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THE EFFECT OF THE CONDITIONS OF A LANDSCAPE ON ITS RETENTION CAPACITY

ABSTRACT

Questions related to the occurrence, frequency, intensity, duration, characteristics and causes of floods have been discussed more in recent years. Two basic approaches to flood control often conflict. The first is based on the assumption of the considerable effect of a landscape's retention capacity, which can in fact prevent surface runoff generation and flood formation and can significantly transform flood wave. The second approach asserts that the retention capacity of a landscape is nearly negligible and that the only reliable flood protection can be provided by extending the technical structures of flood control measures mainly and directly on water courses. Two different approaches were applied to assess the effect of landscape conditions and revitalization measures on surface runoff and flood formation within a catchment and floodplain. The conclusion shows that the effect of landscape revitalization is very important, but mainly for low return periods of flood events, while for extreme events, the effect on landscapes and floodplains becomes less important and even negligible.

INTRODUCTION

The increase in hydrological and climatic extremes and the related frequency and intensity of the occurrence of flood events is a significant part of the discussion on flood control. Two main opinions on flood control principles and strategy are nowadays being reviewed by water managers and environmentalists.

The first opinion is based on the assumption that floods are mainly caused by anthropogenic changes in the landscape, especially massive deforestation, the consolidation of agricultural fields, the reduction in landscape diversity, unsuitably combined crop rotations, the incrementalization of urbanized areas, soil degradation and, last but not least, the regulation of stream channels and the intensive exploitation of floodplains. According to those arguments,

floods could be prevented by the massive and radical revitalization of landscapes, streams and their floodplains.

The second extreme is a purely technocratic approach, which neglects the natural retention capacity of a landscape and prefers technical retention and flood control elements such as water reservoirs, dry polders or increasing the capacity of water course channels to the harmless diversion of extreme peak discharges.

As both practical experience and theoretical knowledge show, the truth can be found somewhere in the middle of both extreme opinions. But the emotions of both extreme lobbying groups and disagreement on the question of the effectiveness of individual retention and flood control measures inhibit pragmatic decision-making. While the technocratic approach is relatively well described and manipulates known and verifiable mathematical, hydraulic

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KEY WORDS

- landscape revitalization,
- retention,
- surface runoff,
- flood wave transformation

and hydrological relations with measurable characteristics, the approach based on natural landscape retention mainly uses hypothetical information – for instance, flow through flood plains with varying degrees of roughness or the transformation of a flood wave in a non-prismatic channel and irregular flood plain. From a mathematical point of view, it is always a very difficult task, as it includes unsteady irregular flow, kinematic or even dynamic wave descriptions or two or three-dimensional flow modeling. The alternative to such methods is an attempt to apply significantly simplified approaches and tools to the description of processes related to the revitalization of landscapes, stream channels and their flood plains and their effect on surface runoff generation, its characteristics and transformation to a concentrated flow and flood wave.

The described project, the results of which are presented within this paper, represents an attempt to quantify the effect of revitalization measures on the production and characteristics of surface runoff. Two different methods of differing accuracy, for different scales and different approaches for an assessment of the above mentioned measures were used. But definitely, in both cases, a significant simplification of the running processes with respect to their physical principles is the basic assumption.

The first approach can be characterized as a “balanced” one, which is suitable for the characterization of larger landscape areas or catchments. This approach mainly concentrates on surface runoff generation and concerns the retention capacity of a landscape, including the effect of individual retention landscape elements not only with an areal, but also a linear, character. The retention potential of the individual elements has been assessed according to an expert estimation and speculation on unit retention volumes. The results obtained could be better used for general relations, deriving trends and documentation than for real flood control or retention measures designed for a certain locality.

The second approach, based on simple hydraulic-hydrological methods and the application of models in combination with GIS routines and generally available GIS data, is suitable for the assessment of revitalization measures in landscapes, streams and floodplains within medium to small catchments. The advantage of the two above-mentioned approaches is the possibility of assisting GIS and data actualization using remote sensing methods, as referred to for instance in [Krása, 2002].

The main task for both approaches and methods was to perform a number of scenarios based on simulations in real and model conditions and to try to derive general rules and conclusions concerning the possible effect of revitalization measures on surface runoff retention and flood wave transformation. It is also a contribution to answer the question of if and how much revitalization measures can contribute to flood prevention.

APPLICATION OF THE BALANCED METHOD

The main task of part of the project presented can be characterized mainly as:

- To compile a catalogue of revitalization measures that are practically applicable within a landscape and to characterize the revitalization effect of each of the measures listed
- To classify the revitalization effect of the individual measures
- To describe the retention effect and mechanism and the incidence of the retention of all the selected revitalization measures
- To classify the retention effect of the individual revitalization measures (point scale)
- To define the three different types of landscapes according to their relation to a natural stage. To prepare matrixes of applicable revitalization elements for each type of landscape to shift as close as possible to an ideal stage, with a synchronous maintenance of the productive functions of a landscape for the present state of the society. The stage will be characterized by the mentioned scaling (point) classification system.
- To apply the maximum number (structure) of revitalization elements for each of the defined types of a landscape
- To formulate appropriate conclusions regarding the possible and effective density of revitalizing (natural) elements within a landscape;
 - To define their basic parameters, desired from the point of view of the maximization of the revitalization effect
 - To answer the question of the retention effect of natural elements within a landscape

1.1 Catalogue of revitalizing elements within a landscape

The following system of revitalizing elements within a landscape has been defined for the presented case study, which can be designed within landscape planning or revitalization projects: **holding cover, forest, balk, green along communications, bank green along water courses and accompanying greenery along water courses, wind-break, wetland, small water reservoir, pool, fallow, orchard and garden, spread greenery (individual trees), grass strips, natural water course, natural meadow.**

To describe and assess the revitalization effect of individual elements, the personal experience of the authors and selected literature sources (mainly, The Stage of Ecological Stability Assessment, according to [Low, *et al.*, 1995]) have been used.

The basic principle of the operation and basic criteria of any revitalizing elements within a landscape is the improvement of its diversity and enabling the life of natural organisms at a given locality. From this point of view, it is essential to set up the conditions and environment which will be colonized by autochthonic

Tab. 1 Comparison of the resulting categorization of individual measures (elements) and resulting classification

Element No.	Type of measure	SES	SES - scaled	Fuller	Fuller - scaled	combination	Combination scaled
1	Forest	3	5.6	7	5.8	11.4	6
2	Holding cover	4	7.4	7	5.8	13.2	7
3	Balk	3	5.6	8	6.7	12.2	6
4	Green along communications	2	3.7	2	1.7	5.4	3
5	Bank greenery – water courses	4	7.4	1	0.8	8.2	4
6	Accompanying greenery-water courses	2	3.7	11	9.2	12.9	6
7	Wind-break	4	7.4	5	4.2	11.6	6
8	Wetland	2	3.7	15	12.5	16.2	8
9	Small water reservoir	4	7.4	11	9.2	16.6	8
10	Pool	4	7.4	13	10.8	18.2	9
11	Fallow	5	9.3	3	2.5	11.8	6
12	Orchard, garden	3	5.6	2	1.7	7.2	4
13	Spread greenery	3	5.6	4	3.3	8.9	4
14	Grass strips	2.5	4.6	8	6.7	11.3	6
15	Natural water course	5	9.3	14	11.7	20.9	10
16	Natural meadow	3.5	6.5	9	7.5	14.0	7
Σ		54	100.0	120	100.0	200.0	100

SES – Stage of Ecological Stability

organisms. To enable the life and development of the species, each element needs to have a certain scale (area, length, width, depth), which is given by the needs of individual organisms which are desired to survive or migrate.

1.2 Revitalization effect

The assessment of the revitalization effect of the individual types of measures is very complicated and, in any case, it depends a lot on the type of landscape where it should be applied. The goal of the methodology presented is to classify the revitalization effect of individual measures within a landscape through comparing them. The ideal result would be an assessment of how close the given measure is to the fully natural state of a given locality. But it is also important to mention that the ideal stage, not the climax stage, of the locality is understood, as it is unrealistic due to the economic and social functions of landscapes in Central Europe. The ideal stage is therefore assumed as one which is as close to natural conditions as possible, but the landscape can still fulfill the economic and social demands of a modern human being.

In order to compare the individual landscape units (elements), they were ordered according to a point rating, determined by two approaches:

- Assessment of the individual type of measure (element) according to its “Stage of Ecological Stability” [Low, *et al.*, 1995]. This methodology classifies the described localities into 6 classes according to their effect on ecological stability (0 – no effect, 5 – exceptional effect)
- Pair the mutual comparison with an application of the Fuller triangle [Říha, *et al.*, 1997]. The ecological effect of each pair of elements is compared and the one with a higher effect receives preference. The total effect of each individual type of element is obtained as the total number of preferences obtained.

In order to provide the described evaluation, a number of simplifying assumptions had to be adopted, which generally concerned not only the goals of the revitalization, but also the parameters of individual elements. Both of the described approaches were combined and the weight of the given element determined by the scaling of the total score according to both methods. The resulting classification can be found in Tab. 1.

In the next step, an appropriate space parameter (area, length, etc.) was set up for each type of measure (element), and its weight was then standardized per unit area.

1.3 Retention effect

The retention effect for individual landscape elements was also simplified and schematized in the next step. The general retention effect of the individual measures was first separated into three basic categories – interception, infiltration and surface retention; each of the element types was then characterized according to all three parts of the total retention. Using expert assessment and expert literature [e.g. Řezáč, 2002; Vrána, et al., 1995, etc.] the unit values of each retention part for each of the assessed landscape units were set up. The infiltration category also has to include the soil conditions at a given locality. Four general soil classes were therefore determined by the aggregation of the HPJ (Main Soil Units). The basic infiltration characteristics were then estimated for each of the defined groups; then, their spatial distribution within the CR, which also determines their predominant potential use, was derived [Šanda, et al., 2006]. The results can be seen in Tab. 2.

The total potential retention for each type of revitalization measure (element) was determined to be the sum of all three types of retention. The total assessed values of the retention for the individual revitalization elements are presented in Tab. 3.

1.4 Classification of elements

The classification of the individual revitalizing elements from the point of view of their retention effect was done by a standardization based on the mean absolute values of the retention capacity per unit of measure.

The mechanisms of the retention effect applied by the individual elements and their assessment were then discussed within the presented project. It is clearly shown that the most important process affecting the total retention capacity of a landscape is the infiltration into soil; moreover, there are characteristics of a causal rainfall event which also significantly affect the total retention of a catchment.

Fig. 1 Behavior of surface runoff for various rainfall events, initial retentions and soil types

An additional chart (Fig. 1) schematically documents the generation of surface runoff on a soil with various degrees of hydraulic conductivity, varying from sands up to well-settled loamy soils ($K = 10^{-4} - 10^{-7} \text{ m.s}^{-1}$) for the assumed event with a duration of 120 min. and a rainfall total of 10 – 60 mm. An initial retention of 10 mm was expected at the beginning of the event, which corresponds to the normal conditions of revitalization elements without a free water level.

The scheme presented documents that conclusively demonstrate that a rainfall event with a total higher than 20 mm.h^{-1} and a duration longer than 60 min unfailingly generates surface runoff.

The scheme presented includes many significant simplifications, which have been mentioned several times in the above text. To derive the chart on Fig. 1, especially its temporal distribution, physically-based mathematical simulation models can be used with a much higher degree of precision and a much better description of all the participating processes. Nevertheless, the presented part

Tab. 2 Summary of soil classification and its characteristics

Soil group	Included HPJ (Main Soil Units)	Characteristics	Average Field Capacity AFC (%)	AFC recalculated to 0.3 m profile (mm)	$K_{\text{sat}} (\text{m.s}^{-1})$
I	Chernozems	valleys, fertile, deep	35.9	110	$2.0 \cdot 10^{-6}$
	haplic Luvisols				
	Albeluvisols				
II	rendzic Leptosols	stony	40.9	120	$4.7 \cdot 10^{-6}$
	lithic Leptosols				
III	Cambisols	medium elevations, the most spread	33.0	100	$4.3 \cdot 10^{-6}$
	gleyic Stagnosols				
IV	Fluvisols	wet, valley bottoms	29.9	90	$1.0 \cdot 10^{-6}$
	Gleysols				

Tab. 3 Retention capacity of types of individual revitalization measures (elements) (mm)

	Interception			Infiltration			Surface retention			Total retention		
	min.	average	max.	min.	average	max.	min.	average	max.	min.	average	max.
Forest	3	7	9	50	110	150	2	4	6	55	121	165
Holding cover	6	9	11	60	120	160	2	5	10	68	134	181
Balk	5	8	10	50	130	180	12	86	168	67	224	358
Green along communications	2	4	6	40	100	140	1	3	5	43	107	151
Bank greenery – water courses	2	4	6	30	70	100	1	2	3	33	76	109
Accompanying greenery-water courses	3	6	8	60	100	140	2	5	10	65	111	158
Wind-break	5	8	10	60	120	160	2	5	10	67	133	180
Wetland	2	4	6	0	1	20	50	300	500	52	305	508
Small water reservoir	0.1	0.5	1.0	0	0	0	50	200	2000	50	201	2001
Pool	0.1	0.5	1.0	0	0	0	300	500	700	300	500	701
Fallow	0.2	0.3	0.4	80	105	120	2	3	5	82	108	125
Orchard, garden	1.2	2.6	4.0	60	105	120	2	3	6	63	111	130
Spread greenery	3	5	7	60	100	140	1	3	6	64	108	153
Grass strips	0.1	0.5	1.0	50	90	130	1	3	6	51	94	137
Natural water course	0	0	0	0	0	0	100	450	600	100	450	600
Natural meadow	0	0.5	1.0	80	105	130	1	3	5	81	108	136

of the projects and therefore also the report seek to categorize the available types of revitalization and retention measures according to their potential retention effect. Therefore, a simplifying, but transparent and synoptic approach, was selected, which allows for the generalization of the results obtained and trends.

1.5 Application of the classifications within a landscape

To be able to apply the proposed classification systems under certain real conditions, it is necessary to define the basic types of landscape. Three basic types were identified as follows:

- Nature-like landscape – a highly diversified landscape with a high presence of forests, richly distributed greenery and a mosaic of extensively used agricultural fields, a low density communication network and a low number of villages with small extensions.
- Medium anthropogenic landscape – a landscape with a medium proportion of forests, miscellaneous agricultural uses and a medium density of communication networks and settlements.
- Highly anthropogenic landscape – a landscape with a negligible proportion of forests and greenery, very intensive agricultural production, a high density communication network and

dense settlements, which are mainly concentrated into larger complexes.

The quantification of the individual characteristics was presented on sample 3 x 4 km plots, randomly selected on maps with a scale of 1:50,000.

1.6 The application of the classification systems

In the first step of this applied part of the study, the model areas (sample plots) were classified in their current (original) state, using the above-described classification scale. In the second step, the model of the revitalization measures which can be applied to the individual landscape types was defined. Maximization of the revitalization effect and maintaining the production characteristics of the given landscape type were assumed. This designed system was then applied to each of the landscape types (sample plots). The results of the revitalization measures applied are quantified and presented for medium anthropogenic landscape as example in Tabs. 4.

The above presented tables of the result document the land-use changes in the case of the adoption of the revitalization measures. The revitalization methodology measures the design; its system and extension have been described above and can be the subject

Tab. 4 Comparison of land-use for original situation and after revitalization measures in medium anthropogenic landscape

Medium anthropogenic landscape		Original state				Designed state				Change
		pcs.	km	ha	%	pcs.	km	ha	%	± %
Forest				360	30.00			372.3	31.03	+1.03
Urban areas				96	8.00			96	8.00	0
Water course – out of forest			8.4	4.2	0.35		8.4	4.2	0.35	0
	Natural		2.5	1.25	0.10		5	2.5	0.21	+0.11
	Bank greenery		6	3	0.25		8.4	4.2	0.35	+0.1
	Accompanying greenery		2.5	5	0.42		5	10	0.83	+0.41
Communications – out of forest			10	5	0.42		10	5	0.42	0
	One side		0	0	0.00		5	2.5	0.21	+0.21
	Both sides		5	5	0.42		5	5	0.42	0
Small water reservoir		6		18	1.50	6		18	1.50	0
Wetlands		2		0.8	0.07	4		1.6	0.13	+0.06
Pools		1		0.6	0.05	4		2.4	0.20	+0.15
Greenery	Holding cover		5	10	0.83		12	24	2.00	+1.17
	Balk		8	8	0.67		12	12	1.00	+0.33
	Spread greenery				0.00			0.12	0.01	+0.01
	Wind-break		0	0	0.00		0	0	0.00	0
Agricultural land				684.4	57.03			642.7	53.56	-3.74
	Arable			410.6	34.22			279.3	23.28	-10.94
	Grass buffer strips		0		0		18	36	3.00	+3.0
	Permanent grass			273.8	22.81			265.8	22.15	-0.66
	Natural meadow				0.00			41.06	3.42	+3.42
	Orchards				0.00			20.53	1.71	+1.71
	Fallow				0.00			0	0.00	0
Total				1200	100			1200	100	0.0

of a broad discussion. Such measures were preferred that would not heavily affect the existing system of landscape exploitation; however, these are not halfway revitalization measures. There can, of course, be doubts about the applicability of the designed measures and their extension, but even now, only very rarely is a full system of designed revitalization measures within the frame of a landscape revitalization project brought into fruition.

Therefore, if landscape revitalization is declared one of the priorities for the development of the Czech countryside, its adoption would not endanger the economic situation in the given regions. Land use changes concern only a small percentage of the catchment areas in all the cases examined. When talking, for instance, about the category of “arable land,” a decrease of 32 % occurs in the case of a medium-anthropogenic landscape and 17.2 % in the case of a highly-anthropogenic landscape. But it should be taken

into account that most of this land is being converted within the agricultural land category into orchards and gardens, which means that these localities will keep their productive character.

1.7 Classification of the effects of revitalization and retention

The next step was the final assessment of the revitalization and retention effects of the designed measures for all three types of landscape. Due to the lack of space in this paper, only the assessment for the medium-anthropogenic landscape is presented in the following paragraphs. The individual measures designed for each of the landscape types and their effects have been quantified in previous parts of the report.

The next summarizing table, Tab. 5, presents in a transparent form a comparison of the total values of the revitalization and retention

effect for the three given types of landscape and two types of land use – the current one and the one after the adoption of the revitalization measures. The results are at first presented in absolute values related to the examined plot of 12 km² and the second in relative values related to the 1 km² plot. Also, the proportional increment of the resulting values related to the revitalization measures is presented in order to compare them better.

The table presented above documents the significant increase in both the revitalization and retention effect due to the designed measures, which varies between 25 to 38% for the nature-like type of landscape. The effect rises up to 245 to 311% for the highly anthropogenic landscape. In the case of the nature-like type of landscape, the mentioned change is conditioned by affecting 16% of the total area (change of 16% in the arable land and permanent grass to other types of elements). In the case of the highly anthropogenic landscape, only 12.5% of the arable land is converted to other land-use types (other landscape elements).

The above-mentioned effects can be understood as the maximum that can be done for the given type of landscape. If further improvements are required, that would practically mean reclassifying the given landscape one stage lower, concerning the land-use type (production potential). This would certainly have a positive effect on nature conservation activities, but rather negative effects on the economic and social sectors.

1.8 Sample calculation of the available retention volume for a medium-anthropogenic landscape

The last step of the presented project was an attempt to estimate the total disposable retention space in a given landscape type (in this case, in a medium anthropogenic landscape) in its current form and after the adoption of the designed measures. The processing was identical to that described above. The only extension was the incorporation of the category of arable land, which has nearly no revitalizing effect, but its potential in infiltration and surface retention is far from negligible. Tab. 6 therefore documents the difference between the retention capacities if only “natural elements” are assumed and all the areas of interest are taken into account. In both cases, the current and design states are assessed.

The above-presented proportion between the volume of stored water within the area of interest in its current stage and after the adoption of the design for the natural elements is 1.04 and 1.32 for the entire area. If the absolute values are compared, they show that only agricultural land alone can theoretically store more than double the water volume than all the rest of the area (the proportion of stored water if only the natural elements are assumed for the entire area was 2.53 for the current stage and 1.95 for the designed stage). This rate indicates a significant increase in the effect of the revitalization measures on the total retention of the landscape in the design stage, but it is still not the crucial part.

This fact can be used and presented several ways (considering the retention capacity and revitalization activities):

- Revitalization (natural) elements are very important within the landscape from the point of view of retention, and the analysis performed documents that their retention potential significantly exceeds the relative values of the retention capacity of other types of elements.
- The retention capacity of the soil definitely presents the most important part of the total retention capacity of the landscape. Therefore, ensuring good soil conditions is the most effective measure to support retention capacity within a landscape.
- The values of the potential retention are only hypothetical; for practical application they should be reduced, based on hydraulic conductivity values, as it is the parameter that determines the storage of water in a soil profile in reality.

1.9 Conclusion of section and discussion

The proposed methodology for the assessment of the revitalization and the retention effect of the revitalization measures in a landscape has been presented in this part of the paper. This proposed methodology should be subject to broad discussion from many points of view. But it should help as one of the steps when searching for a way to assess the effectiveness of designed measures within a landscape from the point of view of not only their revitalization but also their retention effect.

The entire project is based on many simplifying steps for the typology of:

Tab. 5 Final recapitulation of the revitalization and retention effects for original and designed states and for individual types of landscape

Landscape type	Absolute values (per 1200 ha)				Relative values (per 1 ha)				Rate of increment	
	Original state		Designed state		Original state		Designed state			
	Revit.	Ret.	Revit.	Ret.	Revit.	Ret.	Revit.	Ret.	Rev.	Ret.
Natural-like	5552	5406.7	7645.4	6761.6	4.63	4.51	6.37	5.63	1.38	1.25
Medium anthropog.	3897.6	3085.3	6742.5	4077	3.25	2.57	5.62	3.40	1.73	1.32
Highly anthropog.	1244	634	3872	1566.1	1.04	0.53	3.23	1.30	3.11	2.45

Tab. 6 Intercepted amount of water within an entire catchment compared to the volume, stored only within the revitalization elements for current and designed states in conditions of a medium-anthropogenic landscape

Element	Current (ha)	Design (ha)	Mean retention (mm)	Total retention – entire area (m ³)		Total retention –natural elem. (m ³)	
				Current	Design	Current	Design
Forest	360	372.3	121	435600	450483	435600	450483
Holding cover	10	24	134	13400	32160	13400	32160
Balk	8	12	224	17920	26880	17920	26880
Greenery along communications – one sided	0	2.5	107	0	2675	0	2675
Greenery along communications – double sided	5	5	107	5350	5350	5350	5350
Bank greenery – water courses	3	4.2	76	2280	3192	2280	3192
Accompanying greenery-water courses	5	10	111	5550	11100	5550	11100
Wind-break	0	0	133	0	0	0	0
Wetland	0.8	1.6	305	2440	4880	2440	4880
Small water reservoir	18	18	201	36180	36180	36180	36180
Pool	0.6	2.4	500	3000	12000	3000	12000
Fallow	0	0	108	0	0	0	0
Orchard, garden	0	20.53	111	0	22788.3	0	22788
Spread greenery	0	0.12	108	0	129.6	0	129.6
Grass strips	0	36	94	0	33840	0	33840
Natural water course	1.25	2.5	450	5625	11250	5625	11250
Natural meadow	0	41.06	108	0	44344.8	0	44345
Arable land	410.64	279.32	103.2	423780	288258		
Permanent grass	273.76	265.76	113.5	310718	301638		
Urban areas	96	96	75.8	72768	72768		
Total	1192.1	1193.3		1334611	1359917	527345	697253

- a landscape according to its land-use
- involved elements concerning their dimensions and vegetation cover
- involved elements concerning their revitalization effect
- soils concerning their porosity and hydraulic conductivity
- proportion of the individual types of elements within a landscape
- limits of the applicability of the individual measures

The presented method is indicated for the classification of medium to large areas concerning their current situation and their potential improvements due to the application of revitalization measures with a retention effect. As such, this method should be understood only as estimative, and its applicability should never be overestimated, especially for small areas. But the method can also be easily

applied for the assessment and comparison of other revitalization measure scenarios. Similar revitalization and retention effects can be achieved by different combinations of measures with different spatial extensions and patterns.

THE APPLICATION OF THE WMS MODEL FOR A VARIANT DESIGN OF FLOOD CONTROL MEASURES WITHIN MEDIUM CATCHMENTS

The goal of this part of the project was to test the effect of mainly areal measures on the formation and propagation of surface runoff within small to medium catchments. A further task was to assess the practical applicability of the Watershed Modeling System (the WMS mathematical model) [Anonymous, 1999] for these purposes.

Mathematical simulation tools can be effectively used for the assessment of the effects of land use changes on increases or reductions of flood hazards. A large number of different tools, methods and models exist which can be applied for this purpose. For instance, the HEC-1 model [Hydrologic Engineering Center, 1998] can be applied for the described assessment, and it can be practically handled, for instance, within the frame of the WMS tool. Individual areal measures can be taken within the HEC-1 model described using the CN value change, which is used for estimating the effective depth of rainfall using the SCS-CN method.

An assessment of the measures applied directly to the streams can be effectively performed using hydraulic-hydrological models. HEC-1 is a hydrological model, which is also applicable for such tasks; of the hydraulic models, for instance, the HEC-RAS model [e.g., Brunner, 2002a, 2002b] can be mentioned. In the case of the HEC-1 model, revitalization measures within a channel can be simulated by inputs into the simulation, which describe the geometry of the surface roughness of the channel. The model then calculates the channel flow's transformation.

1.10 Scenarios of land-use changes and stream channel revitalization measures

The effect of the mentioned designed measures was analyzed with the assistance of the WMS interface, using the HEC-1 hydrological model. To run this model, the Curve Number method (CN) [Janeček, et al., 1992] was selected in combination with a unit hydrograph approach [Brutsaert, 2005]. Wave transformation in a river channel has been approximated using the Muskingum-Cunge method [Hydrologic Engineering Center, 1998]. The reason one should use this approach (regardless of its age and disadvantages) is mainly its simplicity, relevant results and input data availability. The results presented within this paper originate from analyses done within two experimental catchments. The first of them, the Blinka catchment, is located east of Prague and has an area of around 24 km². This catchment is characterized mainly by its simple hydrographical network and intensive agricultural use.

The second catchment examined was Olesna, which is located close to the town of Pelhřimov in south-east Bohemia. The area of the catchment is around 19 km². The main characteristics of this catchment are: a wide shape, a branched, almost fan-shaped, hydrographical network, and steep slopes. Concerning its agricultural use, this catchment can be characterized as having low-intensity farming, with a medium proportion of arable land.

In relation to the areal measures within the catchment, analyses of the effect of land-use changes (mainly the reduction of the arable land area or its more extensive use) on surface runoff production was analyzed within both catchments. Practically, the mentioned measures were interpreted using changes in the CN value for the

given fields (arable land, permanent grass, forests). These changes were represented by the following scenarios of land-use on arable land:

- LU 01 – actual situation in 2006
- LU 02 - conversion of permanent grass to arable land (simulation of a worse situation concerning surface runoff production; close to unified, socialistic farming)
- LU 03 - conversion of arable land to permanent grass (simulation of extensive land-use with the support of extensive pasture production of meat – current trends)
- LU 04 – conversion of agricultural land into forest – extreme scenario, which is not realistic, but gives information about the limits of the effects of land use changes on surface runoff production

All the described scenarios were assumed in their most extreme alternative – the change was always applied to an entire area of arable land. It is clear that such scenarios are unrealistic in the presented form, but they are appropriate for an analysis of the trends. The outputs should then be understood more in their qualitative rather than quantitative form.

An assessment of the potential effect of the revitalization measures on the formation of flood waves and their transformation in a stream channel was the next task of the presented project. Revitalization measures in this section, mainly changes in the cross section of the channel, its roughness, and the characteristics of the adjacent floodplain, have been assumed.

Three different alternatives were considered. The basic alternative was the actual size of the channel at individual intervals, which were measured during a field survey. A revitalization measure was adopted by reducing the size of the catchment to one half of its actual size. The purely technocratic approach to flood control was interpreted by the alternative, where the size of the channel's cross section was doubled.

The next possible effect of the stream revitalization is a change in its roughness. This could be well documented using the example of streams which in the past were regulated by straightening them. These streams were shortened, and mostly smooth, often concrete, panels were used, with a very low degree of roughness, for their stabilization. To the contrary, a bank and accompanying greenery are often planted along the streams within the frame of revitalization activities, which increase the roughness of the channel banks and floodplains. A total of five individual channel and floodplain roughness combinations were worked out within the analysis performed.

It would, of course, be possible to simulate a number of various combinations of the described scenarios. But this would be effective to do in the event the task is to solve a real situation and find the best alternative for a given locality. But the task of the project presented

was to present trends and tendencies. Therefore, constant conditions were always assumed when the effect of an individual phenomenon was examined. If there were exceptions to this rule, they are mentioned in the text below. But most of the simulations were done with the assumption of varying rainfall events to improve the assessment of the individual scenarios analyzed. The characteristics of these events were defined based on 24 hour totals with return periods varying from 2 to 100 years [Šťamaš *et al.*, 1985]. Using a standard method of total rainfall reduction at a certain time [Hráden and Kovář, 1997] the riskiest events were defined for each examined subcatchment. The most risky alternative was an event with a duration equal to the length of time of the concentration for a given catchment.

1.11 Results

There are results of the analyses made in the Olesna and Blinka catchments. The general conclusions and trends are nevertheless based on a number of simulations performed on a number of other catchments.

The runoff hydrograph is the output of each simulation for each catchment. Entire (complex) hydrographs for individual scenarios were compared in the first step. During the second step, only the main characteristics of the hydrographs, such as peak discharge, time of peak discharge and total volume of direct runoff were analyzed and compared. These analyses predicate that land use changes mainly affect the volume of direct runoff and, therefore, also peak discharge values. The shift of the peak discharge time is not important in these cases. These results were obtained by simulations on both experimental catchments, but have been confirmed by simulations on a number of other catchments. But, it should be mentioned that the rainfall events and land-use changes included in the analyses were extreme ones. If realistic changes and events were simulated, the effect obtained would also be less significant. But the task of the project was to formulate and confirm trends which could be expected for the individual types of the measures. The results of this part of the simulations are presented in Fig. 3.

In the case of the simulation of the effect of various combinations of the surface roughness of a stream channel and floodplain, it was found that it mainly affects the progress of a flood wave through a hydrographic network. It can generally be concluded that increasing the roughness of a channel and floodplain decreases the flow velocity and therefore slows down the progress of the peak discharge. The effect of these measures on the volume of a peak discharge and flood wave is nevertheless nearly negligible. A comparison of the individual scenarios can be seen in Fig. 2 (series “D”).

The results of the analyses concerning the variations of the cross section area of the channels for the individual intervals of a channel document the original assumption that this type of

Fig. 2 Summary chart for all applied scenarios of flood control measures for a rainfall event with a return period of 20 years for the Blinka catchment

measure has an effect mainly on the progress of hydrographs through a hydrographic network. The trend is the same as for scenarios concerning variations of surface roughness. The speed of the progress of a peak discharge downstream through a channel increases with the increasing of the cross section of the channel. This tendency is even accentuated by the fact that the channel itself usually has a lower degree of roughness than a floodplain even if it is intensively used and a channel with a large cross section can route a much higher discharge. The dimension of the channel thus determines the moment when the roughness of a floodplain (where the discharge is significantly slower) can act. As indicated by the results, the cross section of a channel is much less significant for the resulting peak discharge value than the areal land-use changes. The direct effect on the total direct runoff volume is negligible. A comparison of the individual alternatives of the dimensions of channels can be seen in Fig. 2 (series “K”).

Further conclusions can additionally be derived from the results of the simulations performed; for instance, the effect of the individual types of measures was assessed relative to the rainfall characteristics (mainly the total). All the simulated scenarios have therefore been applied to a series of different rainfall events. The variation coefficients were then determined for the individual data sets concerning the changes in runoff due to the individual measures related to the rainfall return period. The variation coefficients show a relative scatter around the medium value. The results show that the effect of all the examined types of measures decreases with an increasing total rainfall (as indicated by the decreasing value of the variation coefficient) – see Fig. 4. This conclusion is valid for all the performed scenarios and for the basic parameters of a surface runoff – total volume of flood wave, peak discharge and time of peak discharge.

Fig. 3 Summary chart of land-use changes for rainfall events with return periods of 2 to 100 years for the Blinka catchment

Fig. 4 Variation coefficients for scenarios of cross section area for the channel for the Blinka catchment

1.12 Conclusions

Up to now the analyses and simulations performed show that both areal land-use changes and linear measures applied to stream channels or in floodplains can have a positive effect on direct runoff characteristics. From the point of view of flood prevention, the effectiveness of a rainfall event with lower return periods should especially be appreciated. In these cases, the reduction of peak discharges can prevent the spillage of water from a channel mainly in localities where lives, health or property can be endangered. This is relevant in places where spilling water is mainly passive to

stagnant; in cases where the damage is caused by a high-velocity water flow, the described mechanisms will not work very well, and a relatively mild decrease of a peak discharge will probably not solve the problem.

Concerning the practical application of flood prevention and public alert systems in the future, the deceleration of peak discharges could have a very positive effect and provide more chances for the implementation of emergency flood protection measures. On the other hand, one should take into account that the running of a flood process caused by a storm event in small catchments is that a fast decelerating effect is negligible.

Generally, it can be concluded that revitalization measures such as a runoff hydrograph will have a positive effect on the formation of flood situations concerning their basic characteristics. This effect nevertheless decreases with a rising return period (total) of a rainfall event. It can therefore be stated that for a complex approach to flood prevention, the most effective alternative is a combination of land-use and revitalization measures in a catchment to decrease the volume of the direct runoff and transform a runoff wave with a lower return period with technical measures directly on the stream to store, transform or divert the flood wave through or around protected localities mainly for extreme return period events.

FINAL CONCLUSIONS

At the end of the presented paper, it can be concluded that both the methods and spatial approaches applied have their logical place in practical management and should not be neglected, but also not overestimated. The project documented that revitalization and landscape management have an important role in the retention capacity of a landscape and therefore also in flood control prevention. But in both approaches it has been proved that landscape conditions play an important role mainly in cases of a small-to-moderate magnitude of flood events. If expressed on a time scale, one can speak about return periods of up to 10 or a maximum of 20 years. Therefore, the conditions of a landscape should be managed and maintained with special care. The most important retention element within a landscape is soil, which in practice is very often underestimated and neglected concerning proper care and maintenance. In the case of the appearance of flood events with a return period of over 20 years, the effect of management practices and landscape characteristics generally decreases very quickly. If the land or structures have to be protected against such extreme events, it is necessary either to apply technical flood control measures or to respect floodplains, maintain open space for the passing of a flood and locate important structures outside such hazardous areas. The advantage of technical flood control measures (such as increasing channel capacity, levees,

dams, retention reservoirs or dry polders, etc.) is that it allows for a much more intensive utilization of a landscape, but absolute certainty never exists concerning the protection level. In the case of the collapse of such control measures, damages are much higher, as territory is used as in the case of no risk. Additionally, there is always the risk of the failure of the human factor, as we can learn from history, where big disasters were mainly caused by human and not technical or technological failures.

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