hazard, Troubky is still a sought after place of living. This is proved by the migration increase in population. This increase is mainly caused by net migration. Natural growth is small (**Fig. 2**). Therefore, it is necessary to raise public awareness of the risk level. The maps of flood hazard and risk can be one of the preventive instruments.

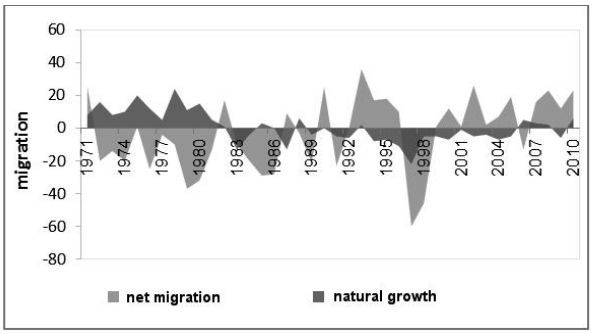

Fig. 2 Population growth in Troubky between 1970 and 2010 (Source of data: Czech statistical office).

3. BASIC CHARACTERISTICS OF FLOOD MAPS, TERMINOLOGY

Flood hazard and flood risk maps are part of the flood risk assessment which is based on EU flood directive. It has 3 stages in the Czech Republic. The first stage, which was completed in 2011, is the preliminary flood risk assessment. Its aim is to determine the areas with potentially significant flood risk. Flood hazard and flood risk maps created for these areas are intended to become part of the flood risk management plans by the end of 2015.

The directive 2007/60/EC defines flood risk as a combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event.

The directive always determines only the requirements that the individual states should reach in their outputs. However, the implementation process itself falls within the competence of individual states. In the Czech Republic, the Methodology of creation of flood hazard and flood risk maps was developed (Methodology of flood hazard and flood risk mapping, 2011, hereinafter called „methodology“). The methodology is based on the Swiss conception of flood risk evaluation (Merz, Thieken & Gocht, 2007). It uses semiquantivative analysis by means of risk matrix.

In the professional terminology of flood maps there are several discrepancies between Czech and English. In English, by flood hazard maps we understand the maps with coloured depiction of individual levels of hazard. A different term is used for these maps in Czech which can be translated as flood danger maps. In Czech, by flood hazard maps we mean source maps such as maps of water depth, maps of flood intensity or maps of flow velocity. As foreign literature is used in this paper, we follow the usual conception in which flood hazard for a given flood scenario with the exceeding probability and a return period is evaluated using the so-called “risk matrix” based on the calculated flood intensity (**Fig. 3**).

4. FLOOD HAZARD AND RISK MAPPING – METHODOLODY, DATA

Flood hazard maps were created using risk matrix. This semiquantitative method expresses the most frequently used risk expression method at present in which a colour scale is used to segment the hazard-prone flood plain into individual hazard categories and subsequently risk categories. When creating risk maps, present land use is taken into account as well as future projects in area use based on local plans. The expression of risk by means of this method enables to acquire results on the basis of relatively accessible data. The method itself consists in doing three steps: quantification of flood hazard on the basis

of acquired input data (flood intensity), quantification on the basis of risk matrix (flood hazard map), risk assessment (flood risk map) (**Fig. 3**).

In order to process the individual steps, the hydraulic modelling of the Povodí Moravy, state enterprise was used to acquire the maps of water depths of flood plain of Troubky and flow velocity grids (in grid resolution 10 x 10 m). The layer of depths was obtained as a difference between flooding level and digital model of the terrain. Then the geographical database ZABAGED was used to create the risk map. Materials of Czech geodetic and cadastral office were also used, mainly as source materials (Base map of the Czech Republic 1:10 000, Ortophoto – pixel size 0,25 m x 0,25 m). The field research served mainly for a more detailed acquaintance with the area and for the determination of sensitive objects on the risk map. And the cooperation with local administration and citizens made it possible to correctly determine the area categories for risk maps (in disputable cases), vulnerable objects and to evaluate the resulting maps in terms of clear arrangement and comprehensibility.

5. PROCESSING PROCEDURE

Maps of flooding depths and flow velocity grids in model area were further processed in ArcGIS program. Flood intensity maps were produced this way. The flood intensity is defined as a product of the above mentioned flooding depth and flow velocity and it is further used for the calculation of flood hazard. The flow velocity in Troubky reached the flow velocity outside the river channel less than 1 ms^{-1}. The flooding depth ranged between 0 and 2 m. Then the flood hazard was calculated according to the formula (Metodology 2011). The calculations are outlined in **Fig. 3**.

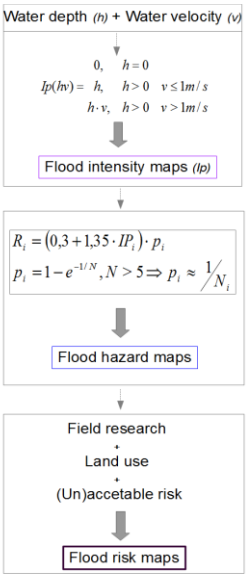

Fig. 3 Simplified scheme of flood hazard and flood risk mapping (*Ri...flood hazard; IPi...flood intensity of a given flood scenario; p_i...probability of occurrence of flood scenario; N_i...return period in years).*

Flood hazard values were transferred by means of risk matrix into resulting flood hazard maps. Besides the scenarios determined by the methodology (Q5, Q20, Q100 a Q500), the hazard map was also created for so-called maximum hazard scenario in which maximum values for every pixel were used when „layering“ the maps of flood hazard for individual scenarios in ArcGIS (**Fig. 4**). Colour composition for all the flood hazard and risk maps is fixed by the methodology including the transparency setting with individual colours (see Method discussion).

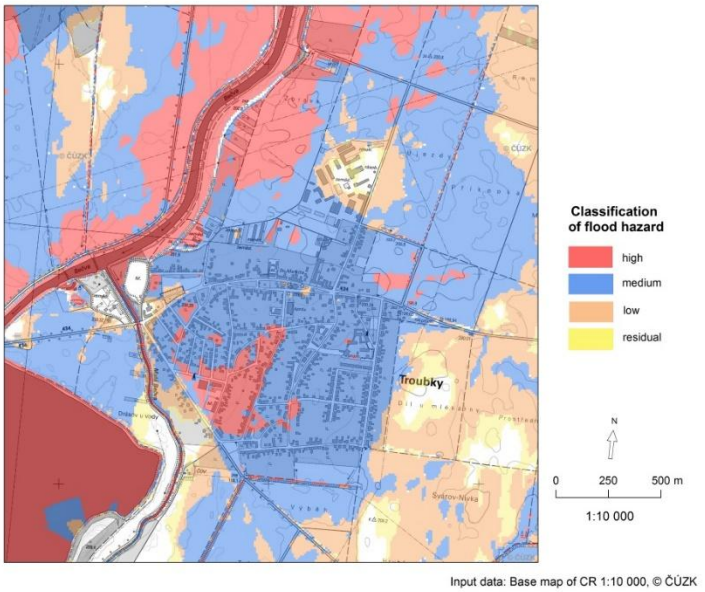

Fig. 4 Map of maximum hazard in the municipality of Troubky.

The principle of risk maps consists in determination of area vulnerability on the basis of its use and subsequently in determination of unacceptable risk for individual area categories. Thus, in the risk map, areas of individual categories of land use are highlighted in which an acceptable risk was exceeded which may result in high vulnerability of the territory.

Table 1. Examples of recommended land use determines by methodology (maximal acceptable risks for hazard categories).

Hazard categories	Land use
Low	housing, mixed zones, public facilities, industrial, manufacturing, technical infrastructure
Medium	sport and mass recreation
High	woods, agricultural land, greenery

In order to acquire the information about land use in the area, it is possible to utilize territorial planning documentation, especially the local development plan. Both current land use and proposed changes and outlooks are then put down into risk maps.

Unfortunately, the municipality of Troubky only has a local development plan of 1995 which is only on paper and it is well out of date. It was not possible to use it to create risk maps. Instead, ZABAGED database was used for mapping of land use (layers Separate building or Block of buildings and Purpose-built buildings). Further data acquired by field research were entered into these layers. Due to the dimensions of individual objects and the effort to observe cartographic vizualization according to the methodology, it was not possible to draw the risk map for individual buildings of ZABAGED database. ZABAGED served as a fundamental basis for the creation of „area use plan“ of the municipality (i.e. a

map depicting area use which in certain aspects approximates to local development plan of the municipality). Objects on the territory of Troubky were classified according to the land use. The Decree No. 501/2006 Coll., on general land use requirements (articles 4 to 19) was used as an aid for the categorization of land use in terms of vulnerability.

The following categories were introduced for the creation of area use plan: living, public facilities, technical facilities, production areas and warehouses, recreation and sport.

Deliberately, the categories of transport infrastructure and greenery were not created for Troubky. The transport infrastructure in Troubky only includes two sheltered bus stops whose area is insignificant in the map scale. The category of greenery was not introduced for practical reasons. This category includes public greenery, gardens, orchards, forests and various undeveloped areas. It would probably be rather disturbing to parcel out housing areas in the municipality to separate buildings and adjoining gardens. Keeping in mind the fact that the main purpose of risk maps is the determination and projection of areas where it is possible to exceed an acceptable risk, leaving this category out will not influence the results in any was because even high risk is acceptable with greenery.

The grid with categories of hazard was trimmed by individual areas and subsequently only those areas were selected in which the level of acceptable risk was exceeded. Categories of hazard were preserved in the risk map base. The risk map (**Fig. 5**) includes the depiction of so-called vulnerable objects that point out the places which need extra attention.

The risk maps expressed this way only confirm the fact that Troubky is a municipality which necessarily needs protection consisting in implementation of some of technical measures. Due to high vulnerability of almost all the living areas, it would also be desirable to take this data into account when implementing non-technical measures (e.g. limitation of new construction). A major problem for the municipality is the fact that most territory of the municipality is flooded with Q20 and falls within the category of medium or high hazard which results in a great number of objects with exceeded acceptable risk level. Therefore it is not possible in Troubky to work on the assumption that the municipality will only be endangered by floods with lower probability of occurrence (Q100, Q500 atd.). This is proved by the fact that the flood in 2010 caused the damage of approx. 400 million (return period was 20-50 years).

6. METHOD DISCUSSION – SELECTED PROCESSING PROBLEMS

The risk assessment by means of semiquantitative analysis is the most widely used method in the Czech Republic these days. The output of this method is maps. This is probably the most understandable possibility of presenting the results to public. Unlike tables and charts, maps use colours which enable quick evaluation, even for a layman. In spite of that there appeared several problems in creating the maps in Troubky which might complicate the presentation and limit the use of maps. Some of them will be presented in the following discussion. Most of the problems were defined with the help of local authorities and lay public.

The main problem is colour projection in the hazard maps and loss of simple legibility in the risk map. In order to enable comparison of flood maps on the territory of the Czech Republic, the methodology defines exact colour scales. However, adherence to the scales lowers the content quality of the created maps. Extremely low transparency of individual colours results in the illegibility of the map. This fact was pointed out by the public when evaluation map outputs for the municipality of Troubky. Therefore, the maps were

modified to enable legibility of the data and simplify the orientation in the area, thus performing its primary function. Another problem, probably more significant, that in author's opinion should have been solved in the stage of methodology approval, is the colour scale for hazard categories. „*Concerning visual aspects, flood hazard maps should meet the recipient's expectations and therefore be elaborated in blue colours which can be associated with water, e.g. water depths. The colours implemented in the Swiss hazard maps*[3] *(red, blue, yellow for hazard zones) do not meet these expectations and are therefore inappropriate for risk communication with the public.*" (Hagemeier-Klose and Wagner 2009: p. 568-569).

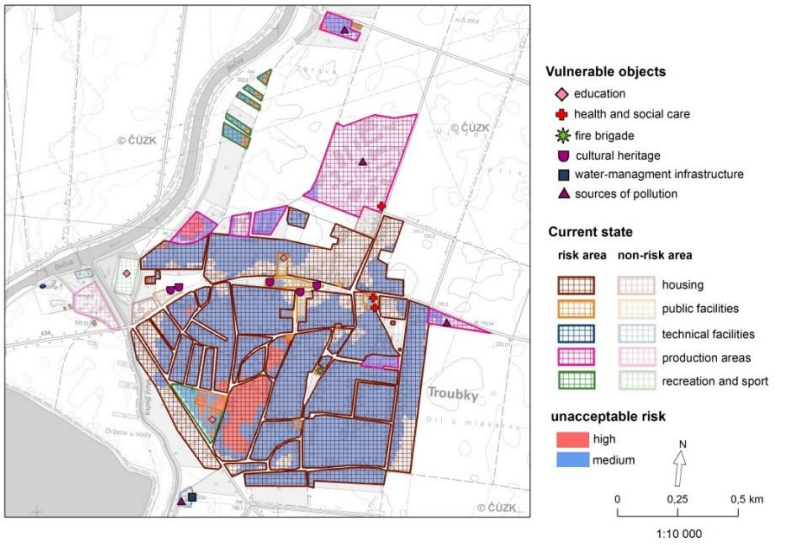

Fig. 5 Flood risk map (20-years return period).

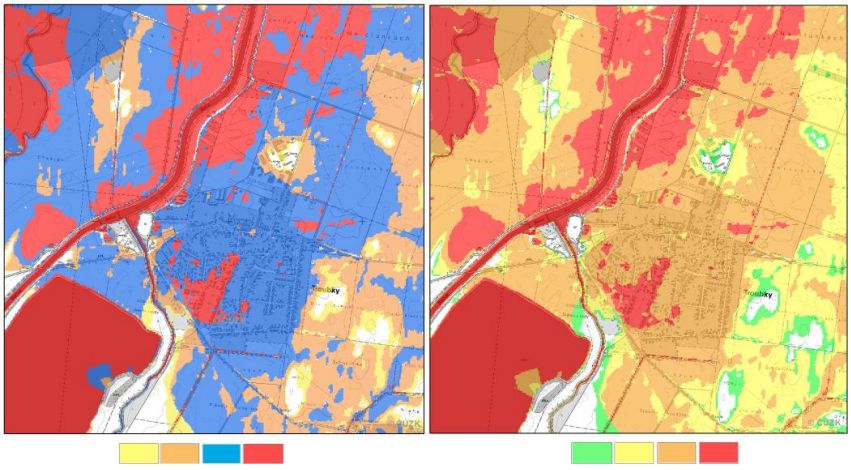

Fig. 6 The comparison of colour schemes of the map of maximum flood hazard (legend: residual, low, medium, high hazard – from the left to the right on scale).

[3] It is also used in the Czech Republic.

It would be more appropriate to use for example these colours: green, yellow, orange, red. (**Fig. 6**). Unfortunately, to enable the use of maps in other documents of the municipality, the colour scale had to be preserved. There is a problem with map legibility in the risk map. In Troubky it cannot be based on the local development plan because it is out of date. Thus the risk map only has one layer. Otherwise the map would contain two more layers. We cannot assume that the map will fulfil its primary task, i.e. an easy transfer of required information to the reader.

When presenting the maps to the public, it is necessary to point out some uncertainties which occur during their creation. In spite of high resolution of input data, it is still a simplification of reality which has a certain level of accuracy. As Merz, Thieken and Gocht (2007) pointed out, it is necessary to make the public aware of the fact that maps are inaccurate as part of the public tends to perceive maps as exact scenarios even for model situations which are extremely difficult to model, such as five-hundred-year flood.

Flood maps are supposed to serve mainly as an introductory step for the public into flood problem. However, the situation is complicated by the fact, that flood hazard maps are not part of Czech legislation. Flood maps only serve as recommendation, which means that building restrictions etc. are not legally binding. The only legally binding map source is the delimitation of flood areas. However, this administrative delimitation does not correspond to risk maps in most cases.

7. CONCLUSION

Flood hazard maps and flood risk maps only started to be created in the Czech Republic owing to the transposition of flood directive. It is a new instrument created by the professionals in GIS software. Maps are supposed to serve as the basis for planning instruments of public administration but it is also an instrument for the widest public.

The correct interpretation of the maps by the public should lead to the improvement of cooperation between the public and the experts in the field of flood problem in the future and it should also accelerate changes in risk communication. However, maps created for the municipality of Troubky according to the official methodology valid for the Czech Republic do not function this way in author‘s opinion. Above all, maps created exactly according to the methodology do not meet the basic requirement for easy legibility. Therefore, they were adapted for the municipality of Troubky after consultation with local authorities. In order to improve the legibility it would also be suitable to change the colour scheme of flood hazard maps. The processing of risk maps into several map sheets would make the map significantly clearer if they were created according to the local development plans. Thus the problem of several overlapping layers could be removed.

The above mentioned modifications, demonstrated on the maps created for the municipality of Troubky can relatively easily be carried out with minor technical interventions into map outputs. However, it would be suitable to realise changes and the level of methodology rather than in individual map outputs, preferably before the flood hazard and risk maps for all the areas with potential hazard in the Czech Republic are widely published.

In order to consider the flood maps created this way to be one of the basic instruments of risk communication and cooperation with the public, it is necessary to solve the legal foundation of flood hazard and risk maps in near future. This also requires mass spreading of the information about maps being created and about the possibilities of their use. It will not be possible to use this instrument effectively if the public is not well acquainted with it.

ACKNOWLEDGEMENT

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LEGISLATION

Decree No. 501/2006 Coll., on General Land Use Requirements. [Online] Available from: http://portal.gov.cz/app/zakony/?path=/portal/obcan/ [Acessed 2nd April 2014].

Directive 2007/60/EC of the European Parliament and of the Council of 23 October 2007 on the assessment and management of flood risks. [Online] Available from: http://portal.gov.cz/app/zakony/?path=/portal/obcan/ [Acessed 2nd April 2014].

SOURCES OF MAP DATA

Base map of the Czech Republic 1 : 10 000 (2011)

ZABAGED® – topography, ZABAGED® – altimetry 3D, rok 2011

Ortophoto – pixel size 0,25 m x 0,25 m

Primary source and copyright:

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Czech statistical office [Online] Available from: http://www.czso.cz/cz/obce_d/index.htm

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Povodí Moravy, state enterprise – flood depth, flood velocity

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