Comparison of Available Measures for Increasing Floodplain Retention Capacity

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Abstract

As in most recent years, there were again serious flood events in the Czech Republic and all over the world in 2010. This situation has been focusing attention on effective measures for controlling floods. Discussions have covered not just implementing purely technical flood control measures but also the feasibility of integrating the natural potential of floodplains in order to absorb and transform a flood wave. The natural floodplain could become an integral and desirable part of a complex basin flood control system, with many side benefits. However, while technical measures have been carefully studied, the effect of close-to-nature measures has not been well described and, especially, has not been well quantified.

This paper therefore presents a research study on river and floodplain restoration and revitalization measures in catchments and their flood-control effect. Mathematical modelling methods were applied for selected localities and parts of river floodplains to estimate the transformation effects of a floodplain. Hydraulic modelling was applied to three case study localities in the Czech Republic, each circa 5–7 km in length. The transformation effect is compared not only for the natural state of the floodplain, but also for various theoretical scenarios in each locality.

Keywords: floodplain retention capacity, flood protection, hydraulic modelling, revitalization measures

Introduction

Floods are natural phenomena, but by adopting the right measures we can reduce their likelihood and limit their impacts. In addition to causing economic losses and social disruption, floods can have severe environmental consequences. The coming decades are likely to see higher floods and greater economic losses.

Flood risk management plans should focus on prevention, protection and preparedness. With a view to giving rivers more space, the plans should take into account where possible the maintenance and/or restoration of floodplains, as well as measures to prevent and reduce damage to human health, to the environment, to cultural heritage and to economic activities. The elements of flood risk management plans should be periodically reviewed, and if necessary updated, taking into account the likely impacts of climate change on the occurrence of floods (European Parliament 2007).

Flood protection

In the section under the heading Influence on Extent and Course of Floods, the Czech National Flood Protection Strategy (Czech Republic 2000) draws a basic distinction between two types of measures – in a landscape, and technical measures.

The measures in a landscape includes firstly changes in land use and vegetation cover, grassing and forestation of banks and floodplains, conservation treatment of soil, and changes in landscape structures in order to increase water accumulation and slow down water runoffs. The technical measures are based on reducing flood effects by retaining flood waves and mitigating flow rates, or by using technical structures to prevent inundation.

The need for a proper evaluation the effects of flood protection measures

The effect of these close-to-nature measures is often either overestimated or underestimated, and there is no adequate answer to how much such measures can participate in a complex basin flood control system. These issues are included in the interdisciplinary project Water Retention in Floodplains and Ways of Increasing Water Retention, which is being undertaken at the Faculty of Civil Engineering, CTU in Prague. This project focuses on testing various methods for assessing the retention capacity of a floodplain in the course of flooding, and for estimating the significance of its water storage for transforming a flood wave.

An objective evaluation of the floodplain mitigation effect provides an undisputed basis for decision making and planning in water management. However, there are also many side benefits of close-to-nature measures, for example in economic, ecological and social benefits, that should be taken into consideration (Pithart 2008).

The importance of flood management issues can be illustrated by a wide range of topical European studies and projects. The function of forests and forestry in surface runoff is described in a project WaReLa – Water Retention by Land Use (Hoang a Schueler 2006), the conservation of wetlands in a project FLOBAR – FLOodplain Biodiversity And Restoration: Integrated natural science and socio-economic approaches to catchment flow management (Hughes 2003). There are also many others, for example Ecoflood Project „Towards natural flood reduction strategies“ (Blackwell and Maltby 2006) or SDF – Sustainable Development of Floodplains (Adamczak et al. 2008).

The result of changes in land use in Golestan river basin in northern Iran is described in Saghafian et al. (2007), Wan Rongrong and Yang Guishan (2007) are focused on testing the dependence on surface roughness on land use. Authors compare five different types of surfaces – forest, shrub, grass, arable land and built-up areas – in relation to generated runoffs on the river Xitiaoxi in China for two different flood events.

Materials and Methods

Methods for evaluating the retention effect

Many authors have mentioned the significance of flood water inundating the floodplain for natural transforming of the flood wave (Vopálka et al. 2000; Květ et al. 2002; Pithart et al. 2003; and others). A qualitative evaluation of this effect, based on an analogy with the estimated volume of water running in the floodplain during a flood with the retention capacity achievable by constructing water reservoirs and dry polders is, however, only indicative. A quantitative evaluation, including an assessment of the measures implemented in the floodplain area for restoring or increasing the natural retention of floodplain area, has to be based on hydrological and hydraulic models (Kreis 2003).

Hydrological flood routing models are based on the continuity equation and on a simplified parametric formulation of the flow dynamics in the analysed stream or river branches (linear or nonlinear reservoir methods, the multilinear Kalinin-Miljukov method, the Muskingum and Muskingum-Cunge methods, and others). Examples of applications are given in Pekár et al. (2001); and in Szolgay et al. (2008). Using an appropriate method, and provided that historical hydrographs are available for model verification, these models can be used not only for a quick analysis of various flood scenarios for the current state, but also to assess the impacts of various measures (construction of retention reservoirs and polders, stream revitalization) on transforming the flood wave (Szolgay et al. 2006).

However, the hydrological approach to a more detailed evaluation of various types of revitalization adjustments is limited by the schematisation of the flow dynamics that is adopted, and by the fact that lower model resolution provides a less detailed geometric description of the stream channel and the floodplain (Bayerisches Landesamt für Wasserwirtschaft 2005).

Hydraulic modelling

At the present time, many applications are available for various hydraulic models using various methods. An overview of existing methods is given in Valenta (2004). One-dimensional (1D) hydrodynamic models using discretization of the real geometry with a set of cross-sections are the most widely used type. This type of model was applied e.g. by Swiatek et al. (2003) and by Zezulák et al. (2006) for determining the retention potential of a floodplain.

Nevertheless, the set of cross-sections may not always be sufficient for a description of the terrain and the modifications, which could involve, for example, a local change in shape or land use. In these cases, it is appropriate to apply a two-dimensional model (2D) for a detailed analysis of the flood flow conditions.

Floodplain retention capacity evaluation

For the purposes of this study, floodplain retention capacity is understood as the volume of water that can be held in a flooded area.

A two-dimensional hydraulic model was selected to provide a suitable description of the flow conditions in modelled floodplains with a complicated morphology. Due to the high computational demands of an unsteady two-dimensional model, the FAST2D steady model (Valenta 2004) was used at first, applying a simplified approach of separate simulations of the flood flow for substitutive series of quasi-steady states. A similar method, using a quasi-stationary 1D model to determine the discharge-retention volume relation, was described in Sartor (2005).

On the basis of the computed water levels and storage volumes for a flow series, a transformation of the entering flood wave is appointed, using a non-linear reservoir method. The underlying assumption is that the method can be applied only for relatively short river sections. A quantification method based on a nonlinear balance equation is described in Valentová et al. (2010).

Subsequently, the transformations of theoretical flood waves with peak discharges Q_{100}, Q_{20} and Q_5 (peak discharges with 100, 20 and 5 year return periods) were calculated using the procedure described above.

In addition to the application of a steady 2D numerical model, the new DIFEM 2D unsteady 2D model was also developed (Valentová, Valenta in Dostál et al. 2010), based on a diffusion wave equation. Recently the new TUFLOW commercial hydraulic model of 2D unsteady flow (Syme 1991) has been included in the evaluation.

The results of the processes of floodplain retention capacity determination presented here are shown in three case studies, which represent different types of floodplains.

Modelled localities

Three case study localities in the Czech Republic, each cca 5–8 km in length, were chosen to test of several methods.

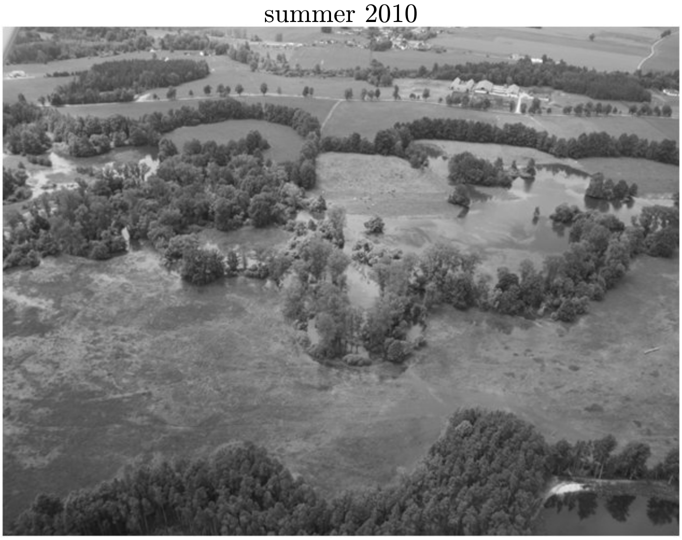
The following parts of river channels and their floodplains differ in terms of morphology, river channel form and training situation, land-use and also the need for flood protection, which has to be provided according to urban structures. The case study areas were selected to represent the main types of floodplains within the Czech Republic for further classification in terms of their flood wave transformation potential. The retention capacity and transformation of a flood wave is further estimated and compared; not only for the current state of the floodplains, but also for various hypothetical scenarios of changes in floodplain and channel geometry and land use.

Pic. 1: Three localities in the Czech Republic

The Lužnice River – natural floodplain conditions

A very natural upper section of the Lužnice River between Nová Ves and Halámky in South Bohemia has a complicated morphology with a meandering channel, numerous pools and cut-offs, and it forms part of a nature reservation. Beside the original floodplain, 6 theoretical scenarios with modifications in land use and geometry were also formulated.

Pic. 2: Meanders in the upper section of the Lužnice River, a flood in summer 2010



The Stropnice River – a trained channel, extensive agricultural exploitation

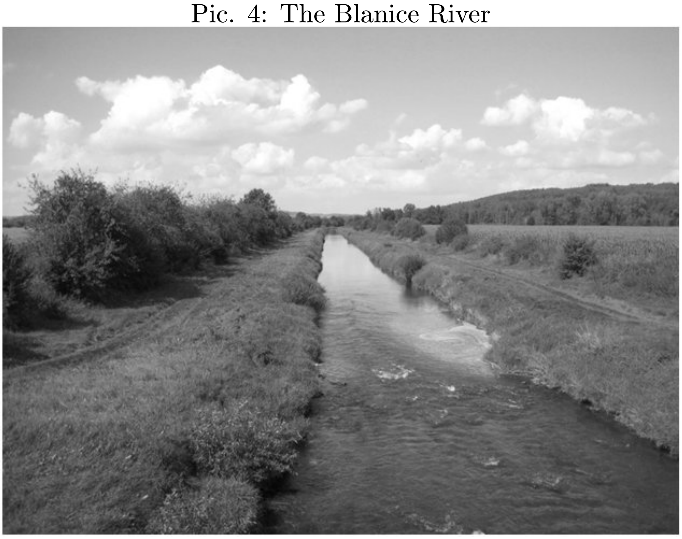
A part of the Stropnice River between Údolí near Nové Hrady and Tomkův Mlýn was chosen for modelling purposes. The channel is nowadays regulated in the section of interest, 1–2 meters wide with steep banks. The flat floodplain is used as intensive meadows. In addition to this state, a prospective revitalization of the channel and its floodplain is under consideration. A total of 6 scenarios with different land use were formulated.

Pic. 3: The Stropnice River

The Blanice River – a trained channel with parallel levees, in an intensive agricultural floodplain A section of the Blanice River between Myšenec and

Heřmaň near Písek is an example of a very flat wide floodplain with intensive agriculture and complicated hydrological conditions. The compound regulated channel transfers flood waves with Q_{20} peak discharges (a 20-year return period). A total of 3 scenarios were defined – original land use and floodplain, different land use (forest) and modified floodplain.

Pic. 4: The Blanice River



Modelled scenarios

The scenarios designed for application within individual experimental floodplains should describe a wide range of possible changes in land use, management and general exploitation of the localities. Technical measures were also taken into consideration.
The Lužnice River

The current natural state of the floodplain is described by Scenario A. Scenario B assumes a considerable increase in roughness in the floodplain due to total afforestation. By contrast, Scenario C describes the situation if the whole floodplain area were to be cultivated as arable land.

The modifications in Scenarios D, E and G assume changes in geometry. Channel improvement is characterized by changing the river line together with a corresponding reduction in channel length and an increase in the longitudinal bottom slope. The natural cross section is improved to a trapezoidal channel shape, having flow capacity values of about $Q_5 - Q_{10}$. The floodplain surface is adjusted and aligned to the edge of the river terrace. In variant D, land use as arable land with no bank vegetation is assumed, while variant E considers surface roughening due to floodplain afforestation.

Scenario G originated from Scenario D, with the adjusted floodplain supplemented by three cross dikes on both sides of the river with a view to increasing the water storage and thus improving the retention capacity of the floodplain. Finally, Scenario F is based on the current state, and assumes parallel floodplain area diking at the so-called „active zone“ boundaries – with this, a part of the floodplain behind the dikes is removed from the flood flow passage. A summary of the scenarios is shown in Tab. 1.

Tab. 1: Summary of the scenarios, the Lužnice River

Scenario	**Floodplain**	**Channel**	**Land use**
A	original	original	original
B	original	original	forestation
C	original	original	arable land
D	modified	modified	arable land
E	modified	modified	forestation
F	modified	original	active zone
G	dikes	modified	arable land

The Stropnice River

A trained channel of the Stropnice River in a modelled section passes through mostly grassy floodplain (Scenario A). The trapezoidal channel with concrete revetment is 1–2 meters wide at the bottom and 1–2.5 meters deep. Scenario B originated from A, but the meadows are changed to forests by an increase in the roughness coefficients.

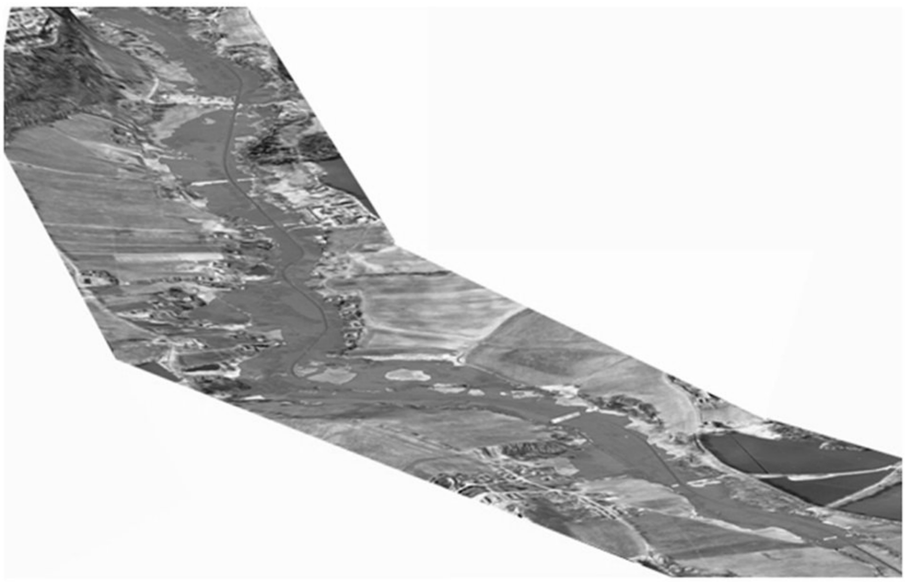
Scenarios C and D describe a variant with prospective revitalization of the channel and its floodplain (meanders, pools), the Scenario C with the original land use – meadows, while Scenario D is afforested. The Scenarios E and F originated in Scenario A, and they are supplemented by five cross dikes on both sides. Scenario E retains the current land use, while Scenario F is afforested on the banks on both sides with circa 10-meters-wide strips (Tab. 2).

Tab. 2: Summary of the scenarios, the Stropnice River

Scenario	**Floodplain**	**Channel**	**Land use**
A	original	original	original
B	original	original	forestation
C	modified	modified	original
D	modified	modified	forestation
E	dikes	modified	original
F	dikes	modified	bank forestation

The simulations were performed and the flood flow characteristics including water elevations, water depths and flow velocities with streamlines were evaluated for particular variants. An example of computed water elevations is shown in Pic. 5.

Pic. 5: The Stropnice River – Visualization of a terrain model and water level, Scenario E, 5-year recurrence flow



The Blanice River

Scenario A is characterized by the current floodplain (arable land, meadows) and the current trained compound channel, about 15 meters wide at the bottom. In Scenario B, the meadows and fields are changed to forests by an increase in the roughness coefficients. Scenario C describes a terrain modification – the removal of two railway embankments in the floodplain (Tab. 3).

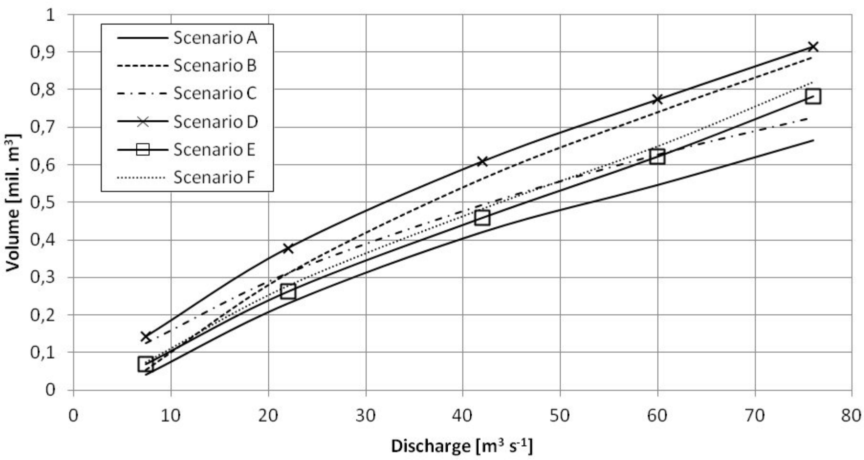
Tab. 3: Summary of the scenarios, the Blanice River

Scenario	**Floodplain**	**Channel**	**Land use**
A	original	original	original
B	original	original	forestation
C	modified	original	original

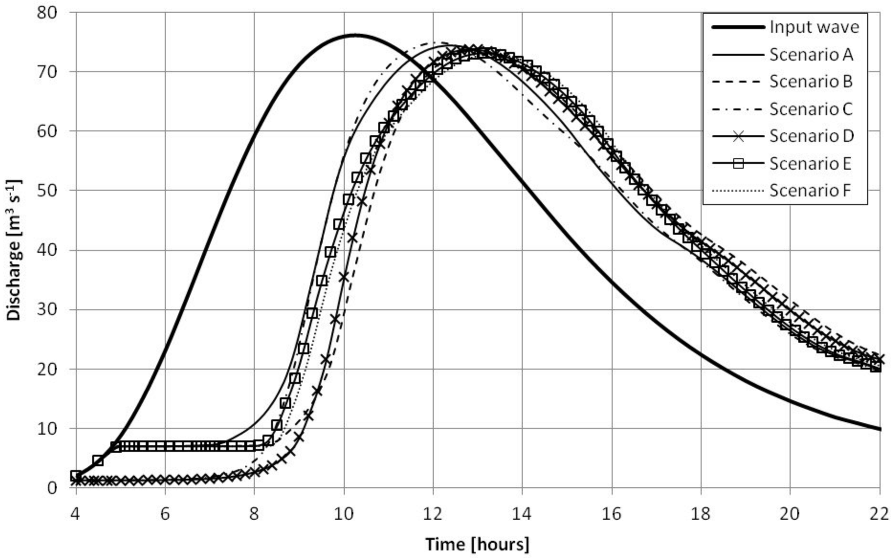
Results

On the basis of two-dimensional hydraulic modelling in FAST2D, the relation between storage volumes and discharges was determined for particular scenarios in all three case study localities, and transformations of the theoretical flood hydrographs were calculated. Graph 1 demonstrates that the restored and forested floodplain (Scenario D) has a greater storage capacity than the current floodplain with a trained trapezoidal channel (Scenario A). Graph 2 illustrates the transformation effect of an input flood wave with 100-year recurrence in the floodplain of the Stropnice River.

Graph 1: The Stropnice River – Storage volumes for particular scenarios



Graph 2: The Stropnice River – Transformation of a 100-year recurrence flood wave



A comparison of the transformation effect for particular variants and localities and modelled flood waves (recurrence 100 and 20 years) is summarized in Tab. 4 and Tab. 5. Both tables show the peak time delay and the transformation rate (the percentage ratio of the reduced peak discharge of the input wave). The scenarios are presented in order, according to their transformation effect.

The tables show, that floodplains with large surface roughness (forested floodplains) have a greater influence on mitigating passing flood waves than floodplains with lower surface roughness. The reduction of the peak discharge varies from 95.8 % to 98.6 %, depending on the variant of the scenario and the peak time delay can even exceed ten hours (The Blanice River).

The evaluation shows, that there is also a positive transformation effect in the variants with cross dikes (The Lužnice R. Scenario G, The Stropnice R. Scenarios E and F) and in the variant with bank side vegetation (The Stropnice River Senario F). The effect in the variants of the prospective channel and floodplain revitalization (The Stropnice River Scenarios C and D) is more significant during lower floods. Scenario F in the Lužnice floodplain (parallel dikes on the boundaries of the "active zone") indicates that reducing the extent of the floodplain, and also urban development, have a negative effect on flow conditions and flood wave mitigation in a floodplain, especially during floods with high peak discharges.

Tab. 4: Summary of the results in all three localities, 100-year recurrence flow

The Lužnice River			The Stropnice River			The Blanice River		
Scenario	**Peak time delay [hours]**	**Transformation rate[%]**	**Scenario**	**Peak time delay [hours]**	**Transformation rate[%]**	**Scenario**	**Peak time delay [hours]**	**Transformation rate[%]**
E	5.5	95.9	F	3.4	96.0	B	14.0	96.5
G	5.5	95.9	E	3.1	96.3	A	8.0	98.5
B	4.5	96.7	B	2.9	96.8	C	8.0	98.6
D	3.5	96.9	D	2.8	97.2			
A	4.5	97.0	A	2.3	97.9			
F	3.5	97.4	C	2.1	98.6			
C	2.5	97.6						

Tab. 5: Summary of the results in all three localities, 20-year recurrence flow

The Lužnice River			The Stropnice River			The Blanice River		
Scenario	**Peak time delay [hours]**	**Transformation rate[%]**	**Scenario**	**Peak time delay [hours]**	**Transformation rate[%]**	**Scenario**	**Peak time delay [hours]**	**Transformation rate[%]**
B	5.5	95.8	B	3.9	95.9	B	12.0	96.3
E	4.5	96.5	D	3.6	96.5	A	10.0	97.5
A	4.5	96.6	F	3.2	97.2	C	9.0	97.8
F	4.5	97.0	C	3.1	97.4			
G	3.5	97.0	E	3.0	97.4			
C	4.0	97.1	A	2.9	97.5			
D	3.5	97.1						

Discussion

The available results show, that a floodplain has a significant potential for transforming a flood wave, and the effects are higher for floods with lower peak discharges. To achieve a good effect, the following conditions have to be met:

- the river channel should have the lowest possible capacity to spill water into the floodplain,
- the floodplain should be morphologically heterogeneous and should have high surface roughness.

The achieved results correspond well with published conclusions in the Glonn river study (Bayerisches Landesamt für Wasserwirtschaft 2005). An analogous case of 30 kilometres long stretch of the Glonn River and 5 different scenarios (various afforestation, extension of channel) was modelled using a 2D unsteady hydraulic model. Different modelled conditions and changes in floodplain have a similar effect on a peak discharge and time delay in both studies.

It should be also mentioned that modelled scenarios are mostly hypothetical, and represent an extreme state of land use or modification in a floodplain. Total forestation of lands is practically unfeasible and brings problems with wood debris and with damming of flow profiles, bridges, culverts etc. However, there are also many economic, ecological and social side benefits of close-to-nature measures that should be taken into consideration (Pithart 2008).

Further research is therefore needed, and types of floodplains convenient for practising close-to-nature measures should be formulated. In addition, it is necessary to monitor and measure flood events and floodplains in order to calibrate and validate the compiled models, because in general not much objective data is available.

Conclusion

Two-dimensional hydraulic modelling has produced interesting results leading to a better and more realistic assessment of the floodplain retention capacity and the potential to mitigate floods.

The results presented here show that this potential has often been underestimated or overestimated. For certain types of river channels, floodplains and land-use patterns the effect can be very important, and revitalization measures are therefore effective and desirable. However, in other cases their effect of the measures is negligible, or measures cannot be applied at all.

The potential to mitigate floods depends fundamentally on floodplain morphology. In the case of 10 km long broad flat floodplains in their natural state the reduction of peak flow by up to 7 % and peak delay of up to 10 hours could be expected. To assess the effect of transformation it is also necessary to consider the volume of incoming waves.

The results also show that there is the possibility of increasing flood mitigation effect adopting changes in land use and supportive measures in the floodplain. Therefore the conservation of these areas is needful and highly recommended.

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Porovnání možných opatření v nivách ke zvýšení jejich retenční kapacity

Stejně jako v předchozích letech i v roce 2010 bylo v České republice i celosvětově zaznamenáno mnoho ničivých povodňových událostí, kvůli kterým se problematika protipovodňových opatření a souvisejících efektů dostává stále více do popředí. Hovoří se o možnostech spojení přirozeného potenciálu údolních niv k tlumení povodňové vlny spolu s ryze technickými opatřeními k ochraně před povodněmi. Tím by došlo k zahrnutí přirozených retenčních vlastností niv do komplexního systému ochrany před povodněmi s mnoha dalšími přínosy. Na rozdíl od technických opatření, jejichž vliv je dostatečně kvantifikován, objektivní zhodnocení přírodě blízkých protipovodňových opatření momentálně chybí.

Příspěvek je proto zaměřen na prezentaci výzkumu zabývajícího se revitalizačními opatřeními v nivách a jejich významem v protipovodňové ochraně. Transformační účinek říčních niv je stanoven pomocí metod matematického modelování ve vybraných oblastech. Dvourozměrný hydraulický model je použit na třech úsecích povodí v České republice o délce 5–7 km. Transformační účinek je následně porovnán nejen pro stávající charakter niv, ale také pro různé teoretické scénáře v každé lokalitě.

Klíčová slova: retenční kapacita niv, protipovodňová ochrana, hydraulické modelování, revitalizační opatření

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