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Stream Transformation Index as an Identification Tool for the River Network Critical Elements from the Viewpoint of the Flood Risk

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Abstract

Intensity of transformation of the river network and of the floodplain represents a significant factor that influences the outflow process during floods. Influence of anthropogeneous interventions in the river network and in the floodplain area consists especially in affecting of the flood wave course, of the floodplain transformation effect, and of efficiency of the territory retention potential usage.

The paper presents a quantitative method for analysis and evaluation of the intensity and structure of anthropogeneous transformation of the river network and its spatial distribution. The source materials for the evaluation are represented by terrain mapping that provides basic information on the watercourses transformation nature and the riparian zonein individual indicators. The Stream Transformation Index is derived based on them subsequently, allowing for overall quantitative evaluation of the river network transformation intensity, and identification of critical elements in the river network from the viewpoint of potential affecting of the course and consequences of floods. The nature of the evaluation allows, at the same time, to compare the river basins with different physical-geographic indicators and the floods consequences.

The methodology has been applied to the Sázava river basin in the Czech Republic, hit by the extreme flood from snow melt in 2006.

1. Introduction

In the course of the decade at the turn of the 20th and 21st centuries, the territory of the Czech Republic, as well as other European regions, were hit by repeated devastating floods, some showing extraordinary extremity. The total damages caused by these events were huge. As for the territory of the Czech Republic only, the floods from the beginning of the 90s of the 20th century caused direct as well as induced damages exceeding the amount of CZK 150 billion, while the damages caused by other natural extremes, such as dry climate, strong wind, landslides etc. even increased this amount considerably.

The unprecedented extent of damages caused by these processes as well as their repeated occurrence have raised questions asking in what extent these events have been affected by the anthropological changes in the landscape. In respect to the social urgency of these problems, new approaches and methods have been developed, at the same time, allowing to identify potentially critical elements in the landscape that, in respect of their condition or nature of usage may worsen the course of the floods.

In respect to the advancement of knowledge in the fields of hydrology and landscape ecology and in respect of possibilities of mathematical modelling methods usage, gradual change of the paradigm in the field of anti-flood protection started to occur, at the same time. The formerly dominant structural approach has been gradually replaced by an integrated view that combines technical measures with measures supporting water retention in the river basin and more efficient transformation of the floodwave in the alluvial plain.

However, quantitative basis evaluating the current condition of watercourses and the floodplain or intensity and nature of their anthropogeneous transformation, respectively, is missing for such approaches.

The paper presents new methodology of evaluation of the watercourses and floodplain adaptation, based on terrain mapping, and subsequent classification of transformation in selected indicators. The Stream Transformation Index has been derived from analytical indicators values of the watercourse transformation and in individual transformation aspects, and the data used serve subsequently to identify potentially critical elements in the river network system. These elements represent segments of watercourses and the floodplain which, based on the transformation nature and structure, represent places with a potentially increased risk of occurrence of destructive effects of the floods.

2. Material and Methods

2.1 Methodology of the Evaluation

Data for the analysis and classification are obtained by field mapping of transformation of the watercourses and consequences of floods. The methodology MUTON (Langhammer et al., 2005) is used for this purpose, developed for mapping in regions hit by extreme floods.

The mapping principle stems from division of the watercourse into partial segments of variable length. The segments borders are chosen in such a manner so that the segment created is homogeneous in one of the key parameters at least, namely: The river bed route course, transformation of the river bed, usage of the riparian zone. Typical length of the segment is 100–500 metres, however, it may change significantly according to the relief nature and landuse. The segment borders, together with the segment code, are marked in the map and digitized subsequently in order to allow interconnection with qualitative information on the rate of adaptation, recorded in forms.

Transformation intensity in individual parameters is recorded in a form. The form is digitized subsequently and evaluated in the GIS environment, together with further hydrological, geomorphological or socio-economic characteristics of the territory.

The total of 13 analytical indicators is mapped, describing various characteristics of the watercourse environment, its adaptation, and identified consequences of the flood (Langhammer et al., 2005). The analytical indicators values obtained by means of terrain mapping are recoded subsequently in such a manner so that synthetic indicators of the watercourse transformation can be derived from them, and so that critical elements of the river network can be identified.

2.2 Analytical Indicators

Three groups of indicators are distinguished among analytical indicators, which provide different informative value and different usage in the evaluation, and the processing of which requires a different approach. They are the *intensity*, *identification*, and *informative* indicators.

2.2.1 Intensity Indicators

These are indicators of transformation and consequences, in which individual partial parameters can be evaluated pursuant to intensity of their potential influence on flowing when a flood occurs. Individual indicators assessed are significant, from the viewpoint of the flood risk system (Langhammer, 2006), concerning the possibility to influence flowing during flood conditions and concerning the influence of the floodwave transformation when passing through the given river basin.

In order to evaluate these indicators, points from a uniform scale are assigned to individual parameters, used subsequently to calculate the flow transformation indexes derived. Intensity indicators are evaluated by means of a single numerical value for the whole segment; as for the riparian zone, the evaluation is performed separately for the right and left bank.

Intensity indicators include:

– Watercourse route modification
– Longitudinal profile modification
– River bed modification
– Riparian zone modification

Partial parameters of the selected indicators including point evaluation are summarized in Table 1.

Parameters evaluating the river bed route adaptation, the river bed longitudinal profile adaptation, are significant especially from the viewpoint of affecting the flow speed in the river bed. On the contrary, the nature and intensity of the riparian zone usage represents an important indicator from the viewpoint of efficient usage of the transformation and retention potential offered by the alluvial plain.

Tab. 1 Transformation intensity indicators.

Watercourse route transformation (T_T)			Longitudinal profile transformation (T_L)		
Code	Parameter	Points	Code	Parameter	Points
1	branched	1	**1**	Segment without vertical obstacles	1
2	meandering	2	**2**	Naturally low steps in the bed	2
3	Naturally sinuous	3	**3**	Naturally high steps in the bed	3
4	Naturally straight segment	4	**4**	Low weir (up to 1 m)	3
5	Bends with signs of straightening	4	**5**	Terraced weir, slide	3
6	Straightened segment	5	**6**	High weir (over 1 m)	4
7	Revitalized segment	2	**7**	Dam	5

River bed transformation (T_B)			Riparian zone usage (T_F)		
Code	Parameter	Points	**Code**	Parameter	Points
1	Natural bed without signs of adaptations	1	**1**	Forrest	1
2	Vegetative fortification, wooden logs	2	**2**	Meadow or pasture	2
3	Bank reinforced by stone sprinkling	3	**3**	Arable land	3
4	Bank or bottom reinforced by grass-concrete pavement	3	**4**	Left arable land	2
5	Bank or bottom reinforced by tiles or concrete	4	**5**	Gardens	3
6	Continuous concrete reinforcement of the bank and bottom	4	**6**	Scattered built-up area	4
7	Piping-in	5	**7**	Urban area	5
			8	Industrial area	5

2.2.2 Identification Indicators

Identification indicators reflects features assessed by the occurrence from the viewpoint of the position, structure, and frequency (Table 2). Together with intensity indicators, identification indicators represent fundamental building stones of subsequent evaluation.

Identification indicators include:

– Potential flow obstacles during floods
– Geomorphological evidences of the flood
– Flood damages

Identification of potential flow obstacles during floods represents an extraordinarily important indicator the meaning of which rises steeply especially in floods with high extremity (Langhammer, 2004). Individual types of potential obstacles have been derived from experience from terrain mapping consequences of floods (Křížek, Engel, 2003).

Tab. 2 Indicators of overflowing and consequences of floods.

Potential flow obstacles during floods	Geomorphological manifestations of the flood	Flood damages
1. Bridge 2. Culvert 3. High weir 4. Obstacle in the bed 5. Buildings in the alluvial plain 6. Road / railway track embankment across the alluvial plain 7. Another obstacle	1. Without consequences in the bed and riparian zone 2. Small bank tears (up to 5 m of the bank length) 3. Extensive bank tears (over 5 m of the bank length) 4. Slides caused by the flood 5. Small fluvial accumulations (up to 100 m^2) 6. Extensive fluvial accumulations (over 100 m^2) 7. Replacement of boulders or large volume of mass 8. Creation of a new bed	1. Damage or destruction of buildings in the alluvial plain 2. Damage or destruction of bridges 3. Damage or destruction of weirs 4. Damage or destruction of communications in the alluvial plain

The nature of geomorphological effects of the flood and damages to property and infrastructure is represented by an indicator allowing, based on apparent manifestations and consequences of the last flood event, to determine the nature of damages in the watercourse segment evaluated, as well as the prevailing nature of geomorphological processes acting during the flood within the floodplain area. To be able to evaluate these parameters, a limiting precondition is represented by the possibility to identify the flood manifestations within the terrain. This possibility is dependent on the time delay of mapping after the flood, while experience from terrain mapping show that traces after flood events disappear from the landscape very rapidly, and that the maximum time delay to capture the majority of the flood manifestations is represented approximately by 3 years (Vilímek et al., 2003).

2.2.3 Informative Indicators

Informative indicators contribute additional information to the evaluation, used in the analysis and typology of the watercourses and floodplain environment transformation and of the floods consequences. This information is also important for detailed evaluation performed in the selected segments, especially in classification of critical segments and in identification of segments potentially suitable for overflowing in the alluvial plain. The following indicators have been included in this group:

– Floodplain width
– Bed width
– Bed depth
– The nature of bank vegetation
– Retention potential of the floodplain
– The extent of the flood spill

Informative indicators are conceived in such a manner so that they allow to evaluate the basic size parameters of the watercourse and of the alluvial plain, and other additional information without the need of geodetic surveying. These indicators (Table 3) are used in evaluation of geomorphological manifestations typology as well as the watercourses transformation as a factor that allows to analyze the parameters evaluated in relation to the size categories of the watercourse and the floodplain.

Tab. 3 Indicators of the nature of the floodplain and the river bed.

Floodplain width	Bed width	Bed depth	The nature of overflowing during the flood	The nature of bank vegetation	Retention potential of the alluvial plain
1. Floodplain not developed 2. Up to 10 m 3. 10–50 m 4. 50–200 m 5. 200–500 m 6. 500 m and more	1. Up to 1 m 2. 1–2 m 3. 2–5 m 4. 5–10m 5. 10–20 m 6. 20 m and more	1. Up to 0.5 m 2. 0.5–1 m 3. 1–2 m and more	1. Water has not left the river bed 2. Overflowing only within anti–flood banks 3. Overflowing into close riparian zone (up to 50 m from the bed) 4. Extensive overflowing into the floodplain with the level height up to 1 m at the river bed 5. Extensive overflowing into the floodplain with the level height higher than 1 m at the river bed	1. Bank without vegetation 2. Individual trees 3. Groups of trees and bushes 4. Band of vegetation along the watercourse 5. Wood	1. Left meander / / watercourse branch 2. Swamp 3. Polder 4. Anti–flood bank 5. Natural or artificial depressions in the alluvial plain 6. Water reservoirs in the alluvial plain

2.3 Synthetic Indicators

Synthetic indicators are derived from basic analytical indicators in order to allow complex evaluation of intensity and structure of the river network adaptation, and to allow mutual comparison of regions with different natural and socio-economic conditions.

The following is evaluated as basic synthetic indicators:

– Stream Transformation Index
– Critical elements of the river network

2.3.1 The Stream Transformation Index

The Stream Transformation Index represents a basic synthetic indicator that evaluates the total intensity of transformation of watercourses and alluvial plains. It is derived based on point evaluation of transformation intensity in individual parameters.

Calculation of the transformation index (I_T) is based on consegment calculation in the following steps:

1. *Determining of transformation values for the main intensity indicators within one segment.* The watercourse route transformation (T_T), the watercourse longitudinal profile transformation (T_L), the bed transformation (T_B), and the riparian zonetransformation (T_F) are included among the main intensity indicators. Values of all the intensity parameters evaluated are found on the same scale in the range of 0–5 points.
2. *Calculation of the segment transformation index.* The segment transformation index value I_{TE} is derived within one segment as the arithmetic average of transformation values of main intensity indicators (1). An alternative expression is represented by expressing the accumulative value of transformation within one segment I_{TEC} (2).

$$I_{TE} = \frac{T_T + T_L + T_B + T_F}{4} \tag{1}$$

$$I_{TEC} = T_T + T_L + T_B + T_F \tag{2}$$

where:
I_{TE} segment transformation index
I_{TEC} accumulated segment transformation index
T_T watercourse route modification
T_L longitudinal profile modification
T_B river bed modification
T_F riparian zone modification

3. *Calculation of the Stream Transformation Index.* The total transformation index I_T, or the accumulative transformation index I_{TC}, respectively, is derived based on the calculated values of the segment transformation index for the watercourse or basin, respectively, under evaluation.

   The transformation index I_T value is calculated as the ratio between the sum of values of the segment transformation index I_{TE} (3).

   The accumulative transformation index I_{TC} is calculated as the sum of values of the segment accumulated transformation index I_{TEC} values (4).

$$I_T = \frac{\sum_{i=1}^{n} I_{TE}}{n} \tag{3}$$

$$I_{TC} = \frac{\sum_{i=1}^{n} I_{TEC}}{n} \tag{4}$$

where: I_T Stream Transformation Index
I_{TC} watercourse accumulated transformation index
I_{TE} segment transformation index
I_{TEC} segment accumulated transformation index
n number of segments evaluated

2.4 Identification of Critical Elements of the River Network

Identification of critical segments is based on multicriterial evaluation of intensity and structure of the river network transformation in multiple indicators.

The threshold criteria for critical segments identification were chosen based on experience with evaluation of flood consequences of extreme floods in 1997 and 2002. The following was chosen as conditions to identify critical elements in the river network system:

- *Occurrence of critical types of flow obstacles*
  Based on evaluation of extreme flood events it shows that objects such as high weirs, culverts, bridges, track embankments represent elements that worsen locally the course and consequences of the floods, and their existence in the floodplain is thus viewed as potential risk in the relationship.
- *Critical intensity of the watercourse modification*
  Mild forms of the watercourse anthropogeneous adaptations usually do not represent a significant risk element by themselves, and they usually affect the flood course in a limited extent (Langhammer, 2004). On the contrary, the concurrence of intensive transformation forms in multiple parameters within one segment represents a factor that manifests itself negatively under suitable conditions in acceleration of run-off during the flood, in reduction of the transformation effect, and in acceleration of geomorphological manifestations of the flood in the alluvial plain. The watercourse segment accumulated transformation index I_{TEC} has been chosen as the critical transformation intensity parameter, exceeding the value of 16.
- *Unsuitable structure of the watercourse route modification*
  Localities where adapted and non-adapted watercourse segments alternate, or places where the adapted and straightened watercourse is led into a naturally meandering or wavy segment, respectively, represent places with increased concentration of erosive, accumulation, as well as destructive manifestations of the flood. These localities are therefore considered as potentially critical localities within the evaluation.
- *Urban or industrial areas in the floodplain*
  Urban areas and industrial plants usually represent places with extraordinary economic and cultural value, and at the same time, places of direct endangering of the inhabitants.

The identification of critical segments is performed based on classification of the mapping results geodatabase in the GIS environment where the results are subsequently verified by means of comparison with the terrain investigation results, with aerial images or other supporting materials.

2.5 Study Area

The methodology has been applied to the Sázava river basin. This region was hit by the extreme spring flood at the turn of March and April, 2006. It was the most extensive flood from snow melting in the Elbe river basin during the last 60 years. Peak flows within the region evaluated reached the recurrence period of 20–50 years. However, flows of this extremity level did not occur during the entire 20th century here, not even during the flood in August, 2002.

The evaluation was performed on the upper river basin of the watercourses Sázava, Šlapanka, Sázavka, and main tributaries of Sázava up to as Zruč nad Sázavou, on the Blanice river basin, and on the lower stream of Sázava from Čerčany to the confluence with Vltava. The total of 620 km of the watercourses length and the floodplain were evaluated.

For the purpose of the analysis, this region was divided into five partial balance river basins, differing from each other by physical-geographic conditions, by the landuse of the region as well as by the course and consequences of the flood in 2006.

– Headwater area of Sázava, representing the river basin from the source to Havlíčkův Brod;
– River basin of upper Sázava, Šlapanka, and Sázavka;
– River basin of central Sázava in the area between Světlá nad Sázavou and Zruč nad Sázavou;
– Blanice river basin;
– Lower stream of Sázava from the city of Sázava to its entry point into Vltava.

3. Results

3.1 Transformation of the River network and Alluvial Plain

Transformation of the watercourse route reflects the most marked anthropogenic interventions in the structure of watercourses – interventions in the river network geometry. Segments of watercourses where traces of watercourse route modification are identified usually also show other traces of transformation that accompany the watercourse route modification. This concerns especially modifications of the cross profile geometry through the river bed as well as artificial steps in the river

Fig. 1 Deep valley of Sázava River on the down course does not allow important anthropogenic transformation in terms of stream route or riverbed modification. However the weirs and natural steps in the riverbed occur frequently in this part of the river. Photo M. Raudenský, 2006

bed that compensate increased slope of the watercourse caused by straightening of the river bed.

In the part of the Sázava river basin under evaluation, watercourse route modifications can be seen especially in the upper part of the watercourse and on small tributaries. In respect of specific morphological conditions, there is minimum occurrence of apparent modifications of the river bed on the lower part of the watercourse. Out of the partial river basins evaluated, the watercourse modification intensity is the highest in the Šlapanka river basin, the lowest on the central and lower part of Sázava and on the central and lower part of Blanice (Figure 3).

A significant factor affecting the course and consequences of floods is represented by *flow obstructions* and modifications of the watercourse longitudinal profile. During mapping, the bridges and culverts in the alluvial plain, obstructions in the river bed, objects in the alluvial plain, and dams crossing the floodplain were considered as potential obstructions. Presence of the obstructions mentioned, as well as of high weirs on the watercourse, is reflected in increased frequency of occurrence of the flood morphological manifestations. It applies especially to the central and lower part of the watercourse – as for the upper part, obstructions accompany the occurrence of erosion, accumulation or destruction manifestations in

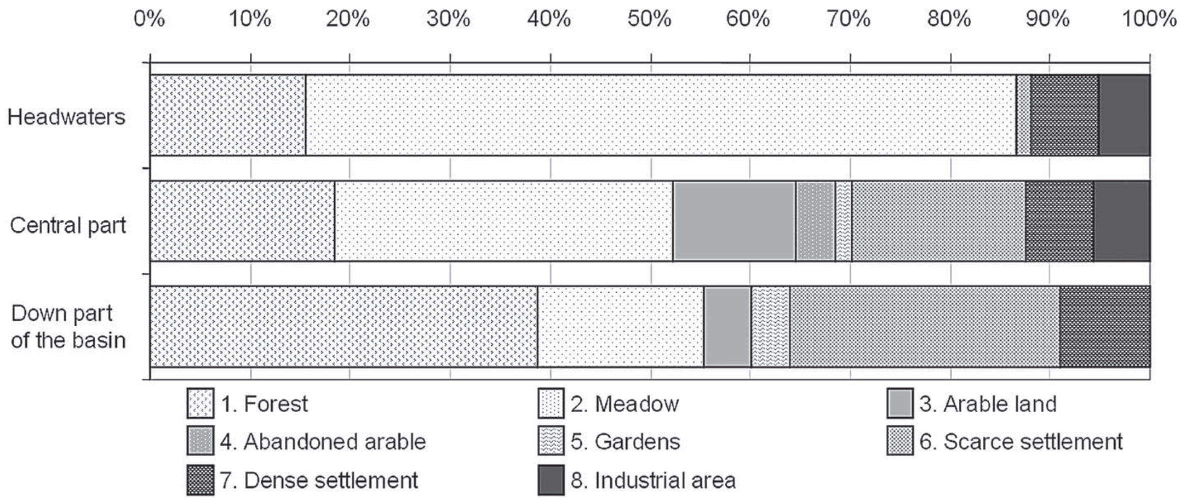

Fig. 2 Structure of the riparian zone landuse of Sázava and Sázavka

53.3% of the segments, in 87% on the central watercourse, and in 100% of segments on the lower watercourse.

Intensity of the longitudinal profile transformation of the watercourses in the Sázava river basin decreases in the direction from source areas toward the lower part. On the contrary, the number of steps in the river bed is the highest in the lower part of Sázava, where 84 steps are found on 96 evaluated segments. A number of them are of natural origin, however, high weirs occur here, too, representing an increased risk in extreme floods. The highest number of steps in the river bed has been recorded in the river basin of Šlapanka and Sázavka, ranking among the most intensively adapted parts of the river basin in most parameters.

The river bed modifications are concentrated especially in urban areas and zones of scarce settlement, while the transformation intensity increases in watercourse segments situated in lower parts of the watercourse. Almost 70% of the watercourse length does not show signs of modification; intensive forms of the river bed modification – partial or complete reinforcement by concrete or tiles occur only in 7.5% of the watercourse length.

Close to nature character prevails in the structure of the *riparian zone usage* on the upper, central, as well as lower segment of Sázava – woods (13.7%) and meadows (42.2%). Arable land occurs in 7.5% of the length of the segments evaluated; the most marked anthropogeneous element is represented by scattered built-up areas (16.5%), occurring especially in the central and lower part of the watercourse (Figure 2). Urban areas, industrial facilities, and mining facilities represent 11.5% of the riparian zone length evaluated. Total intensity of the floodplain area usage increases in the direction from the upper part of the watercourse to the mouth profile where, however, forest coverage grows markedly, too.

The Stream Transformation Index was calculated according the methodology provided above for individual partial river basins of Sázava.

Out of parameters mapped within the framework of the main intensity indicators, basic transformation indexes of individual aspects of the river network transformation were derived – the watercourse route transformation index T_T, the longitudinal profile transformation index T_L, the river bed transformation index T_K, and the riparian zone transformation index T_N. The Stream Transformation Index I_T and the accumulated Stream Transformation Index I_{TC} were derived from them subsequently. Analysis results for individual partial indicators and the derived Stream Transformation Index for individual partial river basins are summarized in Table 4.

Tab. 4 Transformation of the watercourses and riparian zone in individual partial river basins. Data: Faculty of Science, Charles University, Mapping 2006

River basin	**Sázava – headwater area**	**Šlapanka upper Sázava**	**Central Sázava**	**Blanice**	**Lower Sázava**
Number of segments	246	297	317	306	96
Watercourse length	161.9	146.7	124.0	139.7	54.8
T_T – route modification	3.1	3.7	3.0	3.1	4.1
T_L – longitudinal profile modification	1.6	1.5	1.4	1.6	1.3
Total number of steps	46	116	68	23	84
T_B – river bed modification	1.6	1.7	1.9	1.4	1.5
T_F – riparian zone modification	2.3	2.5	2.6	2.6	3.2
I_T – Stream Transformation Index	2.14	2.35	2.22	2.17	2.51
I_{TC} – Accumulated transformation index	8.59	9.42	8.92	8.69	10.15

There are marked differences among individual subbasins both concerning total transformation intensity as well as its inner structure. In general, the least intensively transformed area is the source area of Sázava, on the contrary, the most intensively transformed one is the lower part of Sázava which corresponds with usual schemes of anthropogeneous interventions intensity distribution within the river basin (Figure 3).

The lower part of the Sázava River, found as the most intensively transformed one in evaluation of total values of the I_T transformation index, is not typical in numerous aspects compared to other river basins evaluated. In the

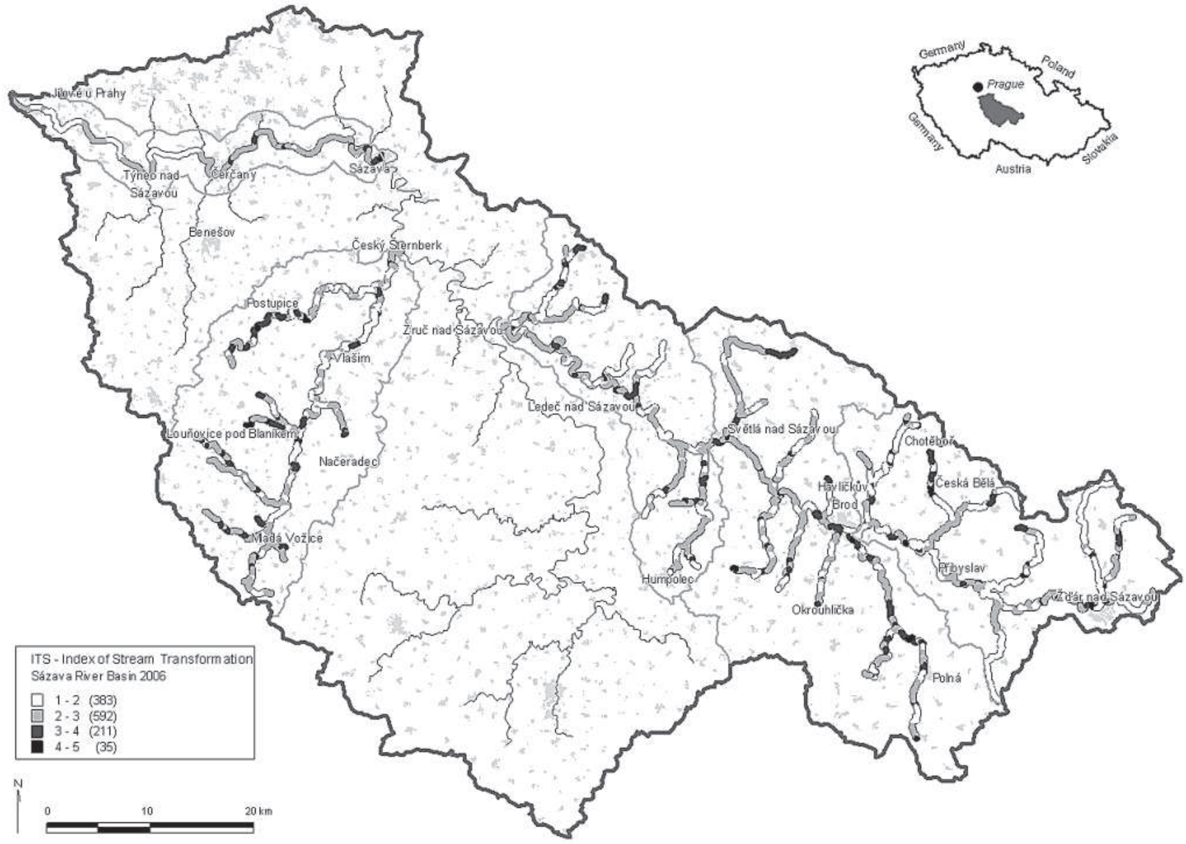

Fig. 3 Distribution of the Stream Transformation Index values in the Sázava river basin. Data: Faculty of Science, Charles University, Mapping 2006

first place, the main watercourse without tributaries is evaluated here, as the tributaries are little affected by marked modifications in this area which causes a relative increase of the total value of the Stream Transformation Index. The Sázava River itself shows the lowest values of the longitudinal profile and river bed transformation intensity in this segment, on the contrary, it shows the highest values of the riparian zonetransformation intensity. Considering the fact that the Sázava River runs through a deep valley in this area the considerable part of which is moreover found in a condition close to nature, the existing anthropogeneous interventions in the watercourse in this area cannot have a marked influence on the course of the flood, and thus they do not represent a source of increased risk.

On the contrary, from the viewpoint of possible affecting of the runoff process, it is necessary to evaluate the intensity as well as structure of transformation of the watercourses in the upper and central part of the Sázava river basin including the river basin of Šlapanka, a tributary of Sázava in the area of Havlíčkův Brod, as potentially critical. This area represents a region where formation and transformation of the floodwave takes place before it is led to the lower valley part of Sázava. It is an agricultural landscape with extraordinarily intensive manifestations of the river network transformation in the majority of the indicators evaluated. Analysis of historical changes of the region usage (Langhammer, 2006a) showed that during the last 160 years, the most marked increase of intensity of pressure on the landscape occurred in this area, in the form of transforming the meadows and permanent grass covers into arable land. There are numerous straightened stream segments intensive forms of transformation of the river beds as well as occurrence of weirs and steps in the river bed.

The lowest intensity of the river network transformation has been recorded in the river basin of Blanice and in the source area of Sázava. The generally low intensity of the watercourses transformation represents a positive element especially in the river basin of Blanice of Sázava. The absolutely lowest intensity of the river beds transformation is observed here, as well as the second lowest intensity of the river bed transformation and the lowest frequency of occurrence of weirs and steps in the river bed.

3.3 Identification of Critical Segments

Four main criteria were used to identify the potentially critical segments of the watercourses – occurrence of selected flow obstructions types (the culvert, bridge, mound across the floodplain), high intensity of the watercourse transformation found concurrently in multiple indicators, non-suitable transformation structure, and finally passing of the watercourse through an urban area or an industrial zone where an increased level of anti-flood protection is required. Segments selected in this manner represent watercourse elements that can be a potential source of risk and occurrence of damages during a flood, and that require priority attention from the viewpoint of protection.

The results show decreasing frequency of occurrence of critical elements in the river network in the direction from the source area to the mouth profile, however, at the same time they document the changing structure of the source of potential risk (Figure 4).

The highest frequency of the critical segments occurrence, especially given by presence of the flow obstructions, is observed in the headwater area, while the hydrological node in the surroundings of Havlíčkův Brod can be viewed as the most critical region. Numerous localities can be observed here where multiple sources of potential danger are accumulated in one segment of the watercourse (Figure 5). Especially these segments where multiple potentially critical parameters occur in parallel must be considered as hazardous from the viewpoint of the flood risk. Although forming a marked minority from the viewpoint of the total proportion in the river network length, experiences with consequences of extreme events show that flood damages are distributed very irregularly in the area, and that occurrence of the most extensive damages to property and infrastructure can be found precisely in localities where the conditions for passing of the floodwave or natural spill are worsened artificially or where accumulated property is found.

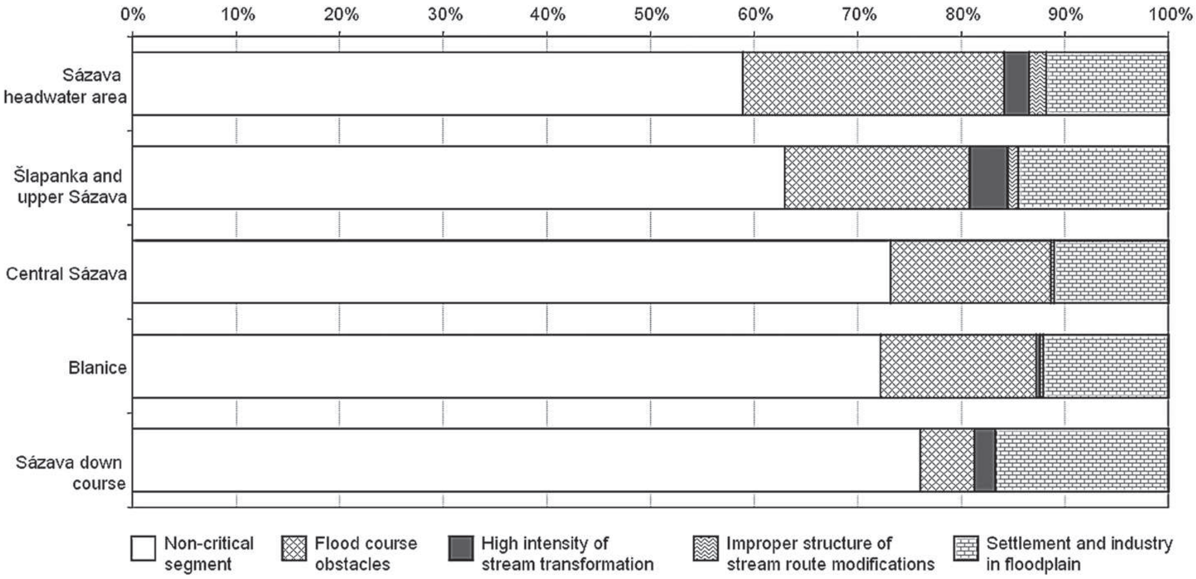

Fig. 4 Occurrence and structure of critical segments in partial river basins of the watercourses evaluated. Data: Faculty of Science, Charles University, Mapping 2006

Fig. 5 Intensive erosion in floodplain in central Sázava course by Poříčí nad Sázavou. The improper use of the floodplain helps to accelerate the geomorphological processess during the flood and leads to rise of the direct as well as secondary flood damages. Photo V. Vilímek, 2006

4. Discussion

The methodology proposed and applied to evaluation of transformation of watercourses and consequences of floods stems from mapping of transformation indicators of the river network and of manifestations of the flood activity in the alluvial plain. Evaluation of the transformation intensity is based on calculation of the Stream Transformation Index I_T, construed based on partial transformation indexes in individual indicators, and its aim is to quantify and objectivize often heterogeneous parameters of individual transformation forms of the watercourse and of the riparian zone. General values of the transformation index I_T as well as partial indexes T_T, T_K, T_L, and T_N, allow direct comparison of balance river basins or watercourses in individual parameters, and they also represent ground materials for subsequent spatial analyses in GIS or geostatistical tools.

Similarly as in, for example, evaluation methodologies of ecomorphological parameters of the watercourses (e.g. Barbour et al., 1999; Vlček and Šindlar, 2002; Havlík, 1997), the fundamental issue for the system proposed is also represented by conversion of heterogeneous watercourse transformation forms to a point system, allowing subsequent quantitative evaluation. The approach chosen stems from several years of experience in mapping using the methodology mentioned in river basins hit by extreme floods leading to generalization of the number of the indicators used as well as their evaluated parameters. The methodology proposed does not seek to involve and quantify the greatest number possible of aspects of the watercourses condition and adaptation, but on the contrary, to select those parameters that are of key importance from the viewpoint of possible affecting of runoff in the event of a flood. The scoring and classification system has been intentionally proposed as a simple and transparent one, so that it allows to distinguish the most apparent forms of intensity of anthropogeneous interventions in the environment of the watercourses and alluvial plain. The system has been proposed and tested on small and medium sized watercourses; for routine usage, its further testing is necessary, as well as verification of general validity and possible modification.

5. Conclusion

Mapping of watercourse transformation and of consequences of floods was performed in the Sázava river basin, hit by the spring flood in 2006. Terrain mapping captured manifestations of the flood in an immediate time delay from the causal event, and it thus allowed to accurately assess the main manifestations and consequences of the flood in individual parts of the watercourse. Extremity of the flood in the spring of 2006 was on the level of the 20–50 years flood in individual parts of the river basin, while it is the most extensive flood event within the river basin for the last more than 100 years. The floodplain of Sázava was generally flooded in its whole during the spring flood in 2006.

Analysis of anthropogenic transformation of the watercourses and consequences of the flood in the Sázava river basin showed high spatial variability of the total intensity as well as structure of interventions in the river network. However, compared to comparable watercourses, total intensity of transformation is relatively low, which is given especially by specific morphology of the terrain. A number of modifications of the watercourse route and river beds built at the beginning of the 20th century or earlier is moreover difficult to identify in the current terrain.

Furthermore, the results showed that the river of Sázava is not currently modified in an extent that could have a considerable effect on the course and consequences of an extensive flood. On the contrary, the upper part of the river basin of Sázava, the river basin of Šlapanka and other tributaries in the surroundings of Havlíčkův Brod, shows very intensive degree of transformation. Analysis of occurrence of critical segments precisely in this part of the river basin identified the highest frequency of occurrence of segments which, in respect of non-suitable type and structure of modification, represent potential risk of increased damages during a flood. This part of the river basin also represents the zone of forming of the floodwave within the river basin, and high intensity of transformation of the river network and the floodplain in this area does not allow to fully use the transformation and retention potential of the floodplain. In this respect, it is therefore possible to recommend implementation of measures to strengthen the retention and transformation effect of the river basin, removal of potential flow obstructions, and slowing down of water runoff from the landscape.

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Résumé

Identifikace kritických prvků v říční síti vzhledem k povodňovým rizikům

Intenzita transformace říční sítě a údolní nivy představuje významný činitel ovlivňující odtokový proces. Vliv antropogenních zásahů do říční sítě a údolní nivy spočívá zejména v ovlivnění průběhu povodňové vlny a snížení transformačního a retenčního potenciálu údolní nivy.

Příspěvek představuje kvantitatvní metodu pro analýzu a hodnocení intenzity a struktury antropogenní transformace říční sítě a hodnocení její prostorové diferenciace.

Vstupní údaje pro hodnocení představuje terénní mapování základních indikátorů upravenosti říční sítě, příbřežní zóny a údolní nivy. Na základě těchto dílčích ukazatelů je vypočten Index upravenosti toku jako syntentický ukazatel celkové míry upravenosti říční sítě. Vyhodnocení je prováděno v prostředí GIS, což umožňuje propojení s dalšími datovými podklady, např. výsledky mapování následků povodní nebo fyzickogeografickými a socioekonomickými ukazateli.

Metodika je aplikována na povodí Sázavy, kde byla využita pro vyhodnocení souvislostí mezi změnami v krajině a průběhem jarní povodně 2006.