FLOODPLAIN RETENTION CAPACITY ASSESSMENT FOR LUŽNICE RIVER

VÁCLAV DAVID, TOMÁŠ DOSTÁL

Czech Technical University in Prague, Faculty of Civil Engineering, Department of Irrigation, Drainage and Landscape Engineering

ABSTRACT

One of main topics of interdisciplinary project NIVA – Water Retention in Floodplains and Possibilities of Retention Capacity Increase is the assessment of flood wave transformation in the floodplain. The project focuses on broad field of floodplain ecosystem services and flood mitigation is a phenomenon which is researched by the team from Czech Technical University from different points of view and using different methods. Despite the fact that the main influence on flood wave transformation is flow retardation due to the flow velocity decrease, the retention in surface depressions within floodplain has been analyzed to get better overview of whole transformation process. Detailed digital relief model (DRM) has been used for given purposes to be able to analyze terrain depressions volumes.

First, the methodology of analysis was prepared and tested on artificial surface. This surface was created using random raster generation, filtration and resampling with final resolution of 1,000 × 1,000 units and height of maximum 10 units above datum. The methodology itself is based on analysis of areas inundated by water at different elevation levels. Volume is then calculated for each depression using extraction of terrain elevations under corresponding water level.

The method was then applied on the area of Lužnice River floodplain section to assess the retention capacity of real floodplain with natural character which usually means higher surface retention capacity in comparison to trained rivers. Results obtained from above mentioned analysis applied on Lužnice river are presented in this paper. The importance of floodplain retention capacity for flood transformation is low as results from obtained values.

Key words: floodplain, retention capacity, digital elevation model, GIS application, Lužnice River

1. Introduction

NIVA project focuses due to its interdiciplinarity on broad spectra of river floodplain ecosystem services (Pithart 2010). Flood transformation is one of these services (Daily 1997) and this process has been analyzed from different points of view and using different tools. The transformation process is described in many studies which are focused on the results of floodplain and river conditions, eg. (Lammersen 2002). However, this process is not usually described in detail and emphasis is put on the relationship between conditions and their effects. The transformation process is rather complicated and many both specialists and laymen are speaking about it a lot without relevant knowledge of its quantification and description. Presented part of the project implementation focuses on floodplain retention capacity which is supposed to be an important factor for flood transformation and thus mitigation of losses caused by flooding.

Application of GIS data and analysis is a good tool for purposes of passive retention capacity calculation of floodplain. The method which has been developed for this purpose is based on the analysis of digital relief model (DRM). It is supposed that natural rivers have much higher retention capacity than trained ones which was the reason for selection of the Lužnice River reach for the case study. Presented analysis is considered to be supplementary to analyses of flood transformation calculation carried out using hydraulic modelling. The paper summarizing all analyses carried out for retention capacity assessment and for the assessment of floodplain condition on flood transformation has been published by Dostál (2011). This paper includes also application of hydraulic models (HEC-RAS, FAST 2D, and DIFEM 2D) for these purposes.

2. Methodology

The methodology is intended for calculation of volume of medium sized depressions in the floodplain which can be captured using aerial photography and other remote sensing techniques and therefore it does not count with microtopography. It also does not count with the state that the depressions are partly filled by water and the vegetation is not taken into account as only possible retention in depressions is calculated. The calculation is based on the analysis of the DRM which should be prepared properly with respect to the given purpose. This means mainly that it must represent the real surface correctly and no procedures can be applied which are supposed to make it correct from the hydrologic point of view by removing pits or sinks (Vieux 2004).

The problem can be caused by both filtering and removing sinks. Filtering is a GIS procedure which

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should smooth the surface which is usually unnaturally rough after interpolation the DRM. This should remove the noise resulting for example from interpolation of scatter point data (Li 2005). The pit removal (Burrough 1998) is a procedure which should guarantee hydrologic correctness which consists in the fact that there are no cells with lower elevation than all surrounding cells. Sink removal is usually necessary for hydrologic calculations carried out using different hydrologic models as these locations are considered as the end of flow lines.

Surface retention capacity calculation is based on GIS analysis of DRM. For the purposes of calculation methodology definition several assumptions had to be adopted:

- Water is considered staying in depressions after flooding of the whole area without infiltration. This means that potential surface water retention capacity is calculated.
- Flooding of the entire area is considered. This means that the possibility of reaching assumed water levels is not considered.
- Inundated areas which touch the lower border of the evaluated area are drained out.

The calculation itself consists of several steps. In general, areas of inundation are depicted first for each given water level and then areas which are not involved in others or drained out areas are searched. Finally, the volume is calculated using zonal statistics over DRM. In detail, following steps are included:

- DRM is reclassified for each considered water level in such a way that cells under the given water level have new value equal to considered water level and other cells are dropped.
- Rasters resulting from previous step are vectorized into polygons.
- Polygons which touch spilling boundary are removed from each polygon layer obtained in previous step.

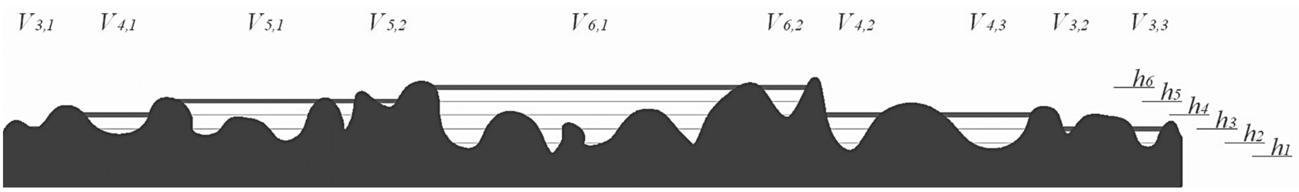

Fig. 1 Scheme of retention volume calculation with water level elevations and partial volumes

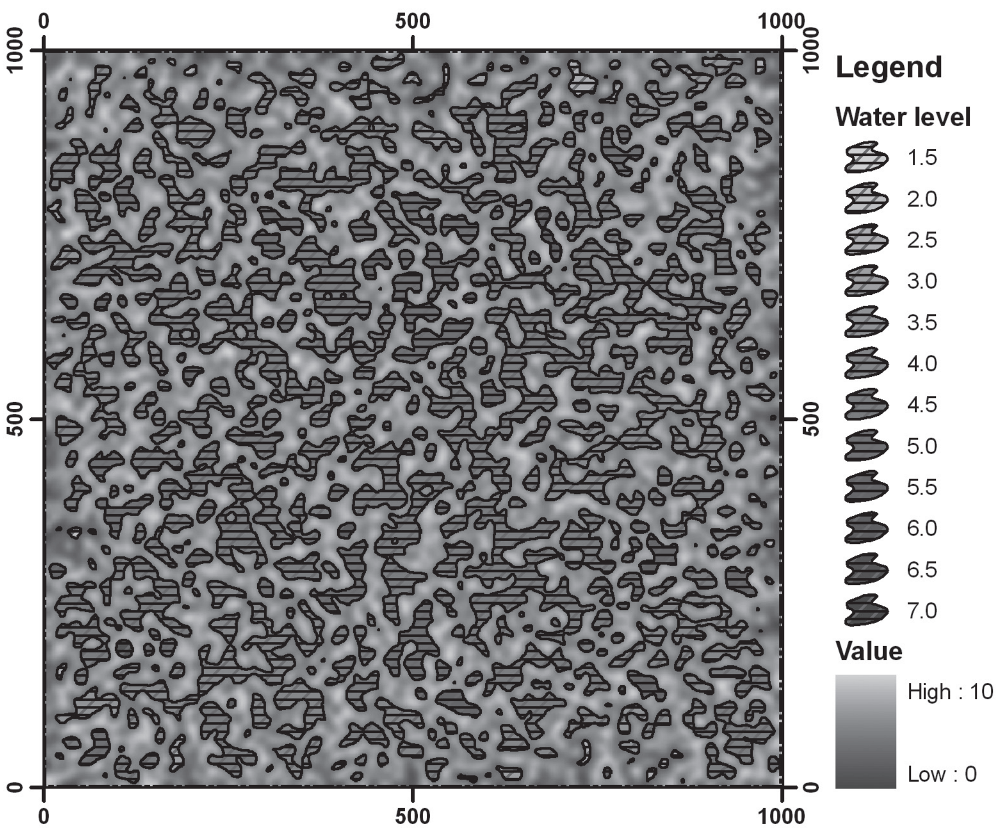

Fig. 2 Resulting map of inundated areas within testing artificial surface

- Starting from the layer for the lowest considered water level polygons which are overlaid by polygons in a layer above are removed.
- All polygon layers are joined into one new layer.
- Mean surface elevation under each polygon is calculated.
- Volume under each polygon is calculated using difference between its elevation and corresponding mean surface elevation and its area.

The calculation procedure is indicated on Figure 1 where partial volumes included in volumes corresponding to higher water levels are marked by thin light blue lines while final volumes considered for the retention capacity calculation are marked by thick dark blue lines. The procedure is in more detail described in (Dostál 2009, 2011). It was also presented at EGU general assembly 2010 (David 2010).

In addition to the methodology development, alternative way of retention volume calculation based on the determination of sinks and their contributing areas but this option has been assessed as not suitable for given purpose.

The calculation is then carried out based on the summation expressed by the equation

$$V_{ret} = \sum_{j} \sum_{i} V_{j,i}$$

where V_{ret} is the total retention capacity, $V_{i,j}$ is partial volume corresponding to water level j, m is number of considered water levels and n is a number of partial volumes corresponding to each considered water level.

Artificial surface has been prepared to test the methodology as the data for the study area was not available at the time when the methodology was being developed. This artificial surface has been prepared using random raster and its resampling and filtering. Its size was set to 1000 × 1000 units and maximum elevation difference was set to 10 units. Resulting map of inundated areas within an artificial surface is shown on Figure 2. The total volume is 334,305 cubic units which corresponds to a layer with the sickness 0.33 units over the entire area which can be considered as rather small value.

3. Study area

Lužnice River is the tributary to the Vltava River which springs close to Czech-Austrian border. The location of the study area is shown on Figure 3. The river reach which was analyzed within this part of the project starts at the point where the conveyor between sand mining area and the road number 103 close to Nová Ves nad Lužnicí crosses the river. The downstream end has been set to the bridge in Suchdol nad Lužnicí (see Figure 4). The length of the section is about 8.6 km while the length of river reach in this section is 16.7 km. The longitudinal slope of the floodplain is very low with an average value 0.15%. Average longitudinal slope of the river reach is much lower due to

Fig. 3 Location of study area – Lužnice river reach

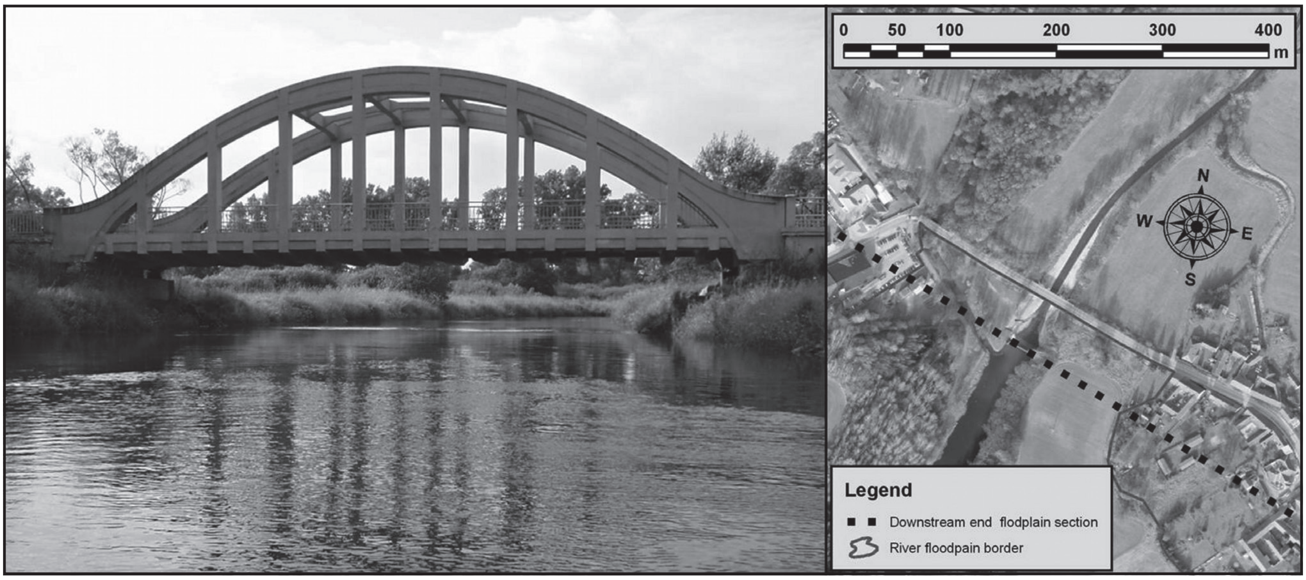

Fig. 4 Downstream end of analyzed floodplain section

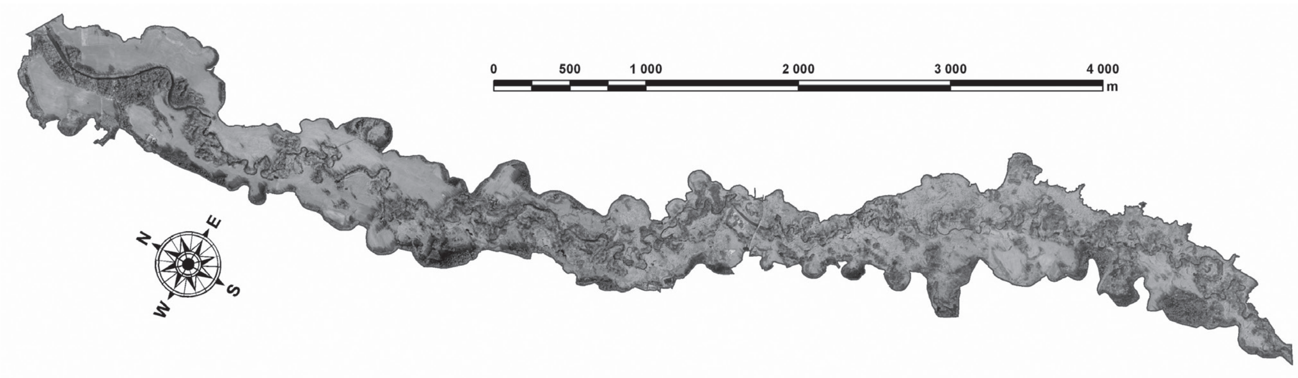

Fig. 5 The section of Lužnice River floodplain which was used for the calculation of potential surface retention capacity (data source: aerial photo with the resolution 50 cm, ČÚZK)

much higher length. The width of the river floodplain reaches at some parts nearly 1 km. The floodplain has very natural character in this area and it is protected as Horní Lužnice Nature Reserve which was established in 1994. The character of floodplain can be seen on aerial photo on Figure 5.

Flood characteristics of analyzed river reach have been provided by Czech Hydrometerorological Institute. This data include peak discharge values for different return periods (see Table 1) and course of flood waves for return periods 20 and 100 years (see Figure 6). Volumes corresponding to flood waves are 25.3×10^6 m^3 for return period 20 years and 41.3×10^6 m^3 for return period 100 years. The basin area corresponding to the location of analyzed river reach is 146.8 km^2 which means that the contributing area is quite large. It predicts that the influence on the transformation of the flood wave cannot be substantial due to proportion of active area to the total basin area.

4. Calculation

DRM which was used as an input for the calculation of surface retention capacity with a resolution 1 m has been prepared and provided by a partner from project consortium based of remote sensing data. The DRM is shown on Figure 7. All the calculation has been carried out using ArcGIS software package with use of the 3D Analyst extension. The border of Lužnice River

Tab. 1 Peak discharge values for different return period

Return period (years)	1	2	5	10	20	50	100
Peak discharge (m^3 s^{-1})	23	39	65	88	114	152	185

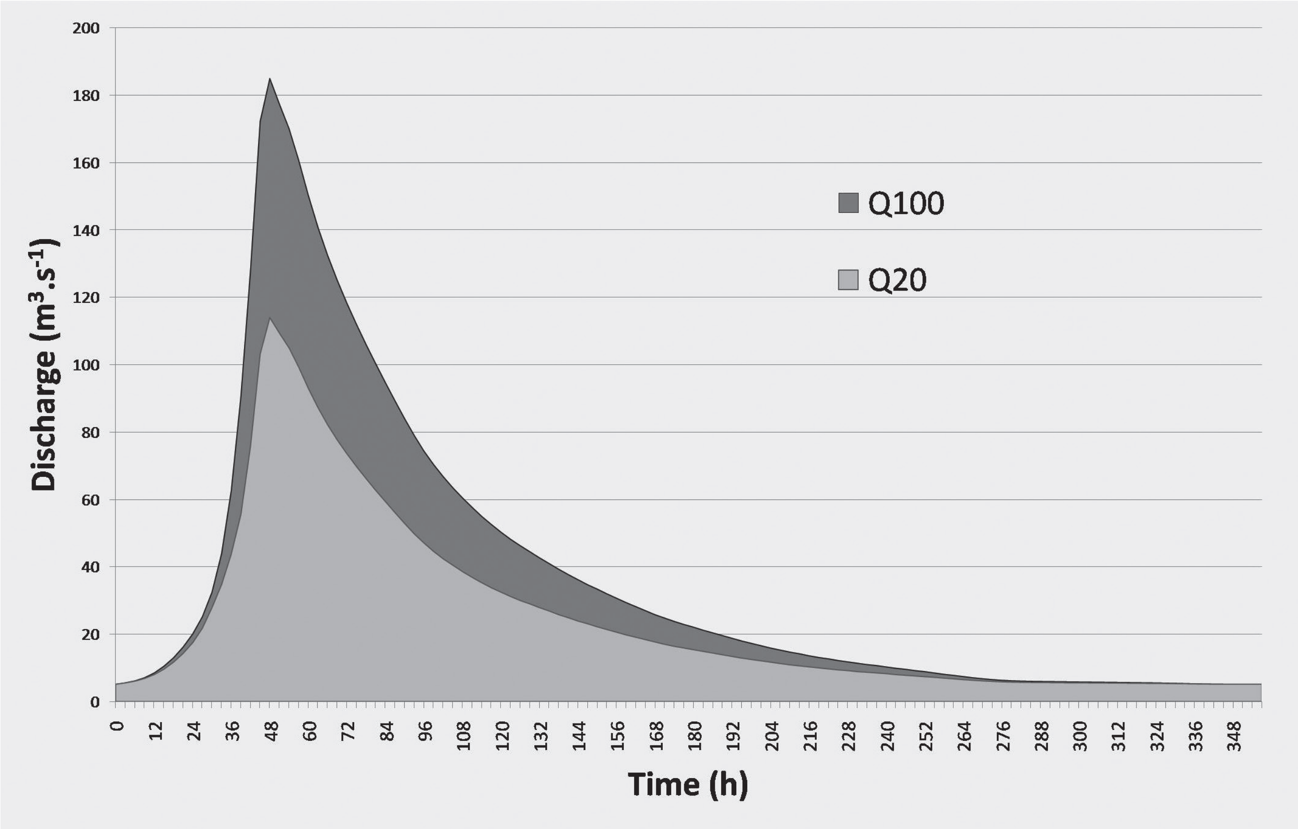

Fig. 6 Flood waves for return periods 20 and 100 years

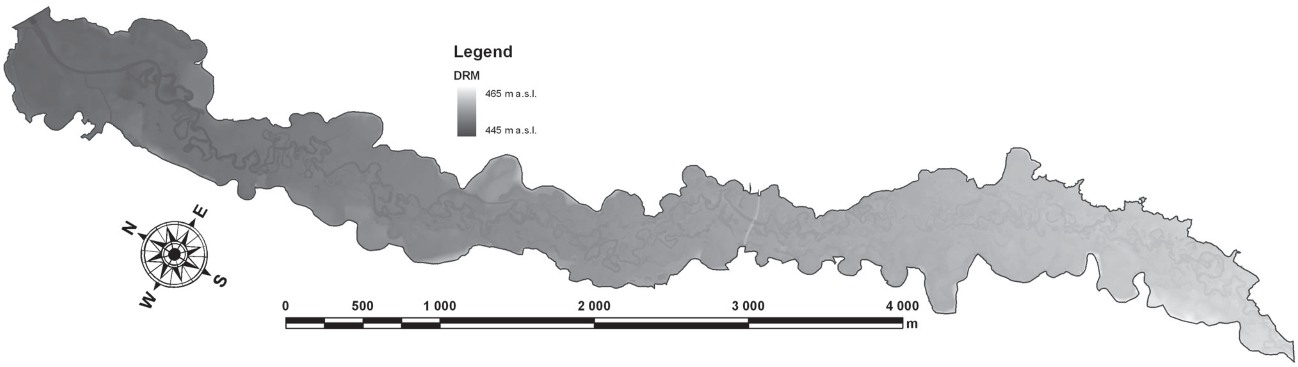

Fig. 7 DRM which was used as an input for the calculation of potential surface retention capacity

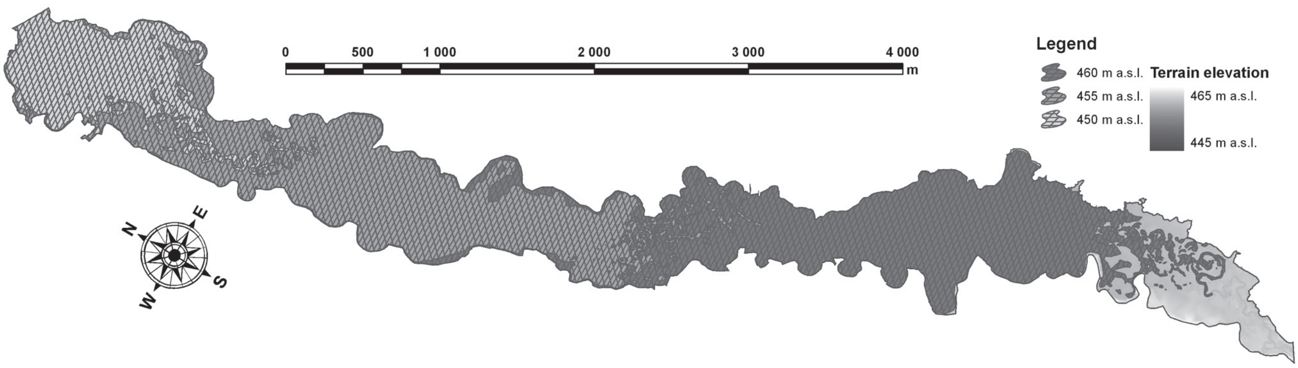

Fig. 8 Inundated areas after vectorization of reclassified DRM – selected elevations

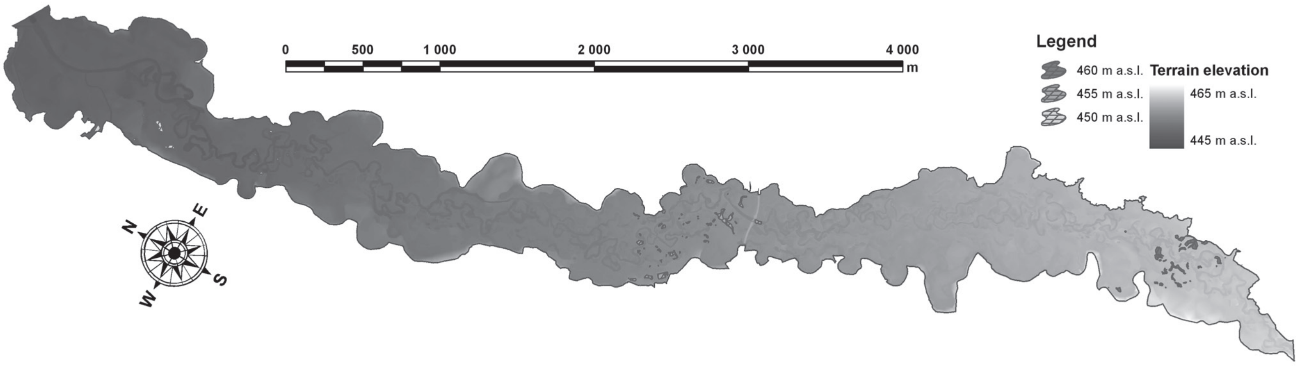

Fig. 9 Inundated areas after removal of areas connected to lower border of the analyzed area – selected elevations

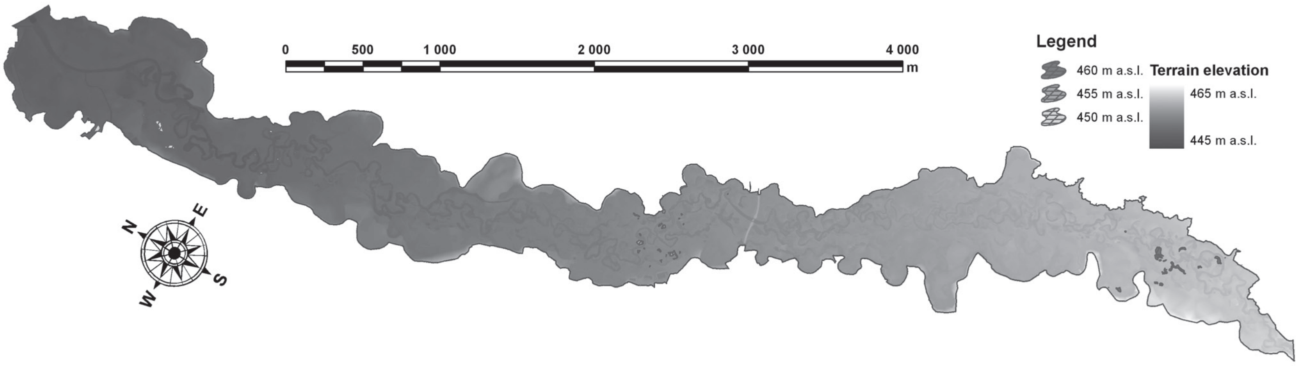

Fig. 10 Inundated areas after removal of areas covered by the layer above – selected elevations

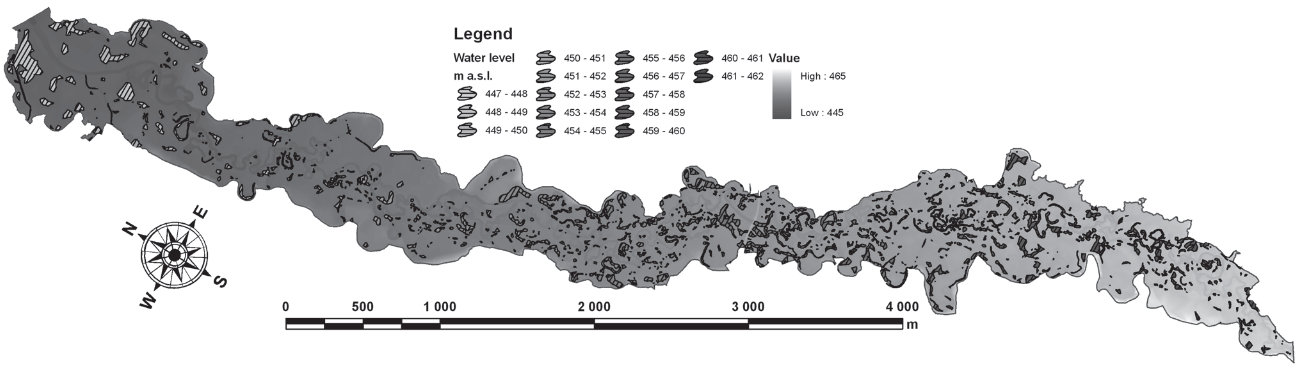

Fig. 11 Final extent of inundated areas for all considered elevations

floodplain has been used as a supplementary input to limit the calculation to the floodplain area. The value of elevation step has been set set to 0.2 m for the calculation. The calculation has been carried out from the elevation 448 m a.s.l. to the elevation 465 m a.s.l. which means that the calculation involved 85 elevation steps within 17 m. Resulting inundation extent for the first step of the calculation is shown on Figure 8, for the second step (removal of polygons which touch spilling boundary) on Figure 9 and for the third step (removal of polygons which are covered by polygons in upper layers) on Figure 10. The final extent of potential inundated areas is shown on Figure 11. The calculation is in more detail described in (Dostál 2011).

5. Results

Results obtained by the calculation procedure described above have been presented in tables, maps and charts. Total area of depressions depicted using presented methodology and shown on Figure 11 is **510,580 m^2** which is about **10.5%** of the total analyzed area in more than one thousand single depressions with an area up to more than

3 hectares. The total volume of depressions which can store water is **105,730 m³** which could be understood as a water layer with depth **0.022 m** over entire analyzed area. Average depth of depressions is **0.21 m**. It is necessary to state at this point that the accuracy of results is highly dependent on the accuracy of DRM which could not be assessed. DRM have been therefore considered as correct as provided by the project partner.

Tab. 2 Overview of partial retention volumes for given water levels (totals for 1 m elevation step)

Water level (m a.s.l.)	*Partial volume (m³)*	*Total volume (m³)*
up to 449	12,356	12,356
449–450	8,341	20,697
450–451	3,294	23,991
451–452	3,607	27,598
452–453	4,980	32,578
453–454	9,513	42,091
454–455	6,735	48,827
455–456	19,545	68,372
456–457	7,868	76,239
457–458	7,340	83,579
458–459	6,386	89,965
459–460	9,019	98,984
460–461	5,073	104,057
461–462	1,511	105,568
462–463	163	105,730

6. Conclusions and outlook

The methodology for calculation of potential surface storage capacity of floodplain was developed, tested and applied. According to its character, the method is very sensitive on correctness of DRM, which is the only needed input. Therefore the DRM must be prepared properly and based on precise input data.

The method was applied on the area of Lužnice river floodplain section with length of 8.6 km. The total surface storage capacity within this section is **105,730 m³** on the area of **4.86 km²**. This would be a layer with depth of **0.022 m** over entire considered floodplain area. Calculated volume corresponds to **0.41%** in case of return period 20 years and **0.26%** in case of return period 100 years. It is obvious from the results that the volume of surface depressions can not affect the flood discharge at all. For example, the storage capacity would be filled in about 15 minutes by the discharge corresponding to 20 years return period which is negligible in comparison to nearly 15 days of duration of the flood wave. Above mentioned facts confirm the initial assumption that the influence of flood discharge is connected mainly to area roughness and other characteristics of the area.

The methodology will be within further research applied on floodplains of trained river reaches to get an overview of the differences between trained and natural rivers. However, it can be expected that the influence of floodplain retention capacity on flood transformation will be much more negligible than in case of natural floodplain which has much more irregular relief which provides higher depression storage capacity.

The surface storage capacity is an important property of the landscape despite the fact that it does not have an important influence on the flood wave transformation when considering only the storage capacity of the floodplain. Its importance consists besides others in the affection of the total volume of runoff. Further research will be therefore focused on landscape surface storage capacity. This will consist in the calculation of the storage capacity of larger areas and in the classification of different types of the landscape from the point of view of runoff affection. There are mainly two tasks which have to be solved for this purpose. The first task consists in improved automation of the calculation procedure which is necessary for the assessment of larger areas. The second task consists in assessment of the possibility to use some land surface descriptors which could be used instead of the calculation of exact value of surface storage capacity. First of these descriptors will be random roughness which was introduced by Allmaras (1966) for purposes of microtopography description. This descriptor has a meaning of standard deviation of the surface elevation in assessed area. Another possible descriptor is the tortuosity which was introduced by Boiffin (1984) also for purposes of microtopography description.

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RÉSUMÉ

Stanovení retenční kapacity niv řeky Lužnice

Předmětem článku je odvození a popis metody pro stanovení retenční kapacity niv založené na aplikaci prostředků GIS. Metoda vychází z analýzy digitálního modelu terénu. Prezentována je aplikace na úsek toku řeky Lužnice mezi Suchdolem nad Lužnicí a dopravníkem mezi pískovnou SV od Nové Vsi nad Lužnicí a silnicí č. 103. Délka tohoto úseku činí cca 9 km nivy. Na základě zjištěných výsledků se prokázal prvotní předpoklad, že retenční kapacita nivy nemá u toků takovéto velikosti příliš velký význam, jelikož celkový potenciální retenční objem je velmi malý ve srovnání s objemy povodňových vln pro doby opakování 20 a 100 let, které byly pro posouzení získány od Českého hydrometeorologického ústavu.

Václav David
Czech Technical University in Prague
Faculty of Civil Engineering
Thákurova 7
166 29 Prague 6 – Dejvice
E-mail: vaclav.david@fsv.cvut.cz
Tel.: +420 224 354 743

Tomáš Dostál
Czech Technical University in Prague
Faculty of Civil Engineering
Thákurova 7
166 29 Prague 6 – Dejvice
E-mail: dostal@fsv.cvut.cz
Tel.: +420 224 354 747