INFLUENCE OF LANDSCAPE RETENTION CAPACITY UPON FLOOD PROCESSES IN JIČÍNKA RIVER BASIN

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Abstract

In a survey of landscape retention capability results of measurements obtained during the disastrous flood in June 2009 were used. The original method based on the balance among the daily precipitation fallen on the basin with discharges in the final profile was used on the analogy with transformation of the flood discharge through a reservoir. Following basin retention are defined: dynamic R_d, static Rs including the underground retention Rug and evaporation E, and total R_t. Main principal criteria were the effective static retention of the basin R_{sef} and a coefficient of the effective static basin retention ρ_{sef} (3). The coefficient of reducing flood culmination λ_{cul} (4) was calculated, too. Also investigated factors having the most influence on a retention capacity of a basin are introduced. Summary of results are shown in the Tab. I. Values of the most important criterion quantities are marked in shadow colour. The results show, for example, that the found out coefficient ρ_{sef} is 0.52. It means that the soil (and slightly a vapour, too) in the basin caught 52% of volume of wave in the time of culmination discharge in a basin. Also some further interested findings are introduced in the results and conclusions.

Keywords: landscape, retention, flood flows, river basin

INTRODUCTION

During the June, 2009 the Czech Republic was suffered by destructive floods. Regions of the Northern Moravia and parts of the North and Southwest Bohemia were seriously damaged. Flows often higher than centenary ones killed a several peoples, and made huge economical damages, indeed. Such an event is therefore calling for a radical solution, aiming at reduction, eventually at the elimination of catastrophic impacts of such extreme climatic phenomena. The specialists from the water management range and the specialists for nature conservation are still discussing how to protect the landscape against floods in an optimal way (Prudký, Spitz, 2003). The principal problem is whether to prefer a construction of new reservoirs, eventually a reconstruction of the existing ones, or to increase a retention capacity of the landscape. Methods of a modification of the flood flows using the retention capacity of the reservoir's space (dams, ponds, polders, inundation) are more or less known, while methods of estimation of a landscape retention at the extremely high precipitation are not developed enough, therefore the appropriate quantitative data are missing about it (Spitz, Dumbrovský, Podhrázská, 2000).

Our contribution is therefore aiming at the way of obtaining the proper data to estimate a retention capacity of the landscape during floods, and its application for Jičínka river basin. It was afflicted by floods due to the short term extreme precipitation, failing in the evening 24 th of June, 2009.

The contribution is summing up a knowledge and investigation gained at the solution problems mentioned above at the study, prepared by Dumbrovský *et al.* (1998) within the government project „Evaluation of the flood situation July, 1997".

MATERIALS AND METHODS

A method used contains of two parts: an approach to the quantitative evaluation of the retention

ability of the landscape within a basin, and the way of quantification of factors influencing a retention capacity of a basin.

Quantification of the retention capacity of a basin

A retention capacity of the landscape was investigated for the entire basin by balancing hourly precipitation falls at the basin, and flows at the final profile. A basic principle of the balance approach is at the analogy of filling and evacuation of the retention space of the water reservoirs during the transformation of a flood flow through the resevoir, considering, that the *total water retention* R_t contains of four principal components (Spitz, Prudký, 2000):

- *surface retention* R_{sf},
- *hypodermic retention* R_{hd} containing the subsurface water moving with subsurface water bearing layers,
- *underground retention* R_{ug} containing of a water caught at capillaries of the not saturated soil zones, and of a gravitation infiltrated water, increasing the reserve of the underground water,
- *evapotranspiration E*, i.e. a transpiration from the land surface, together with a transpiration by plants, and interception, i.e. a part of water remaining on the surface of plants.

The used method of determining the retention capacity of the basin is also based on the separation of components of runoff, which dealt many of authors (Kulhavý *et al.*, 2001). In this article has been applied method of analysis of subsidence branch, which dealt in detail for example Slepička *et al.*, 1989; Kněžek, Kessl, 2000, or Serrano, 1997.

During flood duration the volume of the underground retention and of evapotranspiration is changing much slower than volumes of the surface, and hypodermic retention. A sum of these retentions is therefore called a *dynamic retention* R_d. A sum of the underground retention and of an evapotranspiration is called the *static retention* R_s (Chow Ven Te, 1964). A division of the total basin retention R_t to the individual components is shown in the Fig 1.

A relation between the instantaneous total basin retention, a sum of the *hourly precipitation* ΣH_i and a sum of the *hourly flow* off ΣQ_i during a time interval of *i*-hours since a beginning of a flood may be expressed by the following equation:

$$R_{ti} = \sum_i H_i - \sum_i Q_i , \tag{1}$$

while

$$R_{ti} = R_{di} + R_{si}. \tag{2}$$

From the hourly evaluation of data it is therefore possible at the every hour, or for a given time interval to quantify a total retention of a basin R_{ci}, incl. its dynamic R_{di}, and static R_{si} components.

From the point of view of the retention evaluation at the time of a flood, a maximum value of the instantaneous R_{ti} is most important, which decrease the precipitation peak. The value was called the *efficient total basin retention* R_{tef}, and its components are similarly called the *efficient dynamic basin retention* R_{def}, and an *efficient static basin retention* R_{sef}. The efficient total basin retention is taking place usually at the maximal instantaneous (at our case the hourly one) total flow off of the basin (surface flow off + hypodermic + underground ones) at the final profile.

To be able to compare basin researched, the coefficients of retention have been established, i.e. the efficient values of a retention were compared
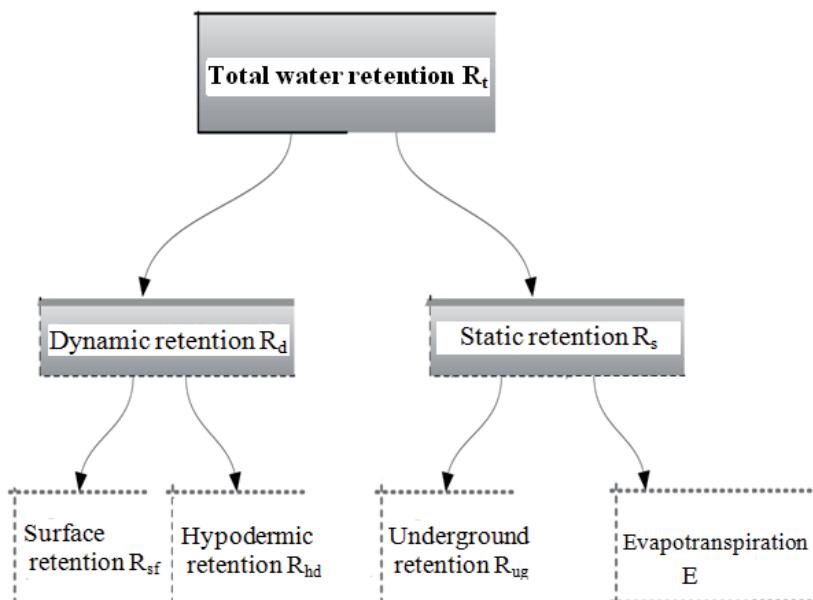
1: *Diagram of the distribution of total retention capacity of a basin R_t to the individual components*

with the volume of the flood wave (i.e. a sum of the *precipitation amount Hi* from the first to last, generally to the n-th hour), which initiated the flood. For instance, a *coefficient of the efficient static basin retention* ρ_{sef} is:

$$\rho_{sef} = \frac{R_{sef}}{\sum_{i=1}^{n} H_i}. \tag{3}$$

Similarly a *coefficient of the efficient dynamic basin retention* ρ_{def}, and a *coefficient of the total basin retention* ρ_{tef} were established. The other important characteristics of a flood are a *maximum hourly precipitation H_{max}*, and a *maximum hourly flow Q_{max}*. It was therefore established a *coefficient of a decrease of the flood culmination λ_{cul}*, expressing a decrease of the precipitation flood peak, due to the total efficient basin retention:

$$\lambda_{kul} = \frac{Q_{max}}{H_{max}}. \tag{4}$$

Since we had hourly amounts of precipitation, and flow floods at our disposal only, we couldn't evaluate time retardation between of maximum flow and maximum precipitation.

Since the paper is aiming at the evaluation a landscape retention capacity during the flood, i.e. to estimate a part of a flood precipitation a basin is able to retain without damages, and to relieve out, (i.e. there was necessary to estimate a part of the flood precipitation caught by a soil and by a vapour), the principal criteria was the *efficient static retention R_{sef}*, and a *coefficient of the efficient static retention* ρ_{sef}.

Quantification of principal factors affecting the retention capacity of a basin

Retention ability of the basin depends on many factors such as: geological structure, type of soil, topographic conditions, natural and hydrographic net (Mioduszewski, 1998).

At Jičínka river basin the factors were evaluated, afflicting a retention basin capacity. These important factors were:
a) *land areas according to the way of land use and built-up area,*
b) *geo-morphologic conditions* characterised by an average slope of a basin,
c) *hydrologic soil conditions* of the agricultural land, divided into 4 groups, A-D, according to a speed of infiltration, i.e.:
A – soils with a high speed of infiltration, higher than 0.12 mm.min^{-1},
B – soils with a middle speed of infiltration from 0.06 to o.12 mm.min^{-1},
C – soils with a low speed of infiltration from 0.02 to 0.06 mm.min^{-1},
D – soils with the very low speed of infiltration, less than 0.02 mm.min^{-1}.

d) *hydrogeology conditions of a subsoil,*
e) *shape of the basin*, characterised by the dimensionless coefficient ω, taking in account a size of a basin F, and a length of a flow valley L, estimated according to the relation:

$$\omega = \frac{F}{L^2}, \tag{5}$$

which expresses a relation between an average width of a basin, and a length of the flow valley; a coefficient ω has a value less than 0.25 for a fan-shaped basins, and larger than 0.25 for an oblong shaped basins,
f) *an average soil moisture before a flood precipitation*, evaluated by the antecedent precipitation index, marked as *API* including a parameter of the declination k < 1, (experimental values of which range from 0.85 to 0.98), and a value P_t of the precipitation lasted t days, at our case 5 days before a start of the flood precipitation, according to a relation:

$$API_t = \sum_{1}^{t} P_t \times k^t. \tag{6}$$

These above factors were determined primarily using the tools of ArcGis 9.3. For determine characteristics of streams and their basins were used as the basis database DIBAVOD (Source: TGM WRI), land use layer was prepared combination of digital data layers LPIS and own field reconnaissance after the flood. Hydropedologic soil properties were derived from the digital soil layer of estimated pedologic-ecological unit. For the processing of hydrological and climatological calculations were used standard tools of Microsoft Excel 2007.

RESULTS

Analysis of contributing factors

Runoff and retention rates in Jičínka river basin by flood in June 2009, is influenced by complex of factors, climatic, hydrological, hydropedologic, factor of vegetation (land use) and morphology.

Vegetation cover

Representation of land use (Fig. 2) is an important aspect for retention and runoff conditions in the river basin, and land use is the only factor that can be affected by human activities directly. Crucial to the formation of runoff processes were representative of the current crops. In this case representation of erosive dangerous plants (Fig. 3) was fortunately low. The higher proportion of wide-row crops in the river basin it can be assumed even more serious consequences of flood.

Morphological conditions

Further important factor that significantly affects the characteristics of runoff and retention capacity is
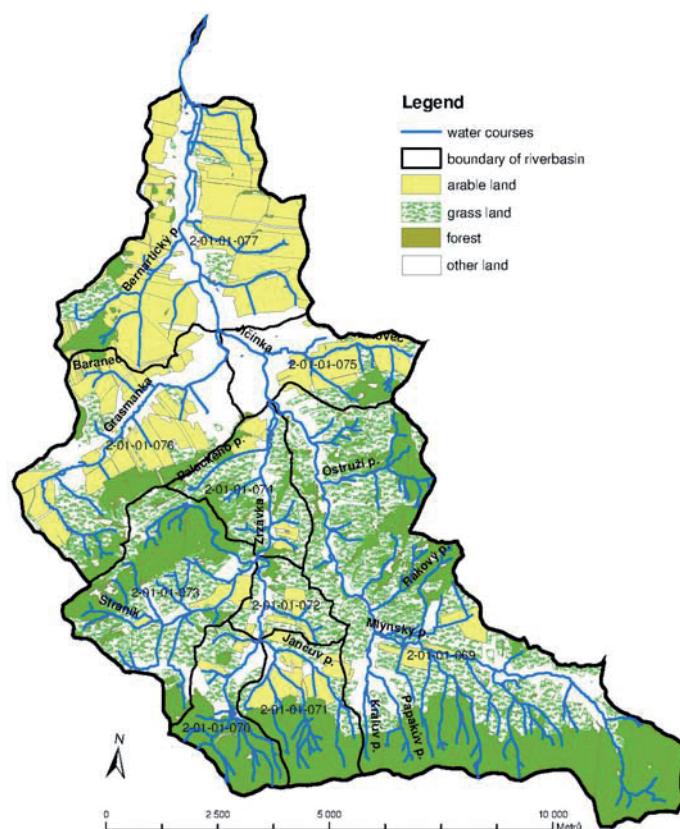
2: *Land Use during flood situation*
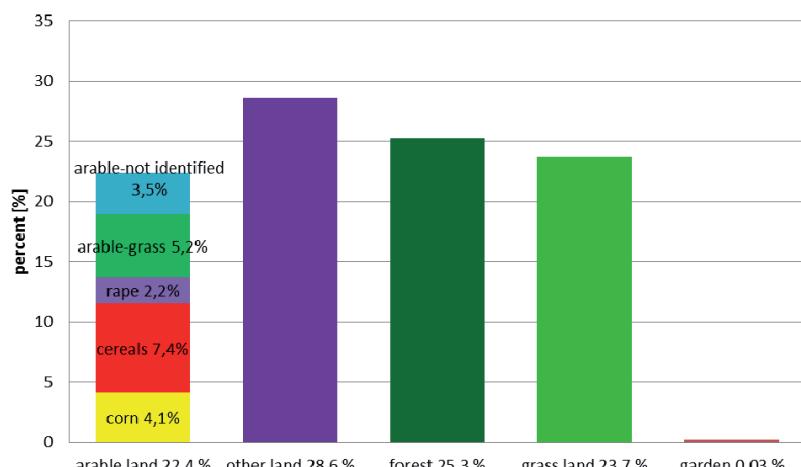
3: *Crops during flood situation*

I: *Morfological characteristics of a catchment*

Slope category	Spatial representation of category [%]
0–5%	25.2
5–10%	25.6
10–15%	16.6
15–20%	10.9
20–30%	12.3
nad 30%	9.4

slope. Conditions of the area are shown in the Tab. I. In the Jičínka river basin is average of slope 13.2%.

Hydrological conditions

Conditions of the area are shown in the Fig. 4.

Climatic conditions

The primary cause of flood in the Jičínka river basin was as a rainfall in the evening of 24. 6. 2009, which reached maximum intensity between 19 and 22 hours according to local residents, so the
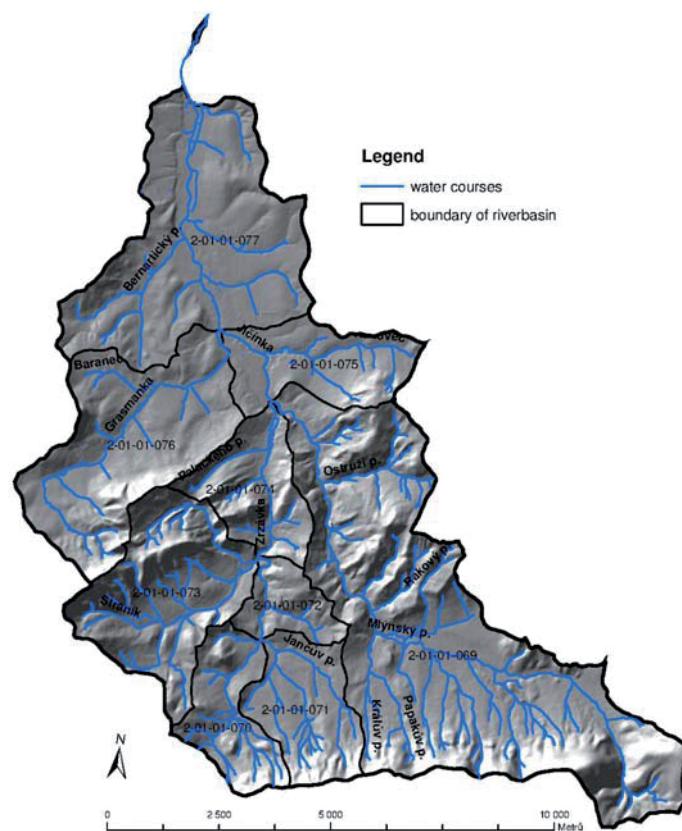
4: *Hydrological network*
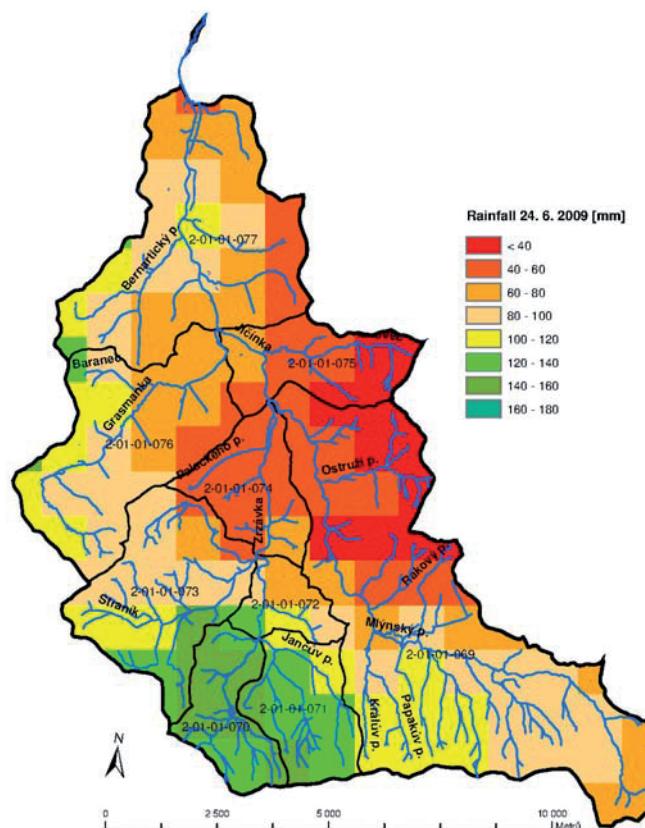
5: *Distribution of precipitation during flood situation*

rainfall in the previous five days, which reached 24th hour precipitation on average 20 mm (source: measurements of local users). In the Fig. 5 is shown the spatial distribution of data on the distribution of causal precipitation of 24. 6. 2009 (source: Czech Hydrometeorological Institute).

Hydropedologic conditions

An important factor which greatly influenced the retention capacity of river basin and characteristics of direct runoff is represented by a high percentage of type of soils with low intensity of infiltration. Hydrologic soil groups (HSG) "C" and "D" type represent approximately 50% of the area of Jičínka river basin (Tab. II).

The primary cause of flooding in the Jičínka basin was torrential rainfall in the evening of 24th June 2009 (according to local people reached maximum intensity between 19 and 22 hours) and rainfall in the previous five days, which reached an average 24 hour precipitation about 20 mm. Basic physical-geographical characteristics of the watershed are shown in Tab. II.

For river basin was evaluated the hourly amounts of precipitation fallen at the basin, and flows at the final profile from the 22th of June to the 5th of July were evaluated by a tabulation and graphically, incl. their cumulative values. A cumulative curve of differences is given at a graph in the Fig. 6, presenting an instantaneous retention of the basin

every hour of the observed period followed. (See the upper curve at the Fig. 6).

The dynamic and static retention were discriminated according to following rules:

a) since a beginning of a flood period (i.e. since the 22th of June, 2009 the gravitation, and capillary pores were filled at not saturated soil layers till a hour, when a flow increased substantially, and since that moment a surface, i.e. dynamic retention (started at the Fig. 6 the phenomenon is represented by differences between dashed and full lines) and the water further infiltrated also into gravitation voids at a constant rate hourly into the underground water,

b) a hour of the end of a dynamic (surface) retention was established at the descending line of hourly flows, when a hourly flow sharply decreased, while the static retention reached maximum, and its evacuation due to the underground flow started,

c) at a graph of an instantaneous total retention a boundary line between a dynamic and static retention is linear, resulting from the assumed constant hourly growth of a static retention connecting points of a beginning and of an end of dynamic retention; from this point a curve continues expressing a decrease of the static retention (a course of the static retention at the Fig. 6 is shown in full line),

d) process of the evacuation of a static retention continued later on, a flood episode could be
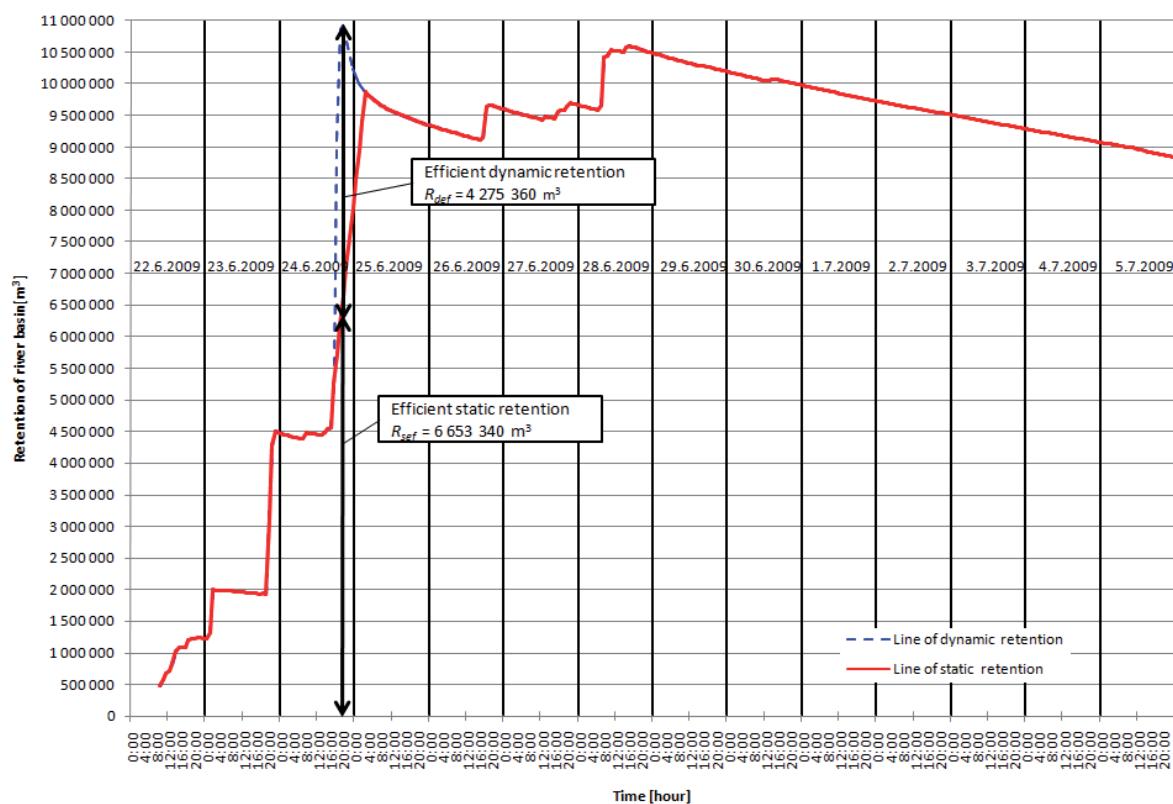
6: *Diagram of the distribution of total retention capacity of a basin R_i to the individual components*

considered as finished, when a value of the hourly flow approached to a starting value again, or is determined the contractual of the floods as in our case.

Results of the basin evaluated are presented at the Tab. II. Basic identification data about basin considered are given at a heading of a Tab. II, while values observed are included at the table itself. Values of the most important hydrological data for an estimation of the basin retention, i.e. concerning the static basin retention, and the decrease of a flood culmination, are introduced in the Tab. II.

Results show, that a coefficient of efficient static retention reaches value of 0.52, i.e. the soil retained about 52% of the wave volume at a time of the outflow culmination. This volume is slightly higher than dynamic efficient retention (including a surface, and hypodermic water), being at value of 34%. A coefficient of the total efficient basin retention reaches value of 86% from the volume

of the flood wave. A coefficient of the decrease of a flood culmination reaches value of 24%.

CONCLUSIONS

Findings, gathered during the research of the retention of the Jičínka river basin during the 2009 floods, can be summarised into the following conclusions:

a) A proposed balance method used which is based upon the evaluation of hourly precipitation and flows at the time of flooding, showed suitable for the study of the quantitative analysis of the retention basin capacity.

b) To improve a reliability of the balance method there is necessary to have the more detailed information about the precipitation, and flows at the beginning of a flood, for instance an 15 minutes values, as well as values of the flood flow volumes, and estimated values of the underground water variation, values of

II: *Summary of data found out in the investigation of the river Jičínka basin in the June flood 2009*

Final profile		Nový Jičín
Flow		Jičínka
Area of the basin F [km²]		93.9
Length of flow L [km]		17.7
Volume of flood precipitation [mil.m³]	ΣH_i	12.74
[mm]		135.7
Efficient static retention R_{sef} [mil.m³]		6.65
[mm]		70.8
Efficient dynamic retention R_{def} [mil.m³]		4.28
[mm]		45.6
Efficient total retention R_{cef} [mil.m³]		10.93
[mm]		116.4
Coefficient of the efficient static retention ρ_{sef}		0.52
Coefficient of the efficient dynamic retention ρ_{def}		0.34
Coefficient of the efficient total retention ρ_{cef}		0.86
Maximum hourly flow Q_{max} [mil.m³]		0.95
[m³.s⁻¹]		263.5
Maximum hourly precipitation H_{max} [mil.m³]		3.89
[mm]		41.2
Coefficient of the decrease of flood culminatin λ_{kul}		0.24
Average inclination of river basin [%]		13.2
Average soil moisture before a flood precipitation API [mm]		20.0
Shape of the basin		0.30
Hydrol. soil group according to a speed infiltration [mm.min⁻¹] A: > 0.012 B: 0.06–0.12 C: 0.02–0.06 D: < 0.02	Agr. land	A [km²] 4.8
		[% of the basin area] 5.1
		B [km²] 40
		[% of the basin area] 42.6
		C [km²] 22.1
		[% of the basin area] 23.5
		D [km²] 27.0
		[% of the basin area] 28.8

transpiration, and of the soil moisture before the start of flooding.

c) Ascertained value of the static basin retention is 52% of the volume of flood precipitation, being at the level of the dynamic retention values that was 34%.

d) Basin decreased the culminant hourly precipitation to the value of a culmination flow, which was equal to 24% of the top hourly precipitation.

Estimated values of hydrology quantities are unique, since such a flood phenomena are rare and are poorly documented at the Czech Republic. The method described can be used even as a base for evaluation of the appropriate measures to increase the landscape retention capacity. Method can be used for evaluation of flash flooding, but also for evaluation of regional precipitation floods.

The obtained results are consistent with the results of Kuráž (1999). The authors describe transformation quantitative capacity of the soil in the rainfall- runoff relationship. As an indicator criteria were selected Hydrologic soil groups, which indicates the soil's ability to transform precipitation and implicitly includes the ability to redistribute land soil moisture. Transformation quantitative soil functions is given by the depth of the soil profile, hydrophysical characteristics of soils, vegetation cover (type and condition).

The findings also confirm the results of research of other authors (Dumbrovský *et al.*, 1998; Spitz *et al.*, 2000; Prudký, 2001; Mašíček, 2010). Reduced water retention capacity in the watershed due to decreased water retention capacity of soils, inappropriate Land Use and Land cover in the basin and the presence of elements increase surface runoff. The negative effect is amplified in the case of saturation of soils in the catchment during the period of extreme precipitation.

SUMMARY

This paper describes the retention capacity of the river basin and its course during a flash flood. Retention capacity of the river basin was measured of balancing of precipitation fallen in the river basin and discharges in the final profile. For determine the retention characteristics of the river basin was used method, which balances precipitation and runoff in the time step (in our case was used hourly balancing step). The method is based on the theory of separation of components of runoff and also used the analogy with transformation of the flood discharge through a reservoir.
In the solved river basin were assessed factors that most influence the retention capacity of the river basin. Processing and analysis of data showed the influence of various causal factors on the individual components of retention capacity.
Retention capacity of river basin during flood episode is a dynamic characteristic that is influenced by many parameters related to the physical-geographic factors of river basin. On the basis of past performance and validation, it can be stated that the method appears to be an ideal tool for evaluating the retention capacity of the river basin, as well as to evaluate the effectiveness of protective measures. The applied method of balancing is very transparency and it is not difficult on the input data that can be obtained from Czech hydrometeorological institute (CHMI) or by own measurements or modeled. The disadvantage of the method is its partial subjectivity.

Acknowledgement

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