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Character and dynamics of the floodplain of the Losenice stream, Bohemian Forest

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Abstract
In this article, indicators revealing a rather high current activity of floodplain dynamics are presented. The evidence for the hypothesis comes from various sources – sediments study, morphology of the floodplain, channel shape, flood wave reconstruction, joint activity of slope and fluvial processes, and other direct or indirect signs of persisting valley floor dynamics. The combined outputs of these methods reveal a picture of a highly dynamic, rapidly changing part of the relief. These findings are particularly important in the light of recent catastrophic events, namely the 2002 flood, which brought significant morphological consequences and changes into the floodplain, and, simultaneously, caused severe, often unexpected or underestimated damage on human activities near the river channels.

Key words: floodplain, GIS delineation, flood consequences, valley floor dynamics, Losenice

Introduction

The floodplain is currently one of the most dynamically changing parts of the relief. It is, however, also a place where the activities of the society often clash with natural processes, particularly during extreme natural events (Křížek et al. in press).

To understand the development, changes and behaviour of the water courses in the valley floor it is necessary to employ a wide range of study methods and techniques, allowing enough data to be collected in order to accurately describe this dynamic system.

Area of interest

The Losenice catchment is situated in the Bohemian Forest (=Šumava Mts.) in southern Bohemia. It is one of the rivers draining the flat relief of the planation surfaces of the Šumavské Pláně plateau and on its 16 km long course towards N and NW steeply descends into the deeply incised valley of the main stream, Otava River (Fig. 1).

The most active segment of the valley under the Celtic site of Obří Hrad tower was chosen for this detailed study, where many traces of recent stream as well as slope dynamics were found. The valley is deeply incised (up to 150 m) with steep slopes and it has a rather narrow valley floor (Fig. 2).

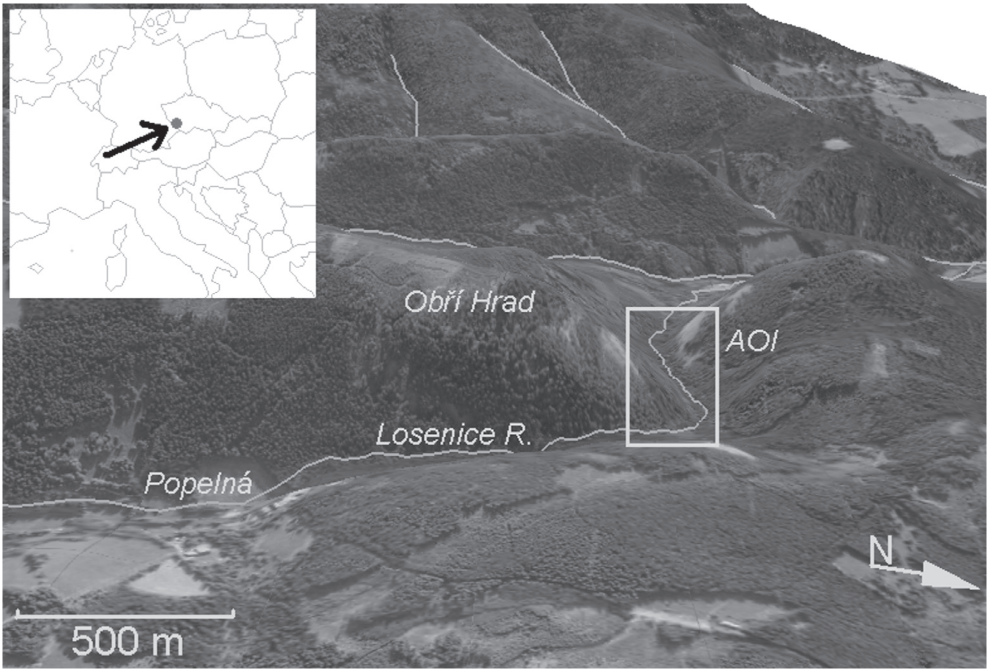

Fig. 1. Location of the area of interest in the middle valley of the Losenice stream. Inset map shows its position in Central Europe, AOI - the area of interest.

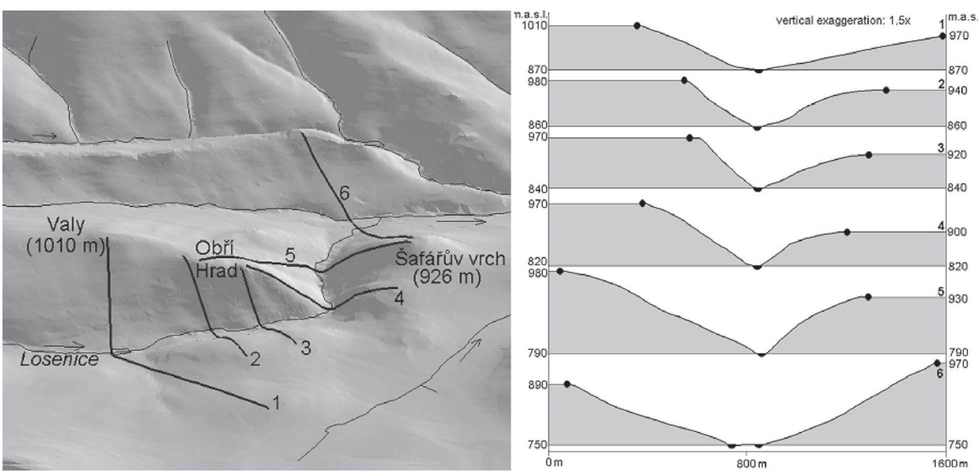

Fig. 2. Series of transverse profiles across the AOI, the narrowest part of the Losenice valley under the Obří Hrad site.

Automated floodplain delineation

Delineation of the floodplain using GIS software has recently become a widespread technique (see e.g. Townsend & Walsh 1998, Andrysiak & Maidment 2000, Gallup 2005), which has, admittedly, its limits and dangers (Horritt & Bates 2001, Noman et al. 2003).

Table 1. Classification matrix for the success rate evaluation of the automated floodplain delineation. Explanations: The raster is divided into 4 categories, where 1 is always the floodplain and 0 no floodplain, in rows according to the model, in columns according to the mapping.

	mapping 1	mapping 0
model 1	correct – 1 (floodplain)	overestimated in the model
model 0	underestimated in the model	correct – 0 (no floodplain)

Table 2. Comparison of success rates of floodplain delineation for the Sázava River and Losenice stream. S = Sázava River (474 954 pixels), L = Losenice stream (8448 pixels); columns 5 and 6 show the percentage of total success rate, columns 7 and 8 show the success rate if we do not take into account the records in the row correct/no (because this value depends on the crop area size, thus biasing the results).

1	2	3	4	5	6	7	8
	S	L		S	L	S	L
	%	%		%	%	%	%
correct / no	53	76	correct	81	85	59	36
correct / yes	28	9					
wrong / overestimated	18	2	wrong	19	15	41	63
wrong / underestimated	2	13					
sum	100	100		100	100	100	100

For the purpose of the delineation of the morphometrically defined floodplain a DEM (digital elevation model) was constructed based on the contour line layer from the Zabaged (2006) 1 : 10 000 (contour line interval 5 m), and a layer of streams also from ZABAGED. The DEM was treated in ArcHydro Tools and turned into AgreeDEM, a smoothened raster with the continuous flow path solution. From the AgreeDEM a raster of slope inclination was derived. Finally, we constructed a DEM from interpolation of the 3D river channels. This DEM raster was subtracted from the relief DEM, thus giving a raster of relative heights above the channel network. Based on the distribution of the relative altitude with a significant peak at 0.8 m above the channel, the value of 1.6 m was taken as a threshold. For the reverse control with the field-mapped floodplain, the raster of floodplain was divided into four classes (Table 1).

The resulting grid map is depicted in Fig. 3. However, if we compare real values of reliability for two different streams, we can observe the influence of the scale on the accuracy. Here the comparison table (Table 2) shows the automated floodplain delineation results for two streams – the rather large Sázava River (213 km, data taken from a 60 km long segment) and our target area, the Losenice stream (16 km, a 1 km segment under the Obří Hrad).

With the decreasing size of the stream in question and growing detailness of the study, the same data source becomes practically useless. In other words, we move into the scale where "meters matter". Therefore, to delimit the floodplain accurately enough to study the valley bottom dynamics the DEM based on this data is far from sufficient – and as we could have seen from the horizontal profiling, it is not only the DEM that is not accurate enough: also the lines of the stream layer are in some places almost 25 m displaced compared to detailed measurement results (Fig. 4). The message is therefore clear – it was necessary to find another, more accurate means for floodplain delineation.

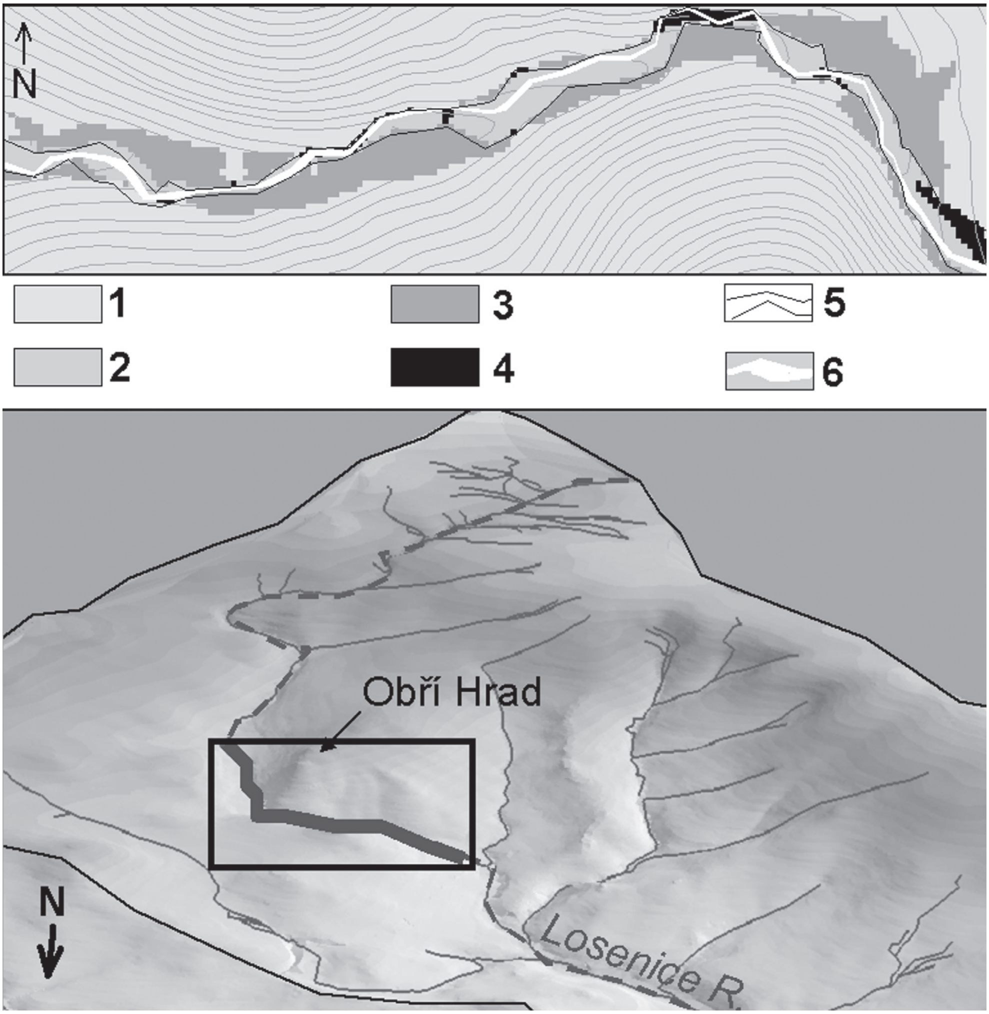

Fig. 3. Cropped raster showing the results of the automated floodplain delineation (top): 1 – no floodplain in both model and mapping, 2 – floodplain in both model and mapping, 3 – overestimated by the model, 4 – underestimated by the model, 5 – mapped extent of the floodplain, 6 – Losenice stream channel. Position of the AOI in the catchment of Losenice stream (bottom).

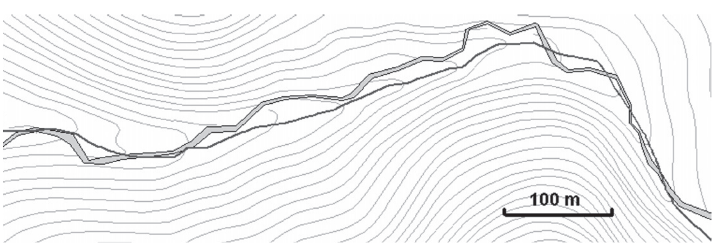

Fig. 4. The difference between the accurately mapped course of the stream (grey line with black rim) and the ZABAGED layer of streams (full black).

The floodplain profiling

Among the indicators showing the degree of the channel activity, longitudinal as well as transverse profiles of the valley play an important role. Quite often these simple morphological signs are the first beacons drawing attention to the interesting localities (Hayakawa & Oguchi 2005). This is due to the simplicity of profile construction (which has become more important with the spread of digital data and GIS software) together with their explicitness for certain morphological indicators, such as knickpoints in the longitudinal profile or the scarps of landslides.

This is also the situation of the Losenice valley under the Obří Hrad. It was detected in a general paper concerning the longitudinal profiles of selected rivers in the Bohemian Forest (Hartvich 1999) that a significantly steeper segment is situated in this area. The first observation was further developed at a more detailed scale (Hartvich 2005b), when the original cartometrical profiling was complemented by detailed geodetical profiling (Fig. 5).

A further stage of the research of this valley segment was closely related to the afore mentioned detailed longitudinal profiling. It consisted of detailed horizontal profiling, complemented by valley floor transversal profiling. There were several objectives:
- to map exact position and shape of the river channel (including the braiding, abandoned channels, etc.) within the valley floor;
- to map exact position and shape of the floodplain;
- to map exactly the fluvial as well as deluvial or fluviodeluvial accumulations within the valley floor;
- to assess the relation between channel and slope dynamics.

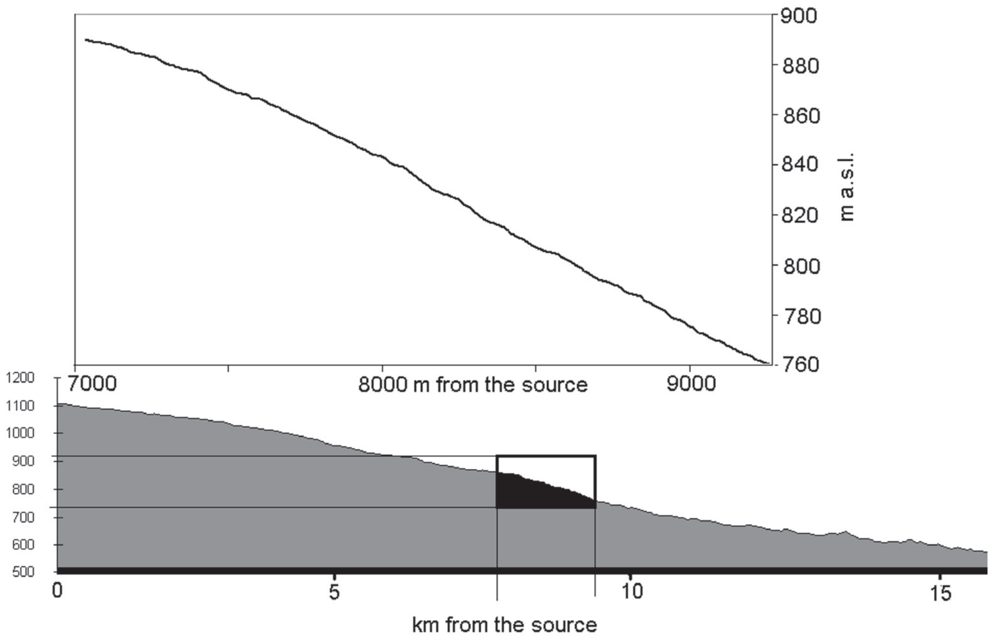

Fig. 5. DEM generated longitudinal profile of the Losenice stream, showing the position of the cropped detail (bottom) and accurate longitudinal profile of the segment under the Obří Hrad site, created with the laser range finder (top).

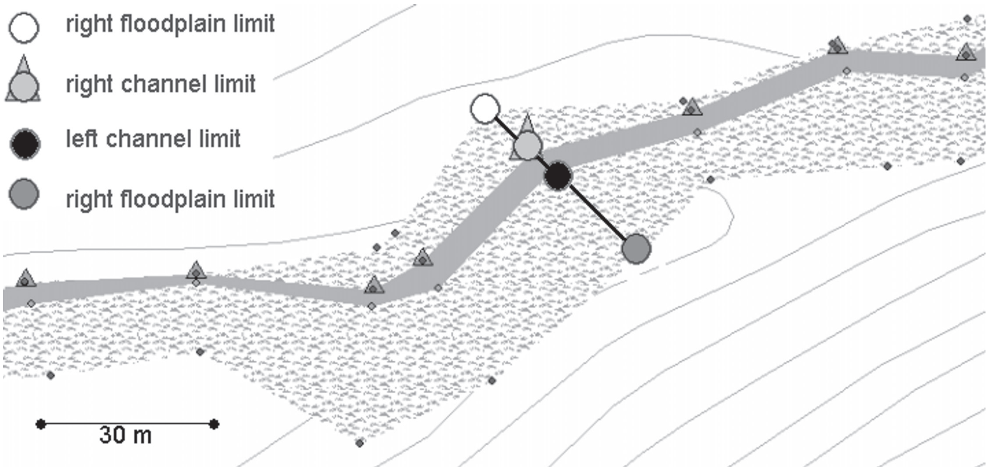

Fig. 6. Example of the detailed profiling of the valley floor showing the limits of the channel and floodplain.

Aside from these chief aims, it showed that, from the techniques, it was also possible to draw by-product information, such as the assessment of the reliability of the most detailed existing topographical map 1 : 10 000, the possibility of calculating discharge volumes in accurate profiles during the flood (in combination with flood consequences mapping performed in 2003), or the construction of rough consumption curves and thus assess the approximate reach of a flood for a given discharge.

The technique of profiling was simple enough, yet considerably accurate. Using a laser range finder (MDL LaserAce) for distance and an accurate compass for bearing, a polyline was constructed. All the track points were placed exactly on the right side of the channel. At each of the track points, a transversal profile across the valley floor was measured, recording all the morphologically significant knickpoints, and particularly both channel and floodplain limits (Fig. 6).

The beginning of the measured track was placed on a footbridge, thus it can be easily embedded into the map. A parallel series of GPS points was also collected; however, their accuracy is dubious, particularly in the narrow incised valley, covered with dense forest.

Floodplain in flood

In August 2002, almost the whole southern part of the Czech Republic was hit by one of the largest floods ever recorded. It was caused by two strong frontal systems passing over the region, and, therefore, the resulting runoff response was extreme because of the saturation of the river basins after the first flood wave. On the Losenice stream, the flood wave was rather strong and violent, changing its path in the valley floor and on the lower course, where some artificial structures were built, causing severe damage, including complete destruction of an 800 m long segment of road (Hartvich et al. 2006).

The construction of a series of detailed transverse profiles allowed reconstruction of the approximate flood discharge. Simplified channel profiles were used for the construction of consumption curves. The approximate watercourse velocities were taken over from a study by Blažek (2006), where the author gives values for the upper Otava catchment as follows:

- channel velocity 1.5–3 $m.s^{-1}$,
- floodplain velocity 1–1.5 $m.s^{-1}$.

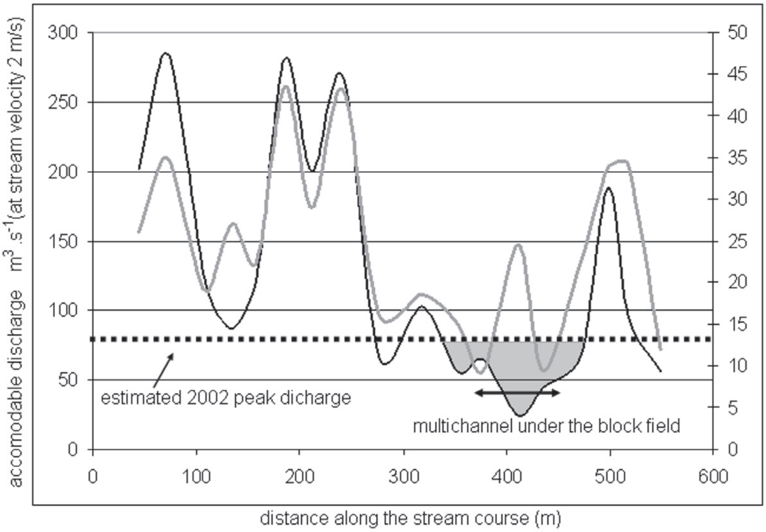

Fig. 7. Correlation between the discharge volume, which can fit into each profile (black line), and the flood-plain width (grey line). The grey area indicates overspill in 2002.

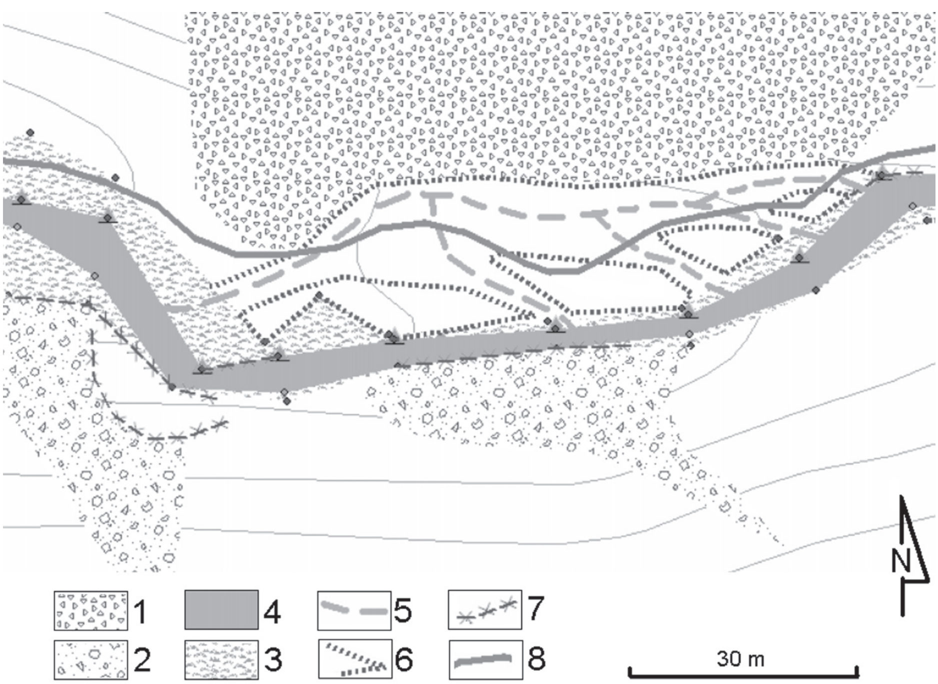

Fig. 8. Example of the detailed profiling of the valley floor showing the braided "multichannel" under the block field at the Šafářův Vrch hill, which was activated during the 2002 flood. 1 – block field, 2 – landslide accumulations, 3 – "regular" floodplain, 4 – Losenice channel, 5 – potential flood channels, 6 – potential floodplain limits, 7 – bank scours, 8 – touristic path.

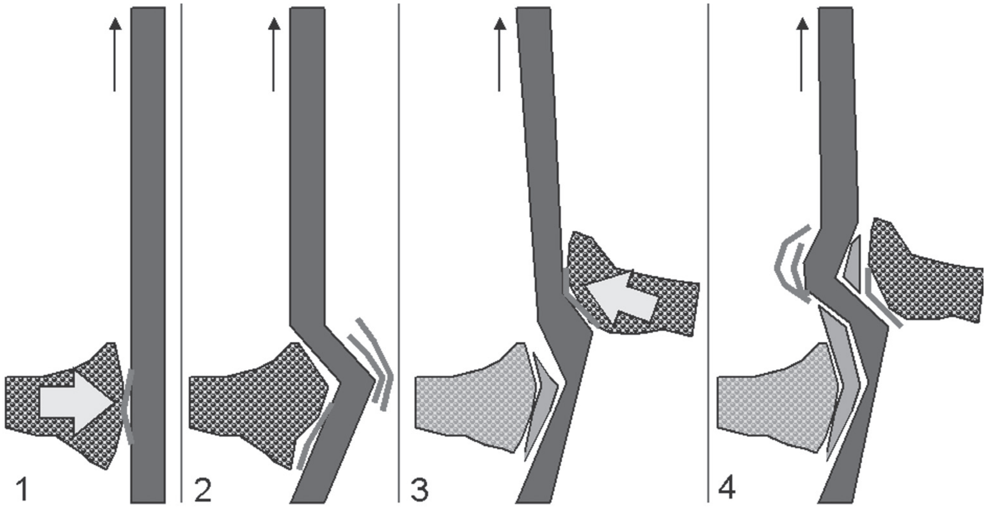

Fig. 9. Schematic illustration of the joint action of the fluvial and slope processes in the valley floor: 1, 2 – left bank landslide accumulation pushes the channel towards the right bank, 3 – undercutting and bank scouring contributes to the activation of a landslide on the right bank, 4 – the process continues downstream, creating forced curves.

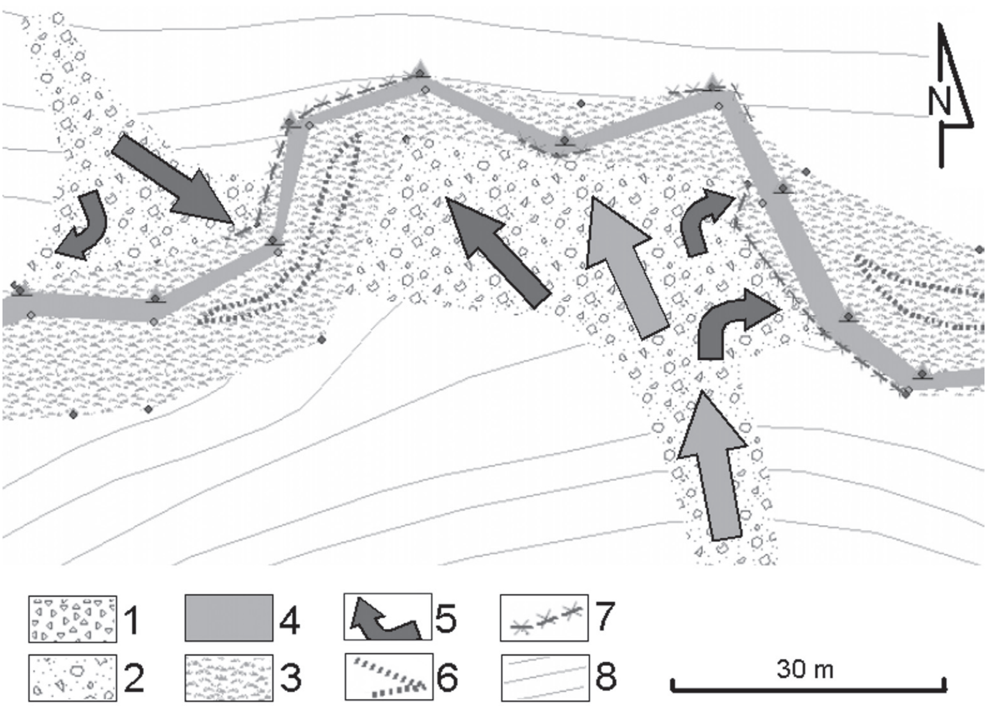

Fig. 10. Real situation of the joint action of the fluvial and slope processes in the valley of the Losenice stream: 1 – block field, 2 – landslide accumulations, 3 – "regular" floodplain, 4 – Losenice stream channel, 5 – direction of the slide movement, 6 – potential floodplain limits, 7 – bank scours, 8 – contour lines.

Using the field-collected data on the flood reach (height above the normal water level), it was possible to calculate approximately the discharge at each profile. Unfortunately, there is so far no measuring gauge at the Losenice stream and, therefore, they are only estimates. From the consumption curves it seems that possible discharge at the culmination might have been between 60–75 $m^3.s^{-1}$ in this middle segment of the catchment, which might correspond well to the estimates of 120–150 $m^3.s^{-1}$ as the contribution of the Losenice stream to the total of 350 $m^3.s^{-1}$ (100-year recurrence period, estimated) on the measured profile in Sušice (Kudrnová et al. 2004).

As already mentioned, the floodwater height was recorded along the stream during the mapping of flood consequences in 2003. Its height above normal water level varied along the course, generally the depth of floodwater increases along the stream, together with growing discharge. Nonetheless, a dependence on the character of the channel and width of the floodplain exists as well. In the scope area of this article – the valley segment under the Obří Hrad site – the changes in the volume of the floodplain were observed on the measured profiles. The results are in Fig. 7. It is clear that there are some places along the segment where the channel cannot accommodate the discharge, estimated for the 2002 event and the water spills across the valley floor. A typical example may be found under the well-know block field on the Šafářův Vrch hill, between approximately 300–500 m of the mapped segment. It is clear from the detailed plan (Fig. 8) that the multichannel riverbed may be activated in the event of bigger floods. This presumption was confirmed by the presence of fresh flood sediments as well as of other flood traces, found during the 2003 mapping.

River channel dynamics and slope activity

The detailed geomorphological mapping together with accurate profiling allowed an interesting hypothesis to be formulated on the joint activity of the slope and fluvial processes on the shaping of the narrow valley floor. The idea came originally from the correlation of the position of the landslide accumulations and the horizontal curving of the channel.

The model (Fig. 9) shows in several steps the forced meandering of the channel caused by the pressure of the developing slope movement accumulation. A similar situation was actually found in two places in the valley of the Losenice stream under the Obří Hrad site (Fig. 10).

Floodplain sediments

Floodplain sediments study was also one part of the complex geodynamic research in the catchment of the Losenice stream. Up to date, soil probing (1 m) and two dug probes were performed in the floodplain, particularly above the possibly most recent slope movement accumulation, which might have blocked the narrow valley floor.

Anticipated lake sediments have not yet been found, there are, however, other interesting findings. In dug probe No. 2, almost 110 cm deep, measuring 150×120 cm, under various flood events sandy sediments and some fluviodeluvial gravels (only slightly rounded blocks up to 40 cm in the longest axis) at a depth of almost 80 cm, several well-rounded, water transported pieces of brick (Fig. 11) were found.

There is only one possible source of the brick – the village of Popelná, nowadays only consisting of two hotels and a few cottages, but at the beginning of the 20th century a blooming village with over 30 houses, a church, and a school (Vinická, pers. comm.). The oldest constructions in the village originated approximately 300 years ago, thus pinpointing the oldest possible period of the said sedimentation. Hence the 80 cm of sediments in the probe,

Fig. 11. A photo of the biggest piece of brick, found in a dug probe 80 cm deep. Notice the almost perfect roundness after merely 600 m transport.

which is located some 25 m from the channel, i.e. rather far in the floodplain, must have accumulated within last three centuries.

During the flood consequences mapping in June 2003, the occurrence of flood sediments as well as channel changes were recorded. To assess the rapidity of the changes, the mapping was repeated in August 2004. Among the most surprising results was the intensity of channel reshaping in the artificially deepened segments of the channel. While in 2003, after the deepening, the channel had a regular V-shaped profile, one year later the channel returns to its natural irregular shape (Fig. 12). Also the biotic succession processes are very fast, covering and reshaping the flood sediments as well as abandoned channels.

Conclusion

To us summarize the most important observations supporting the hypothesis of the current, highly intensive dynamics of the Losenice valley:

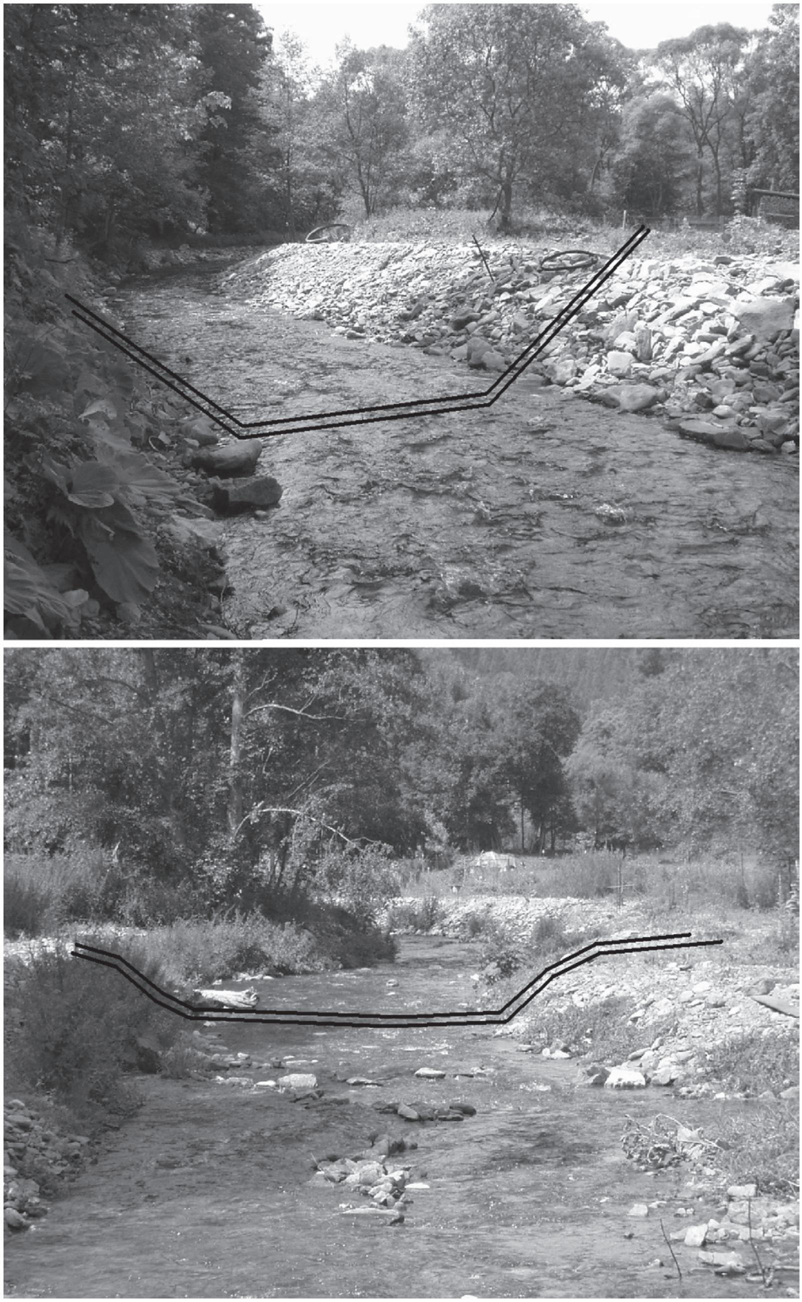

Fig. 12. A photo of a freshly mechanically deepened segment of the Losenice stream from summer 2003 (9 months after the flood, top – notice sharp shapes of the profile) and the same river segment from summer 2004 (bottom) – the channel profile is becoming once again shallower and the removed material is creeping back into the channel.

(i) rough, not well worked boulders, are buried deep in the floodplain sediments;
(ii) high intensity of transportation during singular events is also illustrated by the finding of the fluvially worked bricks under 80 cm of the flood sediments far from the channel, younger than 300 years;
(iii) coincidence of occurrence of steeper and forced meandering channel segments;
(iv) rather young slope movements with apparent accumulation bodies;
(v) on-going influence of these slope movements on the forced meandering of the river channel;
(vi) the calculated channel and floodplain volume corresponds roughly to the estimates of the 2002 flood volume as well as to the mapped traces of the floodwater height – the 2002 flood was an eminent, though not unique event.

Throughout the article, many indicators pointing towards the high current activity of the floodplain dynamics are presented. What is important is that the evidence comes from various sources – sediments study, morphology of the floodplain, channel shape, flood wave reconstruction, collaboration of slope and fluvial processes, etc.

This article deals with the dynamics of the valley floor, however, there are other direct or indirect signs of persisting dynamics higher on the valley slopes. A three-year record of dilatometric measurements indicates continuing movements in the range of mm per year (Hartvich 2005a, Zvelebil & Hartvich 2006). There are also remnants of scarps of landslides, possibly damaging the Celtic fortifications on the NE slopes. If this is the case, the age of the slide should be less than the Halstatt, i.e. 2500 BP (Slabina 2005) – though, there are though, only very small remnants of the slide accumulation. It is therefore likely that the accumulation had already been removed by the erosive activity of the Losenice stream.

From the above it is clear that the shaping and development of the Losenice stream valley is still active and of rather high intensity. This is, however, only a qualitative statement. The next logical step should therefore be an attempt to quantify the valley floor dynamics. The plan includes installing a measuring profile with automatic discharge data logging at the confluence of the Losenice stream with the Otava River, a series of hydrometric bars at the tributaries and in the future also a sediment trap for the assessment of the sediment load, removed from the catchment.

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