The flash flood driven land use changes: Case studies from the Czech Republic

Jaromír KOLEJKA[1], Petr RABANT[2]

[1] Institute of Geonics, Czech Academy of Sciences, Studentská 1768, 708 00 Ostrava-Poruba, Czechia; jaromir.kolejka@ugn.cas.cz

[2] VSB-Technical University of Ostrava, 17. listopadu 15, 708 33 Ostrava-Poruba, Czechia; petr.rapant@vsb.cz

1. Introduction

The economic and construction development of an area takes place on the basis of the participation of many factors, based mainly on the natural and social spheres. These "localisation" or "development" factors are often a crucial backbone in explaining past events and in planning and decision making of public administrations or private entities about upcoming changes also in land use. Dominant orientation on traditionally time-varying socio-economic indicators, however, sometimes neglects the second essential component in the development of the territory – namely, dynamic natural factors, physical-geographic, and in particular dynamic factors and phenomena. They are perceived as incidental, except for those associated with the phases of the annual cycle, as they correspond to the seasons.

The natural components of the landscape (geological environment, terrain parameters, water and climatic conditions, soils and biota) represent significant localizing factors of human activities and factors limiting the choice of appropriate activities for a particular area. Some of their short-term manifestations, especially atmospheric and/or hydrological phenomena, can cause a number of severe limitations for the socio-economic sphere. At present, we can encounter a number of extreme natural phenomena, the incidence of which has increased so much that it represents a serious threat to the continued development of many small localities but also larger territorial units. On a global scale, the impacts of climate change on a regional or local scale are manifested, amongst others, by the occurrence of frequent floods, periods of extreme drought or tornados.

Particularly the last two decades are characterized with the increased occurrence of extreme atmospheric and hydrological phenomena with adverse effects on human society. Floods, among other things, are well known to the public and the experts due to the wide publicity in the media, but also a great attention is paid to basic and applied research of such phenomenon. The main focus of the research is especially oriented to the prediction of regional floods, affecting catchment area in the order of tens of km² and more. It is mainly about the inventory and the analysis of conditions and causes of such floods, the modelling of their course and their extent (Jeníček 2009; Kienberger 2014), and the acquired knowledge should serve both the prevention and especially the early warning. A less noticeable attention is given to flash floods as they are considered as of "incidental" occurrence, with a rapid course limiting predictive and warning capabilities. However, the massive damages, and especially the lost of the victim lives, are not so big as in the regional floods. The reaction of human society to flash floods aims to reduce damages to human constructions and to develop ways to mitigate or to prevent their adverse impacts in the future. However, the statistical data (from Hungary) do not yet show a high probability of the flash flood repeating at the same site and legitimacy of taken measures (Czigány, Pirkhoffer, Fábián, Ilisics 2010). In any case, the reaction of the affected localities seems to be somewhat logical, e.g. in the development of land use, as it is demonstrated below by examples from the territory of the Czech Republic.

The relationship between flood and land use is predominantly studied as the impact of land use changes on the nature of the flood. Typical are studies of the impact of land use changes on the inundation size in a historical context (e.g. Naef, Scherrer, Weiler 2002; De Roo, Schmuck, Perdigao, Thielen 2003; Brath, Montanari, Moretti 2006). The opposite effect, i.e. a land use change as a result of the flood, is studied much less (Raha 2016) and concerns measures to capture the large water in reservoirs, forest stands, or to facilitate safe outflow through hydrotechnical structures. The impacts of flash floods on land use have so far not been studied.

2. Flood floods – concept, properties, course and impacts

Recent climate change has resulted in an increased occurrence of a natural phenomenon that can adversely affect the lives of people – flash floods. A typical feature of these floods is a very fast onset, a relatively short culmination and a rapid retreat. Such flood starts usually in a very short time after the causal rainfall. It can be several tens of minutes to the first hours. In addition, subsequent torrential floods can often affect areas where they may not even rain.

This issue is being addressed in the professional community as well as in the general public. The reason is often the devastating consequences of the event, which are almost instantly presented to the public by media, information and communication technologies.

Flash floods are devastating natural phenomena. The World Meteorological Organization (WMO) annually reports to the 5,000 victims of human lives and massive material damage (Grabs 2010). According to Jonkmann (2005), there is a lower number (about 1,550 victims per year between 1975 and 2002), but it was based on the publicly available databases of OFDA/CRED International Disaster Database, jointly managed by the Centre for Research on the Epidemiology of Disasters (CRED) in Brussels and the United States Office for Foreign Disaster Assistance (OFDA). However, they report only those events where the number of victims was 10 or more. The world population growth, intense urbanization in risk areas, and insufficient flood protection increase the risk. In any case, the number of deaths to the number of persons affected is higher in the case of flash floods than in regional floods (Jonkmann 2005).

Floods represent a major challenge for the human society, accounting for about one-third of all natural disasters in the last 25 years, hit roughly half of all affected populations in the world (Birkholz et al. 2014), accounting for a third of economic losses from all natural disasters (Wehn et al. 2015). For this reason, a great attention is paid to flood forecasts and, above all, to new methods of prediction of flash floods (Rozalis et al. 2010; Borga et al. 2011; Price et al. 2011; Kolejka et al. 2015a; Rapant et al. 2015; Rapant, Kolejka 2017), which are extremely dangerous not only for buildings and infrastructure, but also for residents (Špitalar et al. 2014). The human society is threatened by extreme floods, and therefore the attention to the flood perception increases rapidly (Birkholz et al. 2014; Miceli, Sotgiu, Settanni 2008; De Dominicis et al. 2015; Wehn et al. 2015). A number of experts focus on the active involvement of locals in the flood management (McFadden, Penning-Rowsell, Tapsell 2009; Vinke-de Kruijf, Kuks, Augustijn 2015; Thaler, Levin-Keitel 2016).

The World Meteorological Organization (WMO) defines a flash flood as a flood of short duration with a relatively high peak flow. The American Meteorological Society thus indicates "... a flood that grows quite fast and falls with little or no prior warning, usually due to intense rainfall over a relatively small area". The US National Meteorological Service defines it as a rapid and extreme flow of large water to a normally dry site, or as a rapid rise in water level in a stream or water course above a predicted flood level and it occurs within six hours after a causative event, such as intense precipitation, an ice congestion or a dam collapse (Grabs 2010; NOAA 2010). From a geographical point of view, this is a relatively area and time limited event. In the USA, events reaching a peak of up to 6 hours in catchments of up to 400 km² are considered as flash flood events (Borga, Anagnostou, Blöschl, Creutin 2011; NOAA 2010). According to the analysis of 25 flash floods in Europe (Marchi, Borg, Preciso, Gaume 2010), however, the dispersion of the affected area is considerably larger (from 9.5 to 1,856 km²). Flash floods are becoming more and more frequent natural phenomena (Czigány, Pirkhoffer, Fábián, Ilisics 2010). The progressing global climate change leads to extreme weather fluctuations, droughts are alternated by periods of severe rainfall. Human activities are not able to prevent these extremes, the only option is to learn to live with them, to take them as a natural part of life – to adapt the land use to these floods and to develop procedures that will allow society to react adequately in respect to human lives (Kolejka et al. 2015b).

Increasing frequency of this phenomenon is likely to occur in the context of global climate change (Huntington 2006). Such extreme phenomena in the environment, especially meteorological-hydrological ones, occur more often (Groisman et al. 2004). However, that similar growth of flash floods cannot be proved safely (Huntington 2006), but the increase in flash flood cases is foreseen (Gruntfest, Handmer 2001; Beniston, Stoffel, Hill 2011). Available figures documented this possibilities, but their increase can also be attributed to a better recording of the phenomenon. The flash floods are registered in most of the countries in the world (in 105 of 139 World Meteorological Organizations member states (Grabs 2010).

The flash flood is difficult to predict in terms of location, time, scope and course. However, the long-term statistics identifies areas where the likelihood of floods is significantly higher than elsewhere (Czigány, Pirkhoffer, Fábián, Ilisics 2010; Micu, Chendeş, Sima, Bălteanu, Micu, Dragotă 2010), but the time of the event is practically unpredictable. Current data sources, documenting both direct and indirect factors of the onset and spread of a flash flood, give in conjunction with modern processing procedures the hope that it is highly probable that an event will develop if the causes (precipitations) are already registered and localized (for example by a meteorological radar). As the triggering factor of the flash floods is most often an enormous local rainfall, it is possible to use the data from the weather radar monitoring the atmosphere above the given area for the detection of the occurrence of an increased flood risk (Kolejka et al. 2015a; Rapant et al. 2015; Rapant, Kolejka 2017). The result of the weather radar data processing may ultimately lead to issue an early warning to the vulnerable area before the flood risk increases. This can help, if not to reduce a material damage, at least to the effective salvation of human lives. The latter contribution is a key reason why the possibility of predicting the risk of hitting the area with the flash floods is thoroughly addressed.

The flash flood research has been under way for a long time and national meteorological services pay close attention to them. They have, among other things, drawn up lists of key factors and events that are behind them and affect their course.

As causal factors are considered (FF_EWS 2010, modified):

1. the intensity of precipitation,
2. the duration of precipitation,
3. the size, efficiency and direction of water run-off,
4. the drainage characteristics of the catchment and streams – i.e. outflow relations following the extreme short-term water source in the river catchment.

   Other causes include (NOAA 2010):

5. the dam rupture,
6. the very fast melting of the snow,
7. the collapse of the ice congestion on the water course,
8. the heavy rainfall over recently deforested or burned river basins.

   However, the trigger may also be (according to Micu, Chendeş, Sima, Bălteanu, Micu, Dragotă 2010):

9. the earthquake.

A list of other key factors and events is available (NOAA 2010, supplemented):

1. the scope, efficiency and direction of the run-off,
2. the previous state of catchment and flow,
3. the size and shape of the catchment,
4. the location of the storm, its movement and development, taking the basin into account,
5. the soil type, the depth of soil and the previous soil moisture ratios,
6. the quantity and the type of vegetation cover,
7. the nature of the use, including the degree of urbanization and deforestation,
8. the topography and slopes,
9. the season.

The catalytic character that increases the risk of flooding have other factors (NOAA 2010):

1. the presence of convective storms, of which a large amount of precipitation falls,
2. the anomalous amount of moisture contained in the low layers of the atmosphere,
3. the moving the humid air mass quickly transmitting moisture to the storm,
4. the atmospheric flow conditions promoting ripening and movement of storm cells,
5. the repeated motion of precipitation over the same area.

This group of factors has an additional effect associated with the spatial or time-spatial redistribution of precipitation only.

Known cases of flash floods are time-bound and happen (usually) in late afternoons, which is the time of local maximal atmospheric convection. However, it depends on the specific weather situation. A plentiful case is an isolated storm event with exceptionally high rainfall (see Gruntfest, Handmer 2001; Alfieri, Smith, Thielen-del Pozo, Beven 2011). The devastating effect of the stormy rains on a stagnant meteorological front, when the mild, long-lasting rain saturates the retention capacity of the river catchment, and the resulting stormy activity with intensive profitable rainfalls causes a rapid disastrous run-off (Brauer 2014). These events take place in the warm (not frosty) part of the year. A sufficiently long period leads to the formation of large water contents in local clouds. The maximum condensation and rainfalls occur in the afternoon, due to cooling od air saturated by steam (dependently on the altitude and at the same time with the decrease of the intensity of the sun's radiation – according to the time of day and the degree of sky cloud coverage). The flood then arrives in the late afternoon and runs from the early evening hours to the deep night. Especially the last aspects – the time of the flood's peak – is extremely alarming in terms of saving human lives.

The territory water balance is directly related to the water saturation of the catchment area before the causal precipitation. This is due to the amount of previous precipitations (in the hydrological practice, it means the precipitations fallen during the previous 3 months). For the tactical (operative-short-term) completing of early warning, however, the precipitations from a much shorter previous period are more important, as the water saturation of sub-surface soil horizons and/or the upper layers of the geological environment will force topic precipitations to run-off mainly on the surface. Only then, other area features (the size and the shape of the river catchment, the shape and density of the river network, the character of the soil cover and the geological environment, the slope and the aspect of the terrain, possibly also the vegetation cover and the land use may be involved). The impact assessment of these factors is more based on the idea of their physical nature and their impact on the movement of running water on the surface, rarely based on a real-world testing in a well known specific territory (Brauer 2014). The main problem is that examples of different flash floods in one and the same area are not documented. Only comparison of floods from different territories is applicable.

The main cause of the floods is the short-time massive local rainfall. The rainfalls sums exceeding average rainfall in 24-hours over a 50-year period are considered as torrential (Schumacher, Johnson 2005). In Russia, the "very heavy rain" is distinguished if the rain exceeds 30 mm within 12 hours or more than 50 mm within 24 hours, the torrential "rainfall" exceeds 30 mm within 1 hour, the "steady rain" gives more than 100 mm in 48 hours (Shikhov, Bykov 2014). On the territory of the Czech Republic, the rainfall sum of 10–80 mm within less than 180 minutes is considered as a torrential rain (eMS 2015).

While the most frequent flash flood trigger is represented by an enormous local rainfall, the appropriate attention is paid to them. The torrential rain itself, however, is very difficult to predict. In the world, there are a number of systems aiming to overcome this problem, such as the European Flood Alert System (EFAS), the US ALERT (Automated Local Evaluation in Real Time), ÁKIR (Flood Risk Information System) in Hungary. The private initiative led to the LEPS system creation.

Existing prediction systems generally use multiple rain-run-off and hydraulic models. By means of these, it is possible to estimate whether the water discharge in a particular closing profile reaches the flood-size. Reliability, resp. an error in the expected water discharge rate may range from 10% to 30%; with the time delay of the prediction from the time of obtaining the input data this error increases (Blöschl, Reszler, Komma 2008).

In addition to large-scale regional floods, the occurrence of flash floods from torrential precipitations has also increased in the Czech Republic. The first major flood of this type occurred in 1998 in Eastern Bohemia in the foothills of the Orlické hory Mts. in 1998. Another similar prominent flash flood affected the area of the Nový Jičín district in 2008 (Kubát et al. 2010). Other flash floods after torrential precipitations occurred in August 2010 in some municipalities in the Liberec region in Northern Bohemia (in detail Kubát et al. 2011). The occurrence of floods has generally begun in the Czech Republic to produce studies addressing adaptation strategies on regional and local levels, and as well as in the households affected by flash floods (e.g. Duží et al. 2014). Other studies deal with specific aspects of flood management (Keken, Panagiotidis, Skalos 2015; Klemešová, Kolář, Andráško 2014).

3. Land use status and changes in relation to flash floods

3.1 General principles of behaviour of affected municipalities

While insurance companies have developed significant activities in order to reduce possible insurance losses from unfavourable contracts for properties in flooded areas and ensured the mapping of graduated flood risk throughout the Czech Republic (Popelka 2011), the territorial planning practice reflects in the case of regional floods only a careful approach in incorporating this issue into development plans. At the same time, it is undisputed that with the increasing distance from the time of the flood event, the historical memory of the inhabitants is considerably weakened (e.g. Munzar 2010). Thus, the facts need to be systematically remembered and taken into account in forward-looking solutions and planning practice (Kolejka, Rapant, Krejčí 2017). Different situations are in cases of flash floods – but there is a possibility (and necessary) to recall some possibility of their occurrence and, of course, their repeatability. In the overwhelming majority of cases, the local conditions of their origin have not changed and can make a significant contribution to the dramatic course of events in flash floods. It's only a matter of time when the area will be hit with the trigger in the form of a torrential rainfall.

The main question therefore is how to combine territorial planning and planning activities with the delimitation of areas requiring increased caution in their current and planned use (Kolejka et al. 2015b). So far, almost all planned and realised changes in land use are a response to a real event in the past. Only exceptionally, the municipalities, which have not been affected by the flash floods, organised suitable preparations. However, the misfortunes of other municipalities have motivated them to make preventive adjustments in their administrative territory. As a rule, such advanced villages completed the construction of dry reservoirs for the water above the village, so-called dry polders, and facilitated the safe flow of large water through its built-up area by a reinforcement of endangered objects.

3.2 Overview of impacts of flash floods in monitored municipalities

Although there is not available a precise annual statistics on the number of municipalities affected by flash floods, the published data demonstrate about two dozen municipalities. However, the affected communities can be divided geographically into two basic groups:

1. Municipalities in the source part of the catchment area, affected mainly by water, which fell in the form of precipitation directly in the village and its immediate surroundings,
2. Municipalities on the lower course through hit by the flood wave coming from the upper part of the catchment while the decisive amount of causal precipitation was not falling in the community and its immediate surroundings.

These both types of villages differ in the course and the intensity of the flash flood, in the nature and magnitude of the damage caused. In general, flash floods in the spring part of the catchment show a slower rise of big water and a short lead time from the fall of causal precipitation. The flood also fades very quickly. The flood is rather flat (areal) in nature, although it reaches the highest intensity in the lowest locations at the sites where water flowing down the slopes accumulates. The floods affected large parts of the spring catchment. Damages are widespread, but with some exception it does not cause the destruction of buildings and riverbeds, the typical feature is landfilling of houses and other buildings. Damages are usually removed more quickly if there was ever any need to respond to the consequences of the flood. In general, some efforts lead to implement such catchment adjustments what can enhance its retention capacity. This is done by strengthening permanent crops (forests, shrubs, orchards, grasses), suitable land modifications (formation of vegetation infiltration strips in arable land, alternating crops on adjacent plots), agricultural measures (ploughing in contour lines, combining erosive crops with erosion resistant plants), technical measures (construction of large dry reservoirs – “dry polders”, the construction of circumferential derivation channels – “flood bypasses” for big water), protecting key areas in municipalities by dams.

On lower river courses in the catchment, often outside the area directly affected by causal precipitations, the flood has usually a dramatic character. It is represented by a rapid onset and a relatively rapid fall, although usually longer than in the spring catchment. The damage is concentrated in the belt along the main stream, respectively to the lowest locations along the eater course, often outside the alluvial plain. There are relatively high and strong flood waves with considerable destructive effects in this area. Its effect is increased by permanent or seasonal obstacles to the passage of a flood wave that forces the water to flow through the narrow space. Corrective and preventive measures are characterized by an effort to facilitate the safe flood wave flow through the village. This is done by adjusting the river bed (by straightening, widening, cleaning), by cleaning the potential flood area (by eliminating or minimizing the number and size of runoff obstructions), by increased protection of areas and objects (usually by total or selective protection of key objects by dykes), as well as by the appropriate flood management and the introduction of a communication and warning service (by connecting the meteorological and hydrological service with the disaster management, the introduction of flood communication between the parts of the catchment or the municipalities and their representatives (the disaster management, the introduction of a flood communication between the parts of the catchments, between municipalities and their representatives (municipality disaster management staffs). Types of municipalities are represented in the following overview (Fig. 1).

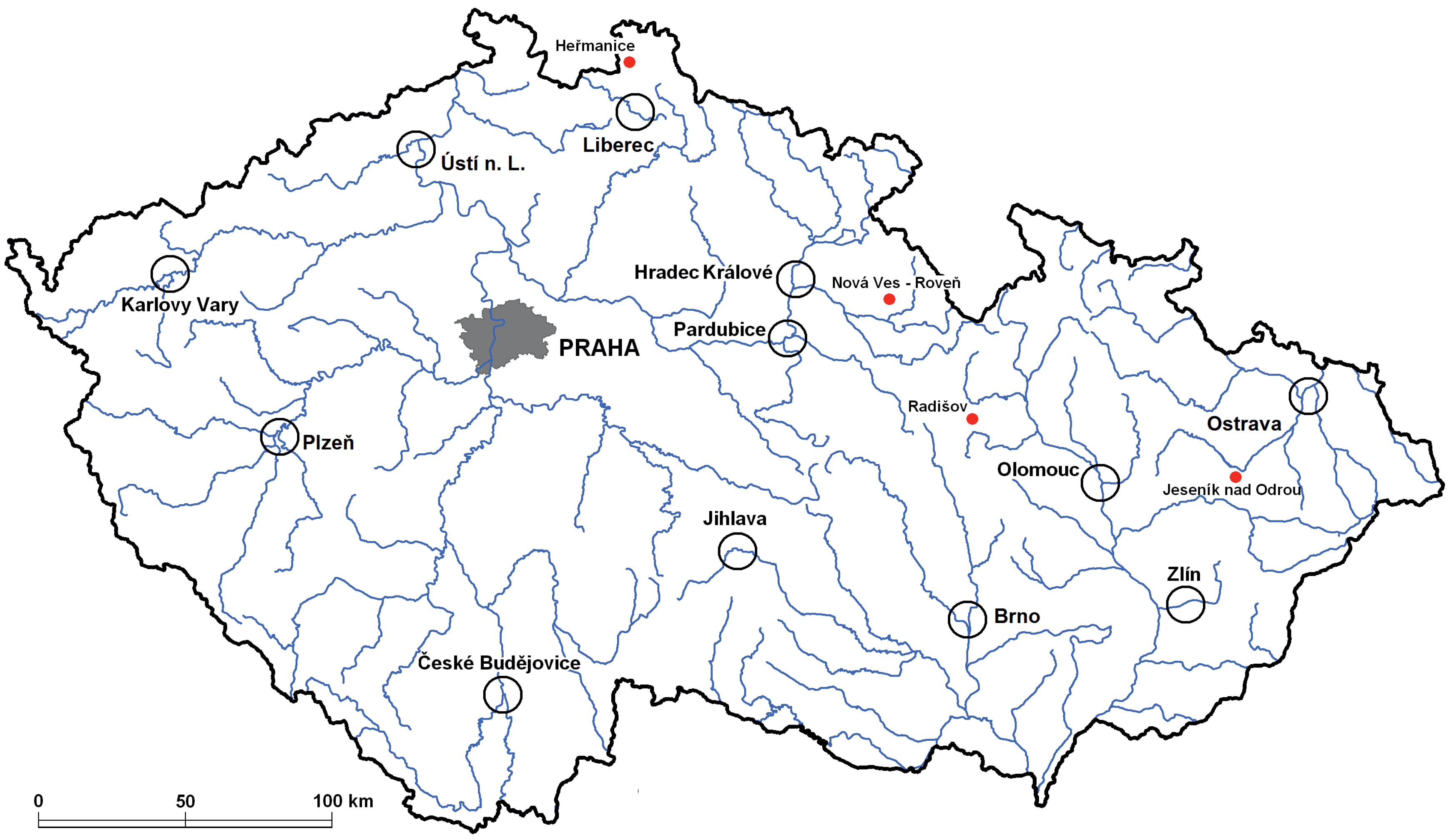


Fig. 1 – The studied municipalities affected by flash flood in the territory of the Czech Republic.

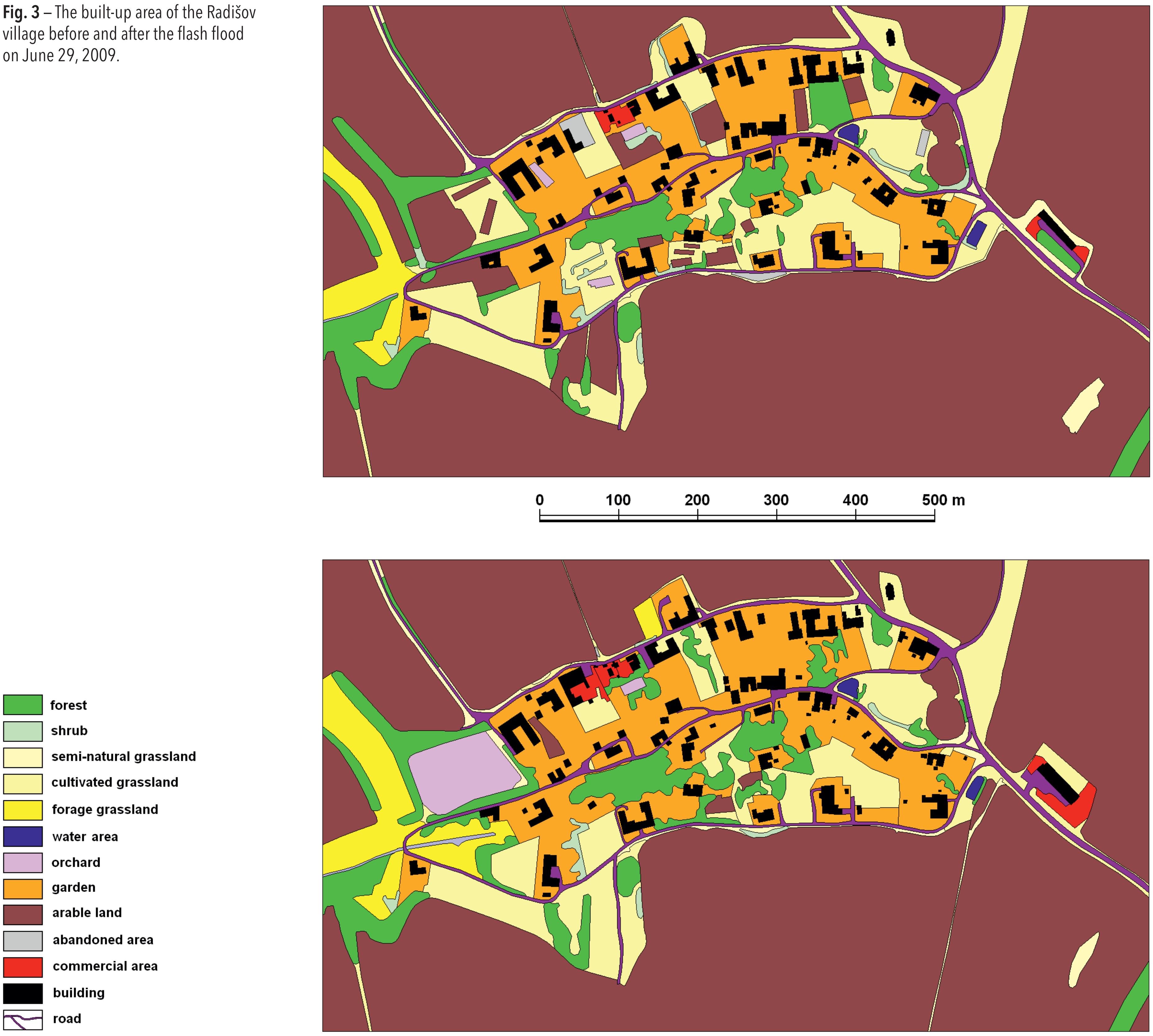
Changes of land use in the village in the spring basin

The common built-up area of the villages of Nová Ves and Roveň (in the district Rychnov nad Kněžnou, Královéhradecký kraj region) was hit by a flash flood in 2011 (August 25, 2011). The villages are situated in an elevated position on the border of the flat Cretaceous Eastern-Bohemian Plateau, locally covered by loess to the sharply rising Podorlická pahorkatina Upland, built here by inclined Cretaceous sedimentary rocks (sandstones, marlstones), in a local saddle position between two deep river valleys (Kněžná River valley in NW and Zdobnice River valley in SE) at an altitude of 370 m a.s.l. Jahodovský potok creek flows through the villages. It originates at an altitude of 450 m a.s.l. at a distance of about 2 km from the villages. The villages areas situated in the wide asymmetrical valley, along the creek, partly also on the adjacent slopes (Fig. 2).

During the flash flood, the rainwater came into the village in several places from the surrounding slopes and in a concentrated form it flown through the centre of the villages in axis of the Jahodovský potok creek. On the way, there was a significant flooding of the village axis with a high flood wave, which damaged several houses (usually flooding of cellars and ground floors of houses, gardens, movable property). The water carried large amounts of floats that covered large areas in the built-up part both of the villages and penetrated into the interior of the buildings. Before the flash flood, large areas in the vicinity of the villages were used as arable land, often sown with corn and cereals. After the flash flood, the arable land areas were partially reduced and the sowing areas of the corn were placed into more distant position away from the villages and equipped with tapping strips sown by other field crops. The share of areas with a long-year agricultural canopies (forage on arable land)

Fig. 2 – The central part of the villages Nová Ves (upper half of the built-up area) and Roveň (lower half of the built-up area) before (top) and after (bottom) the flash flood on August 25, 2011.

Fig. 3 – The built-up area of the Radišov village before and after the flash flood on June 29, 2009.



has grown. The new constructions are mostly located in areas away from the creek and in the higher positions closer to the watershed, even close to the spring. Similarly, commercial areas of business entities grew slightly only at a greater distance from the creek (the axis of the village is identical to the axis of the valley). The water course and its immediate surroundings present virtually no impact.

The Radišov village is formally a part of the municipality Staré Město u Moravské Třebové (Svitavy district, Pardubický kraj region). The flash flood was here in 2009 (June 29, 2009). The village is situated in the Podorlická pahorkatina Hilly-land, near the local watershed in the depressing position of the Moravskotřebovská pahorkatina Upland an altitude of 390–410 m a.s.l., here built by the Permian sediments with local covers of Quaternary loess on the slopes and Neogenic clays on a flat watershed. There is a small stream in the village, which is drying regularly. The settlement of the village is situated in a bowl (dellen) in the gently undulated landscape. During the flood, the water came partly from the plateau, but mainly it accumulated from heavy precipitations directly in the village (78 mm of precipitation, out of which 70 mm in one hour – estimated according to the station in the nearby village of Třebařov distant 3 km). The water gathered on the flat bottom of this tilted (to W) depression, eroded the land on the slopes and flown along the axis of the village into the grassy valley below the village, where it caused virtually no damage. In the village only flooded several cellars and ground floors, damaged the gardens and plasters in the houses, or damaged the wooden and temporary objects.

In the following period of time (Fig. 3), almost all the arable land in the built-up part of the village was almost turned to a grassland. The residential area has not changed (a part serves as seasonal or second – recreational housing for the citizens of the neat-by town Moravská Třebová and other settlements). However, business activities expanded only in a safer position at the elevated edge of the village, where the previously abandoned areas were reused.

Changes in land use in the village at the lower course of the river

The village of Heřmanice is situated at the bottom of a narrow (50–100 m wide at the valley bottom) and a relatively deep valley (50–80 m) of the Oleška River, which is cut deeply into the gently undulated postglacial Frýdlantská pahorkatina hillyland with unique volcanic hills at an altitude of 300–350 m a.s.l. The Oleška River starts about 590 m above sea level in the Jizerské hory Mts. and it reaches the village of Heřmanice after about 30 km downstream, after another 8 km it empties into the Lužická Nisa River on the territory of Poland. The surroundings of the village are among the areas with high precipitation rates (around 1,000 mm/year), which leads to a permanently high water saturation of the geological environment and soils and therefore to a reduced retention capacity of the territory. Most of the agricultural land is covered with meadows. The flash flood occurred here in 2010 (August 7, 2010) after a heavy rainfall in the Jizerské hory Mts. that fell during the previous two days (this rainfall lasted for 30–36 hours). There was a high flood wave that culminated from 11:40 to 16:20. One person was killed, the flood picked up five houses and three other buildings, damaged 32 houses, destroyed 9 bridges and footbridges, another 6 bridges and footbridges were damaged. The waterfront walls and roads in the village were completely destroyed, public lighting, public water supply, children's playground and public greenery were heavily damaged. The recovery in 2010–2014 costed at 92.5 million of Czech crowns (4.4 millions of USD).

During the restoration (Fig. 4), the expansion of the Oleška River bed increased its water flow capacity. In fact, the accompanying tree and bushes along the river bed have been removed, similarly, almost all groups of trees have been removed along the bottom of the valley in the village. The main road has been completely rebuilt and expanded. Bridges and footbridges have been restored but some have been moved to more suitable locations. The houses were restored only partially in the original places. A park without high tree vegetation with a children's playground was laid on the site of one ruined house and garden. Other sites were grassed only and the original owners were provided with a replacement land. Instead of one demolished brick house, a mobile home was installed. Entrepreneurial activities, a new residential developments (in part as a replacement for the destroyed dwellings) and tourist cycling trails (partly on the dismantled railway route) were moved to positions high above the bottom of the valley. The abandoned basalt quarry on the hill north of the village was not included in rehabilitation measures.

Jeseník nad Odrou is a village on the lower course of the Luha River, the right-hand tributary of the Odra River (256 m a.s.l.) at an altitude of 260–290 m. The geological environment of the area east of the village is formed by Paleogenic claystones and sandstones of the Flysh Carpathians, while the geology west of the village is built by Neogenic calcareous clays of the Carpathian foredeep. Tertiary materials are covered with Quaternary loess and continental glacial sediments (Saale) in gently undulated

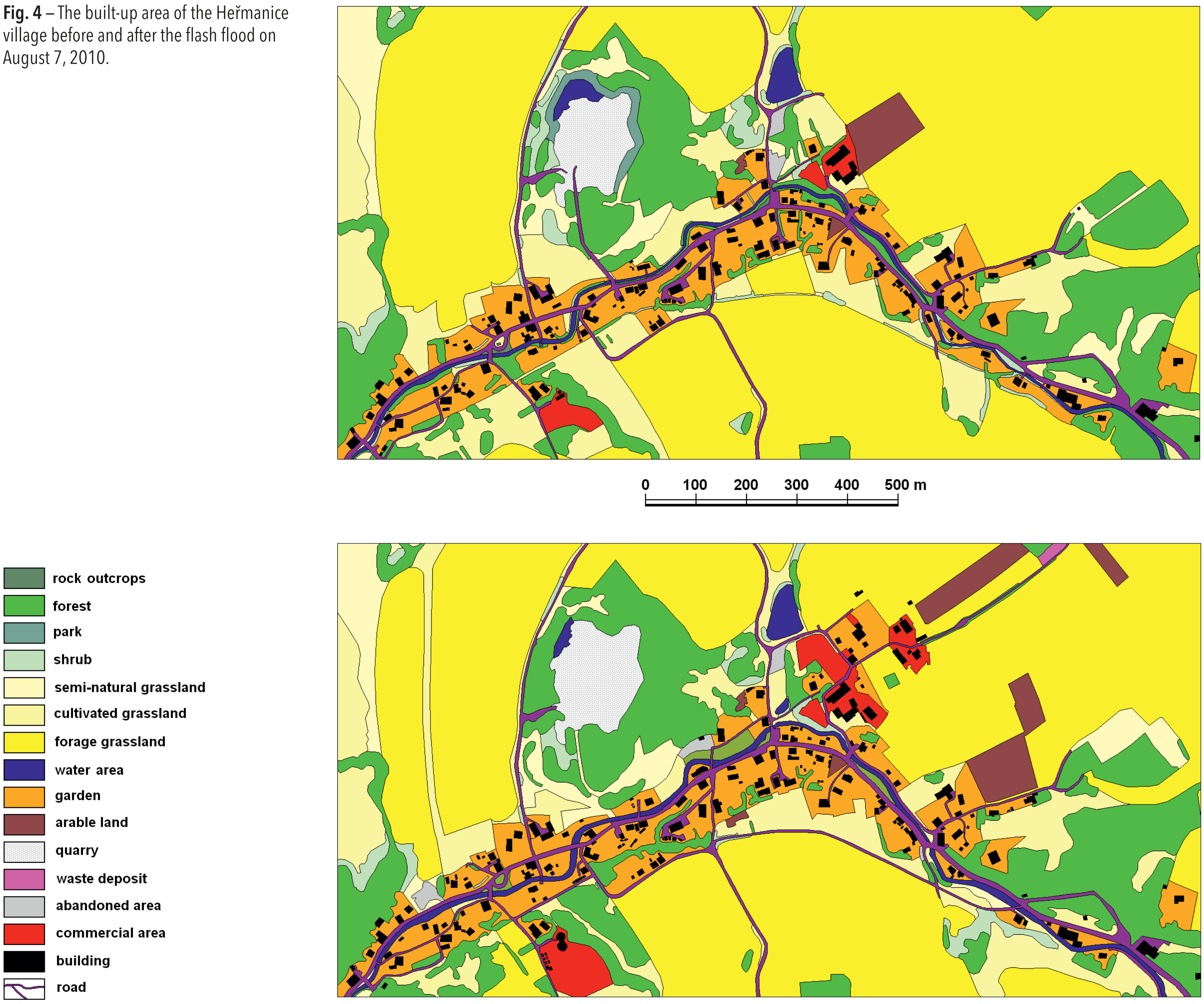
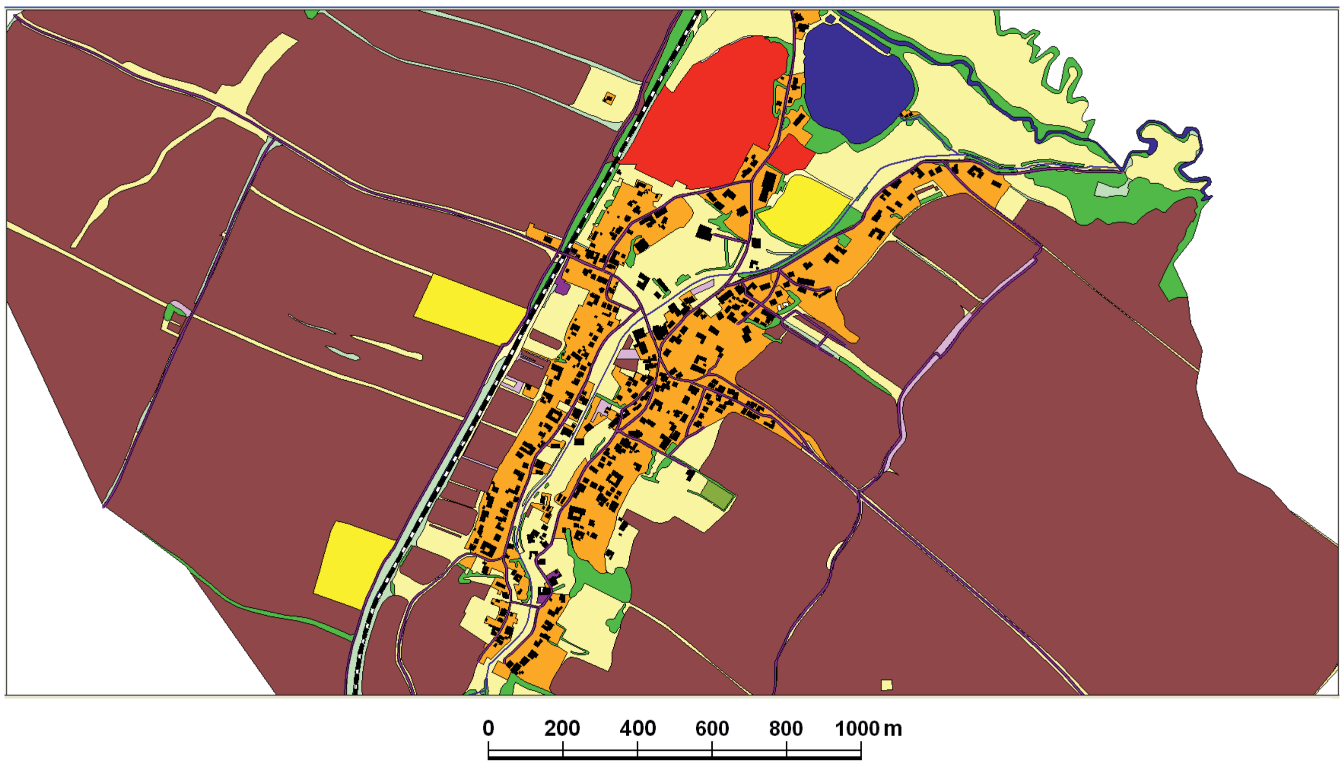


Fig. 4 – The built-up area of the Heřmanice village before and after the flash flood on August 7, 2010.

Fig. 5 – The land use of the Jeseník nad Odrou village before and after the flash flood on June 24–25, 2009.



terrain. The village is situated in a wide valley (200–250 m above sea level) with slightly inclined slopes. The northern part of the village opens up to a wide alluvium of the Odra River flowing to the North of the village. On June 24–25, 2009, the village was hit by a catastrophic flash flood. The flood was triggered by rain that affected mainly the areas south and southwest of the village, where 100–150 mm of precipitation fell from 16:30 to 21:00 local summer time. The flood culminated between 21:30 on June 24 and 01:00 on June 25, 2009. The flood damaged 171 buildings, 23 buildings had to be demolished, 4 people died and the damage amounted to 320 million Czech crowns (15.24 million of USD).

Prior to the flood (Fig. 5), numerous family houses with gardens were situated in the immediate vicinity of the watercourse on the broad banks of the Luha River. Other family dwellings accompanied the roads passing through the valley on the both sides of the river along. Most of these houses were hit by the flash flood. Most of houses, similarly to groups of trees and orchards as potential barriers to the passage of water were usually later removed from the proximity of the watercourse (it was straightened, festooned and deepened in the time before this flood). A more or less contiguous wide strip of grass area passes the centre of the village along the Luha River bed. The new 23 houses were built in the north-eastern part of the village near the centre on the original agricultural land (arable land, meadow, shrubs and trees). Entrepreneurial activities have undergone partial development and commercial areas have grown slightly at a safe distance from the flow. The vast areas of agricultural land in the vicinity of the village on flats and mild slopes have virtually no impact and the arable land still strongly dominates, although large amounts of mud has also been transported into the village by the rain water. The Vienna–Warsaw international railroad along the western edge of the village represents a reliable protection against field spills, although the bridges in the railway body allowed the mud to enter deeply into the built-up area of the village. A similar protective effect is played by a strip of planted fruit trees and shrubs along the field road parallel to the village east of the site.

4. Summary and conclusion

The demonstrated examples of the land use responses to flash floods well describe the situation in the Czech Republic. There run otherwise (and less intensively) land use changes in municipalities and their surroundings in upper catchment positions at the spring courses of rivers. So there are only minor corrections in the land utilising, usually by transferring arable land into permanent crops. On the slopes down to the built-up area, the share of perennial crops (meadows, fodder on arable land) also grows as well. The built-up area was affected with the land use changes only indirectly, by locating new buildings outside the flash flood affected area.

Downstream municipalities have often done a very radical "clearing" of the belt along the watercourse to facilitate an incident-free passage of big water in case of a repeat of the flash flood. Both outflow barriers (trees, low bridges) and potentially endangered dwellings have been removed (if the residents agreed with it, the elderly persons prefer to remain in vulnerable homes), thus facilitating the passage of big water by modifying the flow channel. The municipalities allocated the necessary areas for replacement dwelling construction, usually on the periphery of the village, in a fully secure elevated position. Land use changes practically did not affect areas outside the built-up areas in such municipalities.

The experience of villages affected by flash floods was often initially taken over by other municipalities. Conscious of the fact that global climate change is most often manifested in the Czech Republic by an increase in the number of meteorological and hydrological extremes, many municipalities are actively preparing for potential threats. The crop sowing plans of agricultural enterprises in the neighbourhood of the village are coordinated, so that soil erosable crops are not planted on the slopes near the built-up areas. Pond systems are set up above the villages so that there is a large reserve in the volume to capture the maximum flash flood water. Their surroundings are usually grassed. There is plenty of construction of dry tanks to keep the big water. Adjustments inside the built-up areas are still slower, except for canalisation of watercourses (river bed enlargement, straightening, dam construction). The positive effect of realized land use changes in affected municipalities as well as in previously preserved municipalities can be demonstrated in the future. The above mentioned behavior of municipalities is part of a set of measures to adapt to global climate change by reducing disaster risk. This is done in many ways according to the nature of the expected threat in different countries of the world (Shaw, Pulhin, Pereira 2010). However, it is necessary to build a fully reliable and operational warning system at the same time.

References

ALFIERI, L., SMITH, P.J., THIELEN-del POZO, J., BEVEN, K.J. (2011): A staggered approach to flash flood forecasting – case study in the Cevennes region. Advances in Geosciences, 29, 13–20.

BENISTON, M., STOFFEL, M., HILL, M. (2011): Impacts of climatic change on water and natural hazards in the Alps: can current water governance cope with future challenges? Examples from the European ACQWA projects. Environmental Science and Policy. 14, 6, 734–743.

BIRKHOLZ, S., MURO, M., JEFFREY, P., SMITH, H.M. (2014): Rethinking the relationship between flood risk perception and flood management. Science of The Total Environment, 478, 12–20.

BLÖSCHL, G., RESZLER, CH., KOMMA, J. (2008): A spatially distributed flash flood forecasting model. Environmental Modelling and Software, 23, 4, 464–478.

BORGA, M., ANAGNOSTOU, E.N., BLÖSCHL, G., CREUTIN, J.-D. (2011): Flash flood forecasting, warning and risk management: the HYDRATE project. Environmental Science and Policy, 14, 7, 834–844.

BRATH, A., MONTANARI, A., MORETTI, G. (2006): Assessing the effect on flood frequency of land use change via hydrological simulation (with uncertainty). Journal of Hydrology, 324, 1–4, 141–153.

BRAUER, C.C. (2014): Modelling rainfall-runoff processes in lowland catchments. PhD thesis, Wageningen University, Wageningen, The Netherlands, 98 p.

CZIGÁNY, S., PIRKHOFFER, E., FÁBIÁN, S.Á., ILISICS, N. (2010): Flash floods as natural hazards in Hungary, with special focus on SW Hungary. Riscuri si Catastrofe, 9, 8, 131–152.

De DOMINICIS, S., FORNARA, F., CANCELLIERI, U., TWIGGER-ROSS, C., BONAIUTO, M. (2015): We are at risk, and so what? Place attachment, environmental risk perceptions and preventive coping behaviours. Journal of Environmental Psychology, 43, 66–78.

De ROO, A., SCHMUCK, G., PERDIGAO, V., THIELEN, J. (2003): The influence of historic land use changes and future planned land use scenarios on floods in the Oder catchment. Physics and Chemistry of the Earth, Parts A/B/C, 28, 33–36, 1291–1300.

DUŽÍ, B. et al. (2014): The role of perception in adaptation to floods: the case study of Bečva River. In: Duží, B. et al. (2014): Environmental Change: Adaptation Challenges, Brno, Global Change Research Centre, 71 p.

eMS (2015): Meteorologický slovník výkladový a terminologický (eMS). Česká meteorologická společnost (ČMeS), verze eMS 1.2 (7/2015). [online] http://slovnik.cmes.cz/.

FF_EWS (2010): Flash Flood Early Warning System Reference Guide NOAA National Weather Service, International Activities Office/University Corporation for Atmospheric Research. Silver Spring, 204 p.

GRABS, W.E. (2010): Regional Flash Flood Guidance and Early Warning System. Training for Trainers. In: Workshop on Integrated approach to flash flood and flood risk management, October 2010, Kathmandu, WMO Climate and Water Department, Nepal, 24–28.

GROISMAN, P.Y., KNIGHT, R.W., EASTERLING, S.R., KARL, T.K., HEGERL, G.C., RAZUVAEV, C.N. (2005): Trends in Intense Precipitation in the Climate Record. Journal of Climate, 18, 1326–1350.

GRUNTFEST, E., HANDMER, J. (eds.) (2001): Coping With Flash Floods. In: Proceedings of the NATO Advanced Study Institute, Ravello, Italy, 8–17 November 1999, NATO Science Partnership Subseries 2, 77, 28, 1–322.

HUNTINGTON, T.G. (2006): Evidence for intensification of the global water cycle: Review and synthesis. Journal of Hydrology. 319, 83–95.

JENÍČEK, M. (2009): Runoff changes in areas differing in land-use in the Blanice River basin – application of the deterministic model. Journal of Hydrology and Hydromechanics, 57, 3, 154–161.

JONKMANN, S.N. (2005): Global Perspectives on Loss of Human Life Caused by Floods. Natural Hazards, 34, 151–175.

KEKEN, Z., PANAGIOTIDIS, D., SKALOS, J. (2015): The influence of damming on landscape structure change in the vicinity of flooded areas: Case studies in Greece and the Czech Republic. Ecological Engineering, 74, 448–457.

KIENBERGER, S. (2014): Participatory mapping of flood hazard risk in Munamicua, District of Búzi, Mozambique. Journal of Maps, 10, 2, 269–275.

KLEMEŠOVÁ, K., KOLÁŘ, M., ANDRÁŠKO, I. (2014): Using GIS in the flood management – flood maps (Troubky, Czech Republic). Geographia Technica, 9, 2, 44–53.

KOLEJKA, J., KREJCI, T., RAPANT, P., INSPEKTOR, T. (2015a): Regional and flash flood as a limiting factor for development. In: 18th International Colloquium on Regional Sciences, Hustopeče, Masaryk University, 611–618.

KOLEJKA, J., RAPANT, P., INSPEKTOR, T., BATELKOVÁ, K., ZAPLETALOVÁ, J., KIRCHNER, K., SMETANA, M., KREJČÍ, T. (2015b): Scénáře podpory krizového řízení geoinformačními technologiemi. Optimalizace aktivit při přívalové povodni, při ohrožení svahovými pohyby a toxické havárii na silnici a železnici. ÚGN AV ČR a VŠB-TUO, Brno, 204 p.

KOLEJKA, J., RAPANT, P., KREJČÍ, T. (2017): Hodnocení rizikovosti území obce pro případ přívalové povodně. In: Klímová, V., Žítek, V. (eds.) XX. mezinárodní kolokvium o regionálních vědách. Sborník příspěvků. Brno: Masarykova univerzita, 1–5.

KUBÁT, J. et al. (2009): Vyhodnocení povodní v červnu a červenci 2009 na území české republiky. Souhrnná zpráva. Praha, MŽP ČR/ČHMÚ, Praha, 165 p.

MARCHI, L., BORGA, M., PRECISO, E., GAUME, E. (2010): Characterisation of selected extreme flash floods in Europe and implications for flood risk management. Journal of Hydrology, 394, 1–2, 118–133.

McFADDEN, L., PENNING-ROWSELL, E., TAPSELL, S. (2009): Strategic coastal flood-risk management in practice: Actors' perspectives on the integration of flood risk management in London and the Thames Estuary. Ocean and Coastal Management, 52, 12, 636–645.

MICELI, R., SOTGIU, I., SETTANNI, M. (2008): Disaster preparedness and perception of flood risk: A study in an alpine valley in Italy. Journal of Environmental Psychology, 28, 2, 164–173.

Jeseník nad Odrou – flash flood in valley bottom.
Source: https://www.youtube.com/watch?v=xHh-JfhvWb0.

Heřmanice – during the flood at eve of day.
Source: OU Heřmanice.

Jeseník nad Odrou – new meander originated on the site of walled river bed.
Photo: J. Kolejka.

Heřmanice – during the flood at eve of day.
Source: OU Heřmanice.

Jeseník nad Odrou – new part of the village constructed for victims of flood on the elevated site. Photo: J. Kolejka.

Heřmanice – new children playground on the site of former living house.
Photo: J. Kolejka.

Radišov – small chapell restored after flood in the flat valley below the village.
Photo: J. Kolejka.

Roveň – no landuse changes happened along the creek housed in old artificial bed.
Photo: J. Kolejka.

MICU, M., CHENDEŞ, V., SIMA, M., BĂLTEANU, D., MICU, D., DRAGOTĂ, C. (2010): A multi-hazard assessment in the Bend Carpathians of Romania, In: Glade, T., Casagli, N., Malet, J.P. (eds.): Mountain Risks: bringing science to the society, Strasbourg, CERG Editions, 576 p.

MUNZAR, J. (2010): Examples of great cross-border floods in Central Europe and lessons learnt: (case studies of floods from september and november 1890 on the occasion of their 120th anniversary). Moravian Geographical Reports, 18, 4, 21–29.

NAEF, F., SCHERRER, S., WEILER, M. (2002): A process based assessment of the potential to reduce flood runoff by land use change.Journal of Hydrology, 267, 1–2, 74–79.

NOAA (2010): Flash Flood Early Warning System Reference Guide NOAA National Weather Service, Silver Spring, International Activities Office/ University Corporation for Atmospheric Research, 204 p.

POPELKA, S. (2011): Povodňové mapy na webu ČAP. [on-line]. [cit. 2013-03-28]. Available at: www.gisportal.cz/2011/08/povodnove-mapy-na-webu-cap.

PRICE, C. et al. (2011). The FLASH Project: using lightning data to better understand and predict flash floods. Environmental Science and Policy, 14, 7, 898–911.

RAHA, S. (2016): Cause and consequence of flood disaster in India. The journal of Bengal geographer, 5, 2, 67–78.

RAPANT, P., KOLEJKA, J. (2017): Dynamical Flash Flood Risk Forecast. In Lecture notes in geoinformation and cartography. Volume 1. Cham, Springer, 373–381.

RAPANT, P., INSPEKTOR, T., KOLEJKA, J., BATELKOVA, K., ZAPLETALOVA, J., KIRCHNER, K., KREJCI, T. (2015): Early warning of flash floods based on the weather radar. In: 16th International Carpathian Control Conference (ICCC), IEEE 2015, 27–30 May 2015, Miskolc, 426–430.

ROZALIS, S., MORIN, E., YAIR, Y., PRICE, C. (2010): Flash flood prediction using an uncalibrated hydrological model and radar rainfall data in a Mediterranean watershed under changing hydrological conditions. Journal of Hydrology, 394, 1–2, 245–255.

SHAW, R., PULHIN, J.M., PEREIRA, J.J. (eds.) (2010): Climate change adaptation and Disaster Risk Reduction: Issues and Challenges. Volume 4. Community, Environment and Disaster Risk Management. Emerald Book Publishing Ltd., Bingley, UK, 390 p.

SHIKHOV, A.N., BYKOV, A.V. (2014): Baza dannych ob opasnych i neblagopriyatnych yavleniyach pogody v Permskom kraye kak regionaľnyy analog ESWD. Geograficheskiy sbornik, 31, 4, 102–109.

SCHUMACHER, R.S., JOHNSON, R.H. (2008): Mesoscale Processes Contributing to Extreme Rainfall in a Midlatitude Warm-Season Flash Flood. Mon. Weather Review, 136, 10, 3964–3986.

ŠPITALAR, M., GOURLEY, J., LUTOFF, C., KIRSTETTER, P., BRILLY, M., CARR, N. (2014): Analysis of flash flood parameters and human impacts in the US from 2006 to 2012. Journal of Hydrology, 519, part A, 863–870.

THALER, T., LEVIN-KEITEL, M. (2016): Multi-level stakeholder engagement in flood risk management – A question of roles and power: Lessons from England. Environmental Science and Policy, 55, 292–301.

VINKE-DE KRUIJF, J., KUKS, S.M.M., AUGUSTIJN, D. (2015): Governance in support of integrated flood risk management? The case of Romania. Environmental Development, 16, 104–118.

WEHN, U., RUSCA, M., EVERS, J., LANFRANCHI, V. (2015): Participation in flood risk management and the potential of citizen observatories: A governance analysis. Environmental Science and Policy, 48, 225–236.

WHEATER, H., EVANS, E. (2009): Land use, water management and future flood risk. Land Use Policy. 26, Suppl. 1, S251–S264.