J. Hydrol. Hydromech., *60*, 2012, 4, 252–264
DOI: 10.2478/v10098-012-0022-3

STAKEHOLDER GROUP CONSENSUS BASED ON MULTI-ASPECT HYDROLOGY DECISION MAKING

PAVEL KOVÁŘ[1)], IVAN VRANA[2)], DARINA VAŠŠOVÁ[1)]

[1)]Faculty of Environmental Sciences, Czech University of Life Sciences, Kamýcká 129, 165 21 Praha 6-Suchdol, Czech Republic; Mailto: kovar@fzp.czu.cz
[2)]Faculty of Economics and Management, Czech University of Life Sciences, Kamýcká 129, 165 21 Praha 6-Suchdol, Czech Republic.

Catastrophic impact of floods is the result of an interaction between extreme hydrologic events and environmental, social and economic processes. Therefore, an integrated approach to flood management plays an important role in sustainable development. Such an approach requires a team comprising experts from the fields of hydrology and water resources, nature protection, risk management, human security, municipalities, economics and land use. The estimations of experts can serve for finding a solution to specific YES/NO problems and for estimating the value of specific attributes or parameters. In order to measure and evaluate the level of agreement between experts, a newly developed method for assessing the level of agreement and the value of τ-agreement, based on the Shannon theory of entropy, was applied. The use of such fuzzy-group-agreement decision making procedure, involving a broad range of stakeholders, is illustrated by the Flood Control Case Study, Zarosice, Czech Republic. In the case study of the Zdrava Voda catchment, where a part of the urbanised territory of the Zarosice village suffered from periodical flooding, a group of experts analysed the catchment data, focusing particularly on designed rainfall data. The KINFIL model was subsequently applied.

KEY WORDS: Ungauged Catchment, Biotechnical Measures, KINFIL Model, Group Decision Making, Fuzzy Ambiguity, Expert Evaluation, Consensus.

Pavel Kovář, Ivan Vrana, Darina Vaššová: SKUPINOVÝ KONSENSUS ZAINTERESOVANÝCH SUBJEKTŮ ZALOŽENÝ NA MULTIKRITERIÁLNÍ METODĚ ROZHODOVÁNÍ. J. Hydrol. Hydromech., *60*, 2012, 4; 22 lit, 6 obr., 8 tab.

Katastrofální dopad povodní je výsledkem vzájemné interakce extrémních hydrologických událostí a environmentálních, sociálních a ekonomických procesů. Z tohoto důvodu je integrovaný přístup k řešení protipovodňové ochrany důležitou součástí trvale udržitelného rozvoje. Tento přístup vyžaduje tým odborníků z oborů hydrologie a vodního hospodářství, ochrany přírody, řízení rizik (risk managementu), bezpečnosti osob, samosprávy, ekonomiky a hospodářského využití půdy. Názory těchto odborníků slouží k nalezení odpovědi na specifické otázky typu ano/ne, případně ke stanovení přesných hodnot parametrů. Pro měření a vyhodnocení konsenzu odborníků je použita nová metoda pro stanovení míry souhlasu a hodnoty τ-agreement vycházející z Shannonovy teorie entropie. Metoda je popsána na případové studii prováděné v části katastru obce Žarošice, která je často zaplavována. Tým expertů, zahrnující široké spektrum zainteresovaných subjektů, se zaměřil na dostupné informace o povodí, zejména na návrhové srážky, které byly následně vstupem do matematického srážko-odtokového modelu KINFIL.

KLÍČOVÁ SLOVA: nepozorované povodí, biotechnická opatření, model KINFIL, skupinové rozhodování, fuzzy neurčitost, expertní hodnocení, shoda.

Introduction

It is a well known fact that floods, which are caused by extreme hydrological events, have environmental, social and economic consequences. The Zdrava Voda catchment case study shows how proper water resources management can reduce these consequences. The lower part of the Zdrava Voda catchment is periodically exposed to floods, which are mainly due to the catchments' soil low infiltration capacity. In the past, the village of Zarosice has been flooded on several occasions, causing important damage to land owners and to the surrounding infrastructures.

During the last several decades the ungauged Zdrava Voda catchment made some flood disasters with high damages of flooding and soil erosion. Because of the ungauged catchment the KINFIL model (*Kovar* et al., 2002) has been used to illustrate the "Fuzzy Consensus-Based Approach". Models of this kind are used to carry out analysis of flood events on small catchments, where both land use and management play a significant role, and where man-made interventions in land use can decisively influence the design discharges. The combination of geographical information system (GIS) techniques with the KINFIL model, based on a physical infiltration approach, and on kinematic wave transformation of direct runoff, provides a tool for the analysis of rainfall-runoff events, design discharges assessment and flood scenarios simulation.

Materials and methods

Case study catchment

The Zdrava Voda catchment, situated in southern Moravia, Czech Republic, has an annual average temperature of 9 °C and an average precipitation of 560 mm. The area is formed with loess and loess loam, covered with Chernozem, calcic Leptosols and haplic Luvisols. The entire catchment area is 11.19 km^2. Arable land covers 42.0% of the area, forest covers 35.0%, permanent grassland covers less than 5.0%. The rest is urbanized area, including some scattered greenery.

The catchment area was surveyed and the resultant data was charted in GIS maps. The map shown in Fig. 1 presents the runoff Curve Numbers (CN). The CN values (*US SCS*, 1985; *Ponce* & *Hawkins*, 1996; *Šraj* et al., 2010; *Váňová* & *Langhammer*, 2011) are based on Hydrological Soil Groups (A, B, C and D) classified according to permeability, land use and management and antecedent precipitation (see Tab. 1). The higher CN represents the higher runoff potential. Fig. 2 presents the subcatchment Zdrava Voda – polder which endangers the downstream inhabited part of the Zarosice village. This is the core of the Case Study. The area and other physiographical parameters of this subcatchment are provided in Tab. 2.

From Tab. 1 it is clear that the main problem of the subcatchment is its extended area of arable land (77.0%), with high CN-value (78) which is usually a source area for direct runoff, instead of infiltration in the soil.

T a b l e 1. Hydrological soil groups on the Zdrava Voda subcatchment – polder.

Soil group	B			CN F_i/F
Land use	F_i [ha]	[%]	CN	
Arable land	14.14	77.0	78	60.1
Orchard (unmaintained)	3.43	19.0	55	10.5
Retention reservoir	0.84	4.0	61	2.4
In total	18.41	100.0	–	73.0

Flood transformation processes on catchment

The flood transformation process in the catchment under investigation is shown in the Fig. 3 Flow Chart. Transformation of rainfall-runoff process depends on how much rainfall takes part in direct runoff (rainfall excess). The direct flood wave impact can be reduced and the flood wave can be delayed by planning a properly landscaped catchment area. Biotechnical improvement measures on a catchment represent the "hydraulic roughness". The transformation process depends very much on the proper implementation of such measures. Non-structural flood prevention measures of agrobiological character and structural (technical) measures which include hydraulic structures (e.g. dikes and polders) are also found in the Fig. 3, together with the necessary measures and proposed actions.

A team of specialists participated in the decision making process (*Refsgaard* et al., 2007). Specialists in hydrology and water resources management, nature protection, risk management, land use, civil service, municipalities, economist, rescue team coordinators and land owners were all invited to be part of the team.

Fig. 3 shows an estimate of the real value parameter (less arable land) in a fuzzy number or a fuzzy interval and also a binary, two-value yes/no logics. The most appropriate runoff transformation measures can thus be determined. The group of specialists made a comprehensive flood control evaluation. The section where the involvement of the team of specialists is most important is indicated in Fig. 3.

The flood impact mitigation procedure (2), as shown in Fig. 3, was based on computation of the design rainfalls of *N*-year return period, which cause the design input discharges, and ultimately floods. A specialist in meteorology will determine

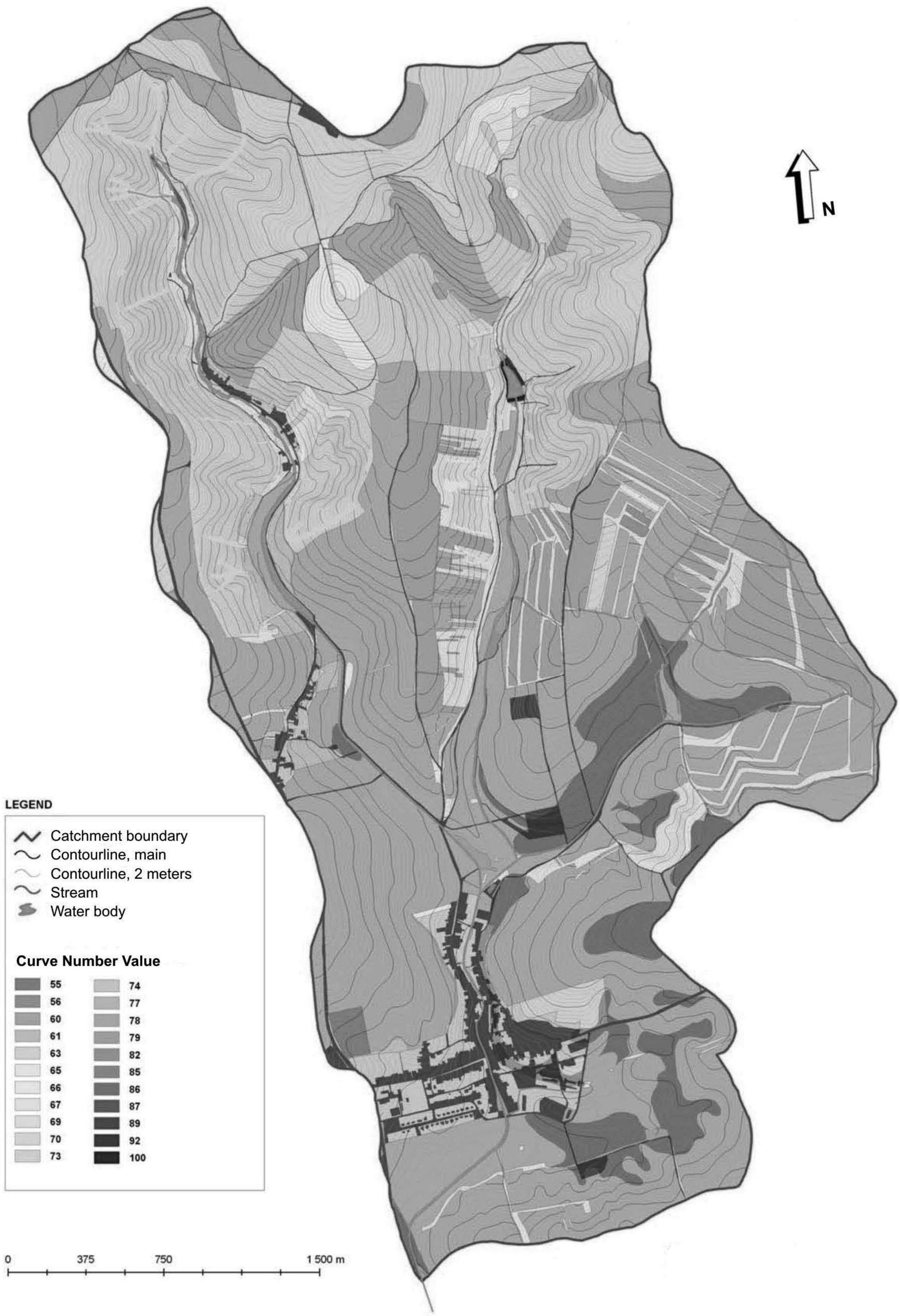

Fig. 1. The Zdrava Voda catchment – runoff Curve Numbers CN.

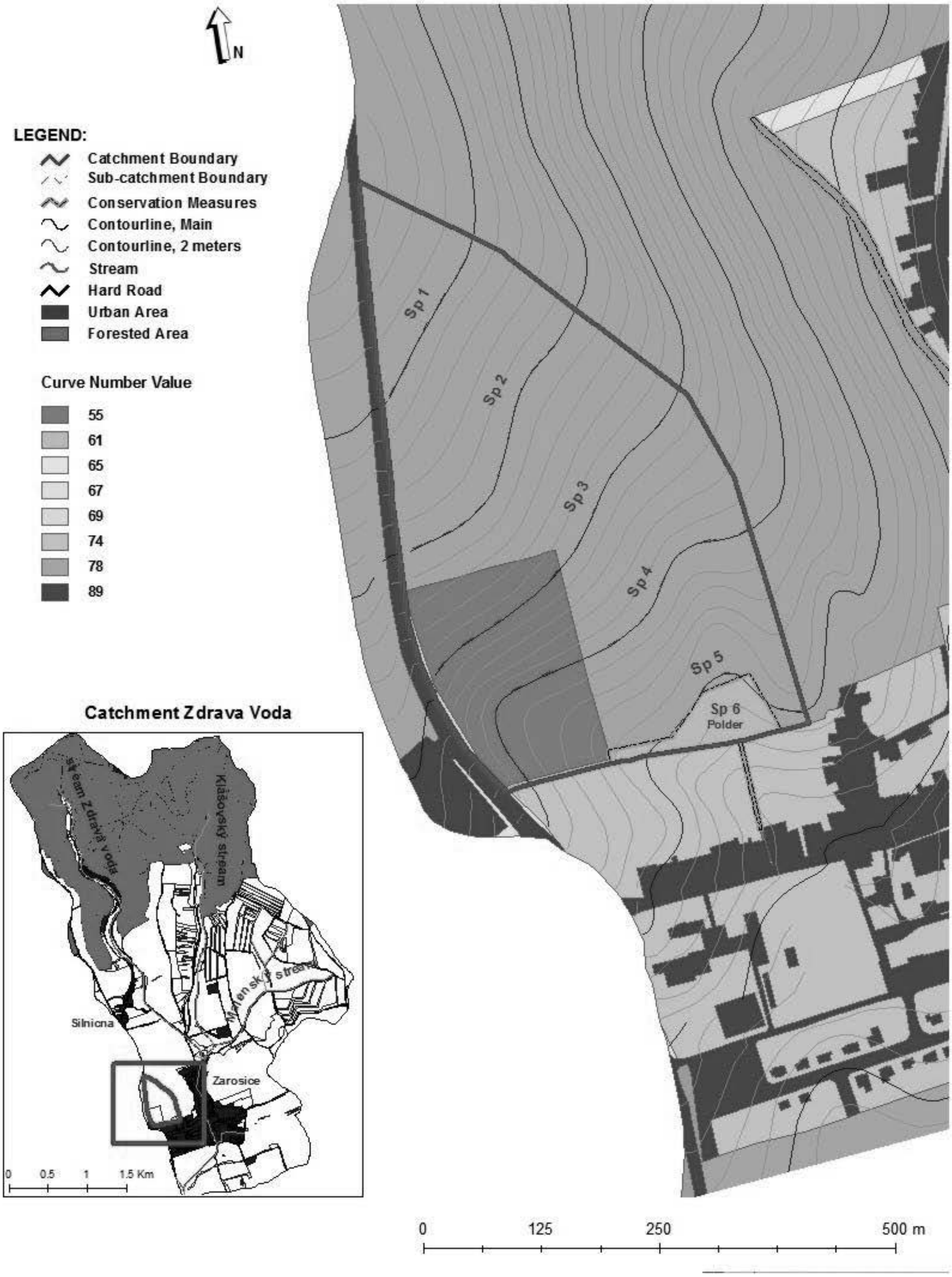

Fig. 2. Runoff Curve Numbers (CN) in the Zdrava Voda subcatchment – polder.

T a b l e 2. Characteristics of the Zdrava Voda polder subcatchment.

Subcatchment runoff areas	Total area [ha]	Average length [m]	Average width [m]	Average slope [%]	Land use: Arable land [ha]	[%]	Other [ha]	[%]	Erosion control [ha]	[%]	Orchard [ha]	[%]
Sp1	1.41	112	127	5.5	7.6	100.0	–	–	–	–	–	–
Sp2	3.59	121	297	8.2	19.4	99.7	0.06	0.3	–	–	–	–
Sp3	4.48	135	332	7.4	18.8	77.2	0.30	1.3	–	–	5.2	21.5
Sp4	4.21	117	361	8.8	14.5	63.7	0.3	1.4	0.07	0.3	7.9	34.6
Sp5	4.04	139	291	7.3	15.7	71.6	–	–	0.7	3.3	5.5	25.1
Sp6	0.68	68	100	5.1	0.5	16.2	–	–	3.1	83.8	–	–
In total	18.41	691	266	8.5	76.6	–	0.7	–	4.0	–	18.7	–

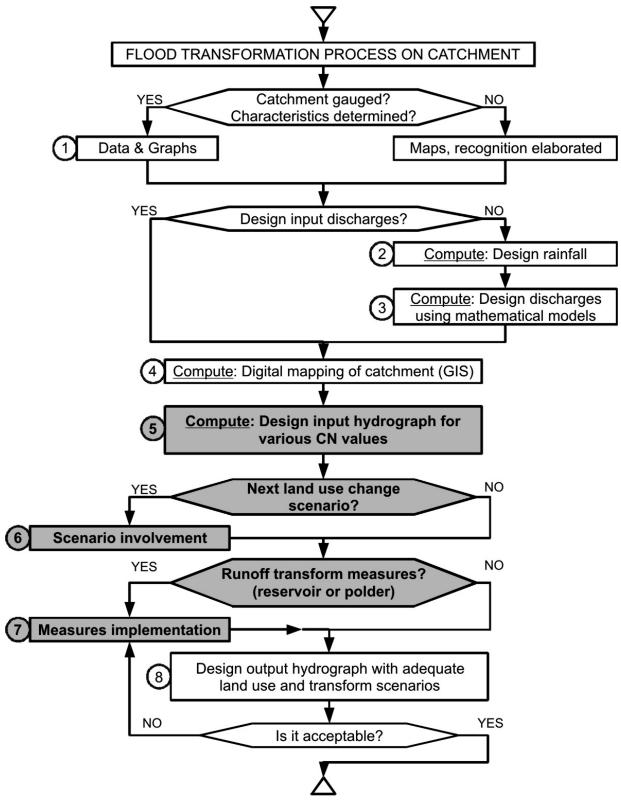

Fig. 3. Flowchart of flood transformation processes on a catchment.

the relevant rainfall station (Kyjov) with N-years observations of the 1-day maximum rainfall, $P_{1d,N}$, and further calculated for a short duration t_d as rainfall depth $P_{t,N}$ and corresponding rainfall intensity $i_{t,N}$ for N = 10, 20, 50, and 100 years and t_d = 10, 20, 30 and 60 minutes (see Tab. 3).

A functioning simulation model is very important, as indicated in step (3) – Fig. 3. Therefore, the KINFIL model was chosen as most appropriate (*Kovar* et al., 2002). The KINFIL models' parameters correspond with the Curve Number (CN) developed by US Natural Resources Conservation Service (formerly US Soil Conservation Service; *US SCS*, 1985; *US SCS*, 1986). The KINFIL model implements the CN method. At the same time it eliminates its weak physical background by replacing it with the physically-based infiltration theory (*Morel-Seytoux* & *Verdin*, 1981). The CN values and soil parameters relationships (e.g. saturated hydraulic conductivity K_s and sorptivity at the field capacity S_f) were determined by correlation of the parameters of design rainfalls in the Czech Republic (*Kovar*, 1992). The KINFIL model determines CN-values and measured soil hydraulic parameters K_s and S_f, corresponding to CN-values: CN = $f(K_s, S_f)$, (*Kovar* et al., 2002). Computed infiltration in time $v_f(t)$ and initial surface retention R_1, subtracting, both from the height of design rainfall $r(t)$, and getting an effective rainfall hyetograph $r_e(t)$, is expressed in the following equation computing infiltration rate from:

$$r_e(t) = r(t) - v_f(t) - R_1. \qquad (1)$$

This infiltration part of the KINFIL model is based on the infiltration theory of Green and Ampt applying the concept of ponding time and storage suction factor S_f by *Morel-Seytoux* (1982):

$$V_f = \left(\theta_s - \theta_i\right) \cdot \frac{dz_f}{dt} = K_s \cdot \left(\frac{z_f + H_f}{z_f} \right), \qquad (2)$$

where θ_s is saturated soil moisture content [–], θ_i – initial soil moisture content [–], z_f – depth of infiltration front [m], H_f – capillary suction on infiltration front [m] and K_s is saturated hydraulic conductivity [m s^{-1}].

Another aspect of the KINFIL model is its runoff component, expressed in the kinematic wave equation for catchments, as described by *Kibler* and *Woolhiser* (1970) and *Beven* (2006):

$$r_e(t) = \frac{\partial y}{\partial t} + \alpha \cdot m \cdot y^{m-1} \cdot \frac{\partial y}{\partial x}, \qquad (3)$$

where $r_e(t)$ is effective rainfall intensity [m s^{-1}], y, t, x – ordinates of depth, time, and position, respectively [m, s, m], α and m are hydraulic parameters.

ArcInfo (GIS) was applied in action (4) – Fig. 3, assessing the drainage pattern in the catchment. Eq. (3) was computed, using finite differentiation methodology and the explicit numerical Lax-Wendroff scheme (*Singh*, 1996).

Individual small subcatchments are thus replaced by a system of serial and parallel cascades of planes, arranged according to flow direction. That is the advantage of the KINFIL model. It features the geometric parameters of planes (length, width), slopes and CN values, as well as the Manning roughness n and flow pattern (fragmentation) system. The fragmentation subcatchment system Sp1 to Sp6 is illustrated in Fig. 2, respecting slopes and land use. All these parameters have been used on the Zdrava Voda polder subcatchment, simulating design rainfall-runoff events for N = 10, 20, 50 and 100 years. The time of concentration on the Zdrava Voda polder subcatchment is approximately 30 min. This is a critical period of time corresponding with the highest rainfall intensity, in N-year return period and t_d-minutes duration. The series of design hydrographs were computed in step (5) – Fig. 3, in order to determine the corresponding design rainfall duration t_d = 10, 20, 30 and 60 min for the return period N = 10, 20, 50 and 100 years. The 30 min design rainfall hydrographs were the highest and thus the most threatening due to their concentration in time. They are plotted in Fig. 4.

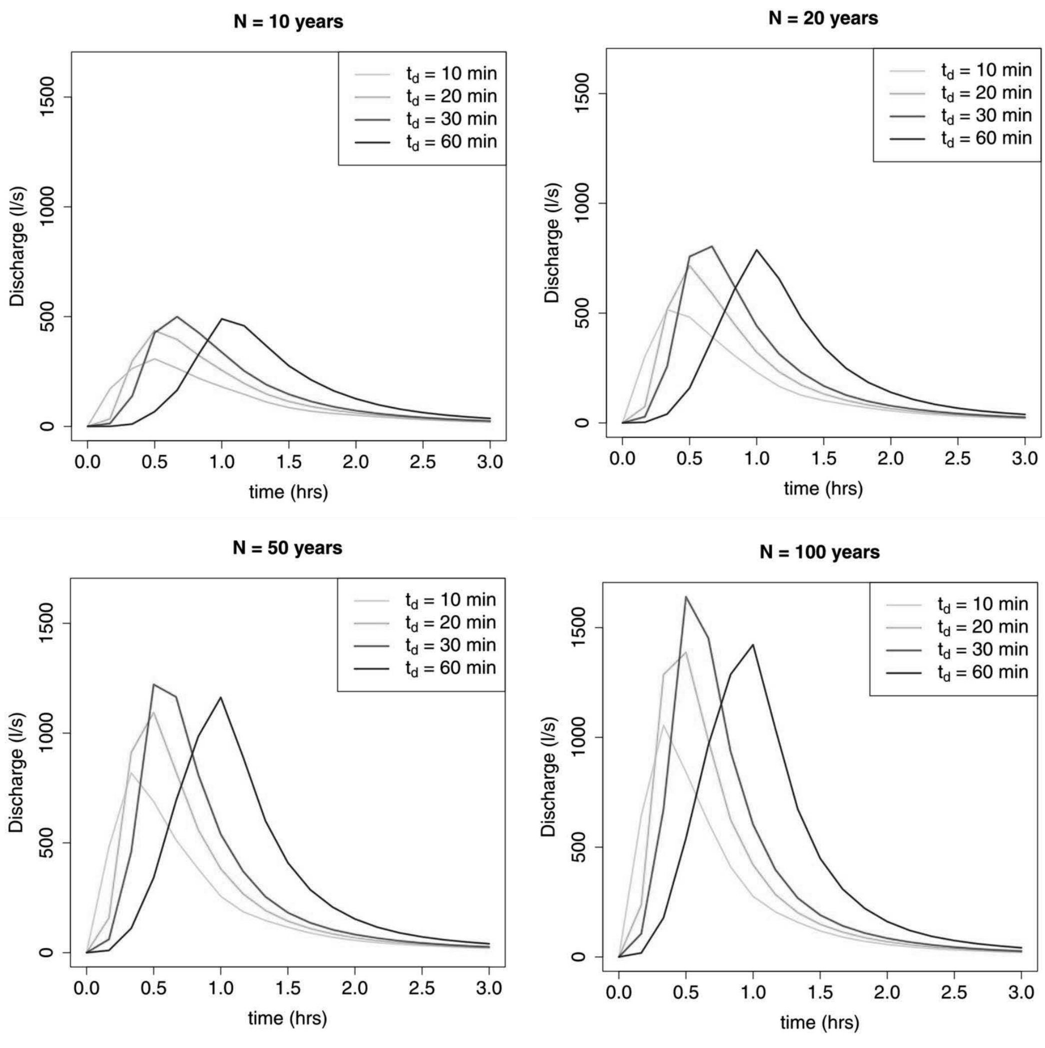

Fig. 4. Design hydrographs of the subcatchment of polder Zdrava Voda with return period N and different durations of rainfall t_d.

New fuzzy expert method

We distinguish two types of flood prevention measures for mitigating design discharges: a) the non-structural and b) the technical. Major CN parameters in the KINFIL model can be effectively decreased through non-structural flood prevention, thus diminishing the peak flow. The CN parameters of arable land contribute to the reduction of floods. The extent of this reduction depends on "policy and priorities" of the stakeholders. The team of experts was established to suggest the best flood prevention measures. The team involved the following experts: two hydrologists and water resources management specialists, one nature protection specialist, one risk management specialist, two land use specialists, two representatives from the municipalities, one economist and two land owners. All together the team had eleven members.

T a b l e 3. N-years design rainfalls at the Kyjov station (N = = 10, 20, 50 and 100 years).

N	Rainfall duration	Rainfall depth	Time step Δt = 10 min					
[years]	[min]	[mm]	1	2	3	4	5	6
10	10	20.8	20.8	–	–	–	–	–
	20	26.4	13.2	13.2	–	–	–	–
	30	30.3	10.2	10.1	10.1	–	–	–
	60	36.2	6.1	6.1	6.0	6.0	6.0	6.0
20	10	25.5	25.5	–	–	–	–	–
	20	32.6	16.3	16.3	–	–	–	–
	30	37.6	12.6	12.5	12.5	–	–	–
	60	45.2	7.6	7.6	7.5	7.5	7.5	7.5
50	10	31.6	31.6	–	–	–	–	–
	20	40.6	20.3	20.3	–	–	–	–
	30	47.0	15.7	15.6	15.6	–	–	–
	60	57.0	9.5	9.5	9.5	9.5	9.5	9.5
100	10	36.1	36.1	–	–	–	–	–
	20	46.8	23.4	23.4	–	–	–	–
	30	54.4	18.2	18.1	18.1	–	–	–
	60	66.0	11.0	11.0	11.0	11.0	11.0	11.0

In this connection it may be noted that during the International Water Disaster Prevention Workshop (WDP in 2010), organised annually at the Faculty of Environmental Sciences at CULS Prague, a seminar was held involving the above mentioned experts. Flood prevention and evaluation methodology, as well as the reading and interpreting of hydrographs were discussed. Impact of flood prevention was pre-calculated for six scenarios combining partial reduction (30%) or full reduction (100%) of arable land substituted by permanent grassland with structural measures (polder vs. reservoir), as depicted in Tab. 4. Besides other information all team members obtained design hydrographs, pre-calculated for time recurrence N = 10, 20, 50 and 100 years for non-structural scenarios A0 and B0 corresponding to 30% and 100% reduction of arable land, respectively scenarios, see Fig. 5. Hydrographs for two technical scenarios, one with a classic streamflow reservoir and one with a dry polder were adopted after decision about percentage of arable land reduction was made (see Fig. 6). According to these scenarios, the KINFIL model parameters were set up to simulate the individual scenario, respecting the change of land use and the hydraulic property of reservoir or polder. For the sake of simplicity on these technical measures, the length of safety spillway differs, 10.0 meters on the reservoir, 20.0 meters on the polder. The changes of land use characterized by different CN for the different scenarios are provided in Tab. 5.

T a b l e 4. The scenarios to mitigate flood impacts on the Zdrava Voda – polder subcatchment.

Scenario description	Non-structural measures (Land use change)	Technical measures	
		Reservoir	Polder
Present status	No change	NO	NO
Scenario A0	−30% arable land	NO	NO
Scenario A1	−30% arable land	YES	NO
Scenario A2	−30% arable land	NO	YES
Scenario B0	−100% arable land	NO	NO
Scenario B1	−100% arable land	YES	NO
Scenario B2	−100% arable land	NO	YES

Note: All arable land reduction is substituted by permanent grassland

At the WDP Workshop the hydrographs provided by experts with information of impact of arable land reduction and of the selection reservoir or polder (i.e. flood prevention measures) were given to the participants in expert role to learn the Stakeholder Decision Making Method. The team members were aware about the necessity of taking measures for flood prevention and all of them were asked the same question: "Propose the proper reduction of arable land to be transferred to grassland as a measure for mitigating risk of flood. Express your proposal in percentages from the range 0–100% and indicate the recommended upper and lower limit of your proposal". It means that specialists had to express their proposals as fuzzy numbers with a triangular membership function. (Readers who are not familiar with a fuzzy set theory can find details about the application of fuzzy set theory to decision-making and expert systems in *Zimmer-*

mann (1996) or *Vaníček* (2009)). Proposals of experts are in Tab. 6. The first column indicates the category of the expert, the second column shows the position of the peak value of the triangular fuzzy number of the proposed arable land reduction, and the third and the fourth columns show the deviation of the base of the triangular fuzzy number in both directions around the position of the peak value (e.g., values 40, 3, 6 indicate that the corresponding land use expert's proposal is a triangular fuzzy number with a base of 37%–46% and a peak at 40%). The rightmost column assigns weights to individual experts in order to achieve the same (one) overall weight for each category of experts. The weights can also serve to express e.g. the qualification of individual experts or to distinguish importance of individual aspects of the decision problem, see *Vrana* et al. (2012) for details.

Expert proposals had to be aggregated in order to achieve a common standpoint, see e.g. *Grabisch* et al., (2011) for aggregation functions. These proposals of experts were aggregated by calculating the Maximum Agreement Mean – *MaxAgM*, a special averaging operator that maximizes agreement. This optimum averaging operator generalizing *Tastle* et al. (2007) consensus approach was developed and introduced in *Vrana* et al. (2012). According to *Vrana* et al. (2012), the specialists' opinion can be expressed as a choice of any real number on the closed interval $[X_{min}, X_{max}]$. Then, the formula for τ-agreement is

$$Agr(\mathbf{X} \mid \tau) = 1 + \frac{1}{M} \sum_{i=1}^{M} \log_2 \left(1 - \frac{|X_i - \tau|}{2d_X} \right), \qquad (4)$$

where M is the number of specialists. The *MaxAgM* is defined as such value τ for which τ-agreement $Agr(\mathbf{X} \mid \tau)$ reaches its maximum. Thus, this averaging operator represents a value τ for which the best collective agreement of all estimates is achieved.

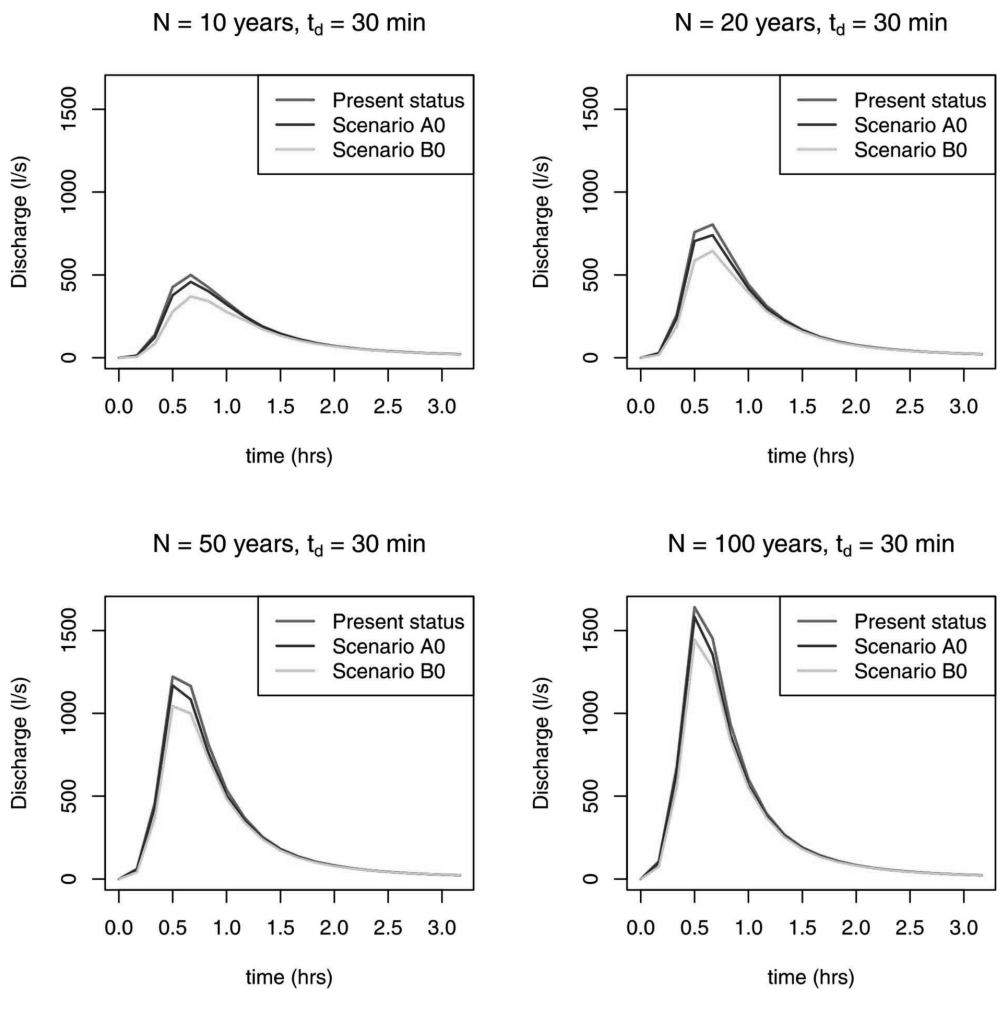

Fig. 5. Design hydrographs of scenarios A0 (−30% of arable land) and B0 (−100% of arable land) for return period N = 10, 20, 50 and 100 years and for time duration t_d = 30 minutes.

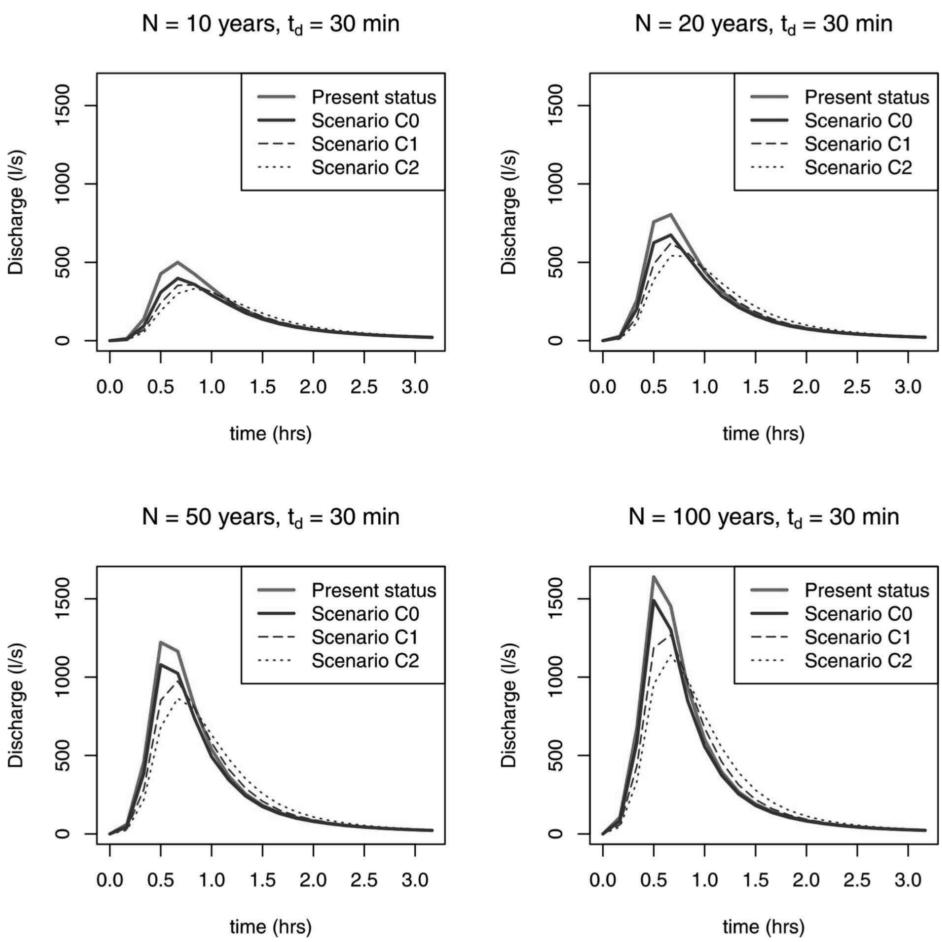

Fig. 6. Design discharges for the C scenarios (C0: 79% reduction of arable land, C1: reservoir transformation, C2 polder transformation).

T a b l e 5. Land use – curve number values for different scenarios on the Zdrava Voda – polder subcatchment.

Scenario	Land use	Area F_i [ha]	Area [%]	CN	CN · F_i/F	Change in total CN value
Present status	Arable land	14.14	77.0	78	60.1	
	Permanent grassland	–	–	69	–	
	Orchard	3.43	19.0	55	10.5	
	Polder area	0.84	4.0	61	2.4	
	In total	18.41	100.0	–	73.0	0.0
Scenarios A0, A1, A2 (−30% arable land)	Arable land	9.90	54.0	78	42.1	
	Permanent grassland	4.24	23.0	69	15.9	
	Others (const.)	4.27	23.0	61	14.0	
	In total	18.41	100.0	–	72.0	−1.0
Scenarios B0, B1, B2 (−100% arable land)	Arable land	0.0	0.0	78	0.0	
	Permanent grassland	14.14	77.0	69	53.1	
	Others (const.)	4.27	23.0	61	14.0	
	In total	18.41	100.0	–	67.2	−5.8

The *MaxAgM* is the optimum operator for achieving the best agreement of expert opinions because it corresponds to the highest value of the τ-agreement, and therefore, it is superior to all other averaging operators. The details of how to calculate the highest value of the τ-agreement is described in *Vrana* et al. (2012).

T a b l e 6. Proposals of experts about reduction of arable land.

Expert	Reduction of arable land %	− %	+ %	Weight
Hydrology	100	15	0	0.5
Hydrology	90	10	10	0.5
Nature protection	90	5	5	1
Risk management	95	10	5	1
Economy	35	0	0	1
Land use	20	0	5	0.5
Land use	40	3	6	0.5
Municipality	98	5	2	0.5
Municipality	95	5	5	0.5
Land owner	35	2	2	0.5
Land owner	0	0	15	0.5

There are cases where the experts' assessments are not equally important, e.g. because of their different qualifications or because of different numbers of representatives from individual categories. In such cases, τ-agreement was in (*Vrana* et al., 2012) naturally generalized to the weighted τ-agreement defined by the formula

$$Agr_w(\mathbf{X}\,|\,\tau) = 1 + \frac{1}{\sum_i^M w_i} \sum_{i=1}^{M} \log_2 \left(1 - \frac{|X_i - \tau|}{2d_X} \right), \qquad (5)$$

where w_i is the weight coefficient of the i-th expert.

Vrana et al. (2012) also introduced the MaxAgr software which calculates the *MaxAgM* from the specialists' evaluations. This software was used in our case study to aggregate expert opinions from the Tab. 6. It calculated such value of an arable land reduction for which Agreement reaches its maximum: *MaxAgM* = 75 with *MaxAgr* = 0.74.

If the proposals of experts were considered as crisp values (at the peak of their triangular membership functions, i.e. the second column of the Tab. 6), we achieved *MaxAgM* = 75 with *MaxAgr* = = 0.73, whilst Median = 90 and Arithmetic mean = = 63.45.

The aggregated value of arable land reduction was also calculated for this weighted situation where each category of experts was assigned an equal total weight one. We achieved a result: *MaxAgr* = 0.76, *MaxAgM* = 83 for fuzzy input data and *MaxAgr* = 0.75, *MaxAgM* = 84 for crisp input data.

In non weighted situations of all crisp and fuzzy expert proposals the maximum agreement 0.74–0.75 was achieved for reduction of arable land of 75% which rests between Median = 90% and Arithmetic mean = 63.45%. We can see that the Median and the Arithmetic mean have very distant values in our case and therefore these averaging operators provide only very inaccurate estimates of expert standpoints. In the weighted alternative situations of all crisp and fuzzy expert proposals the maximum agreement 0.75–0.76 was achieved for reduction of arable land in the range of 83% – 84%. If we consider the average of non-weighted and weighted situations, the best agreement of all specialists for all four situations is to reduce arable land by 79% in favour of the permanent grassland. Therefore, this value was adopted for the final calculation of CN (see Tab. 8.).

T a b l e 7. Proposals of experts to build a reservoir or a dry polder. Likert scale: definitely reservoir (DR), rather reservoir than polder (RtP), no preference (NP), rather polder than reservoir (PtR) or definitely polder (DP).

Expert	Proposal in Likert scale	Proposals in numerical scale	Weight
Hydrology	RtP	75	0.5
Hydrology	DR	100	0.5
Nature protection	DP	0	1
Risk management	NP	50	1
Economy	DP	0	1
Land use	PtR	25	0.5
Land use	DP	0	0.5
Municipality	DR	100	0.5
Municipality	RtP	75	0.5
Land owner	PtR	25	0.5
Land owner	DP	0	0.5

Analogically as in *Vrana* et al. (2012), also other approaches to weighting could be considered, e.g. to assign weights to individual experts according to their qualifications. It proved to be problematic to measure expertise of individual specialists because such a weighting might introduce rather subjective and political than rational aspects into the evaluation process. That was why these approaches of weighting were not adopted in our case study.

The above mentioned measure decreased the peak flow, depending on the *N*-years input in the hydrograph. According to the acquired data, as indicated in Tabs. 5 and 8, arable land can be transferred to permanent grassland, with the effect of reducing the CN value and thus also the direct runoff (*Woodward* et al., 2003; *Soulis* et al., 2009).

The KINFIL parameters K_s and S_f were derived from the corresponding CN-values which reflect the changes in land use scenario. The Manning *n* and physiographic values (length, width, and slope) are identical. This land use transformation weighted the CN-value by 4.5 points. This is evident in Tab. 8.

Those measures which require important financial investments are defined as structural or technical flood prevention measures (see step 7 – Fig. 3). Because the catchment includes areas which must be protected from floods (urbanised areas), structural measures seemed to be necessary. There were two options: 1. construct a classical water reservoir, lowering the level of flood waves by means of a reservoir safety spillway, or 2. to build up a polder, with a similar water storage capacity as a reservoir, however with a much larger flooding area and a longer safety spillway (doubled). The second solution is both cheaper and a more close to nature. Both options are based on the simple transformation procedure, which is described by the continuity and momentum equations (i.e. safety spillway). Fig. 6 indicates measurements made by four design hydrographs for N = 10, 20, 50 and 100 years, each for rainfall duration t_d = 30 min (critical time), indicating the runoff from the Zdrava Voda catchment, with two scenarios of structural measures (C1 for reservoir and C2 for polder) with 79% reduction of arable land (scenario C0).

T a b l e 8. Land use – curve number values for the best agreement of all experts, that means reduction of arable land by 79% in favour of permanent grassland on the Zdrava Voda – polder subcatchment.

Scenario	Land use	Area F_i [ha]	Area [%]	CN	CN F_i/F	Change in total CN value
Present status	Arable land	14.14	77.0	78	60.1	
	Permanent grassland	–	–	69	–	
	Orchard	3.43	19.0	55	10.5	
	Polder area	0.84	4.0	61	2.4	
	In total	18.41	100.0	–	73.0	0.0
Scenarios C (−79% arable land)	Arable land	2.97	16.0	78	12.5	
	Permanent grassland	11.17	61.0	69	42.0	
	Others (const.)	4.27	23.0	61	14.0	
	In total	18.41	100.0	–	68.5	−4.5

The team of experts tried to give answers to two questions:

1. "Is it better to keep the current situation (without structural change), or should structural flood prevention measures be implemented?" The answer to this question was a unanimous YES to structural flood prevention measures.
2. "Which flood prevention measure is more adequate: a reservoir or a dry polder? The answer to this question was to be formulated using linguistic terms according to the Likert scale: definitely reservoir (DR), rather reservoir than polder (RtP), no preference (NP), rather polder than reservoir (PtR) or definitely polder (DP)". Answers are found in Tab. 7. They were transformed to a numerical scale [0, 100], where 0 corresponds to DP, 25 to PtR, 50 to NP, 75 to RtP and 100 to DR. With use of the MaxAgr software the value *MaxAgM* = 30 was calculated for the non-weighted case with *MaxAg*r = 0.71 and Median = 25. For the case when individual experts were assigned weights in order to achieve the same overall weight 1 for every category (see the right-hand column of Tab. 7), the aggregated value of weighted proposals was calculated with the result: *MaxAgM* = 25, *MaxAg*r = 0.73. The dry polder solution was opted for by the majority of experts, being the most feasible option, with least investment required. The area could be turned into permanent grassland. Resulting design inflow/outflow hydrographs were calculated for time recurrence N = 10, 20, 50 and 100 years and for CN = 68.5 which corresponds to 79% reduction of arable land. This final suggestion was indicated as the scenario C, when C1 presents the flood transformation by reservoir and C2 the transformation by polder. The corresponding hydrographs for N = 10, 20, 50 and 100 years caused by the most critical design rainfall duration t_d = 30 minutes are depicted in Fig. 6.

The flood wave transformation by means of a dry polder offers a lower peak with less money required. A polder flooded area is larger than an alternative reservoir area. Together with arable land reduction, this proposal offers a solution which was confirmed by mutual consensus of all experts involved in the project.

Conclusions

The aggregative approach, assuming a general consensus of all experts, together with the aggregation operator Maximum Agreement Mean *Max-*

AgM, is presented herewith. The value of *MaxAgM* falls in the interval between the arithmetic mean and the median. The method calculating *MaxAgM* has the advantage over existing aggregating measures, in as much as it directly calculates a value, which corresponds to the maximum consensus of all involved experts. If the experts' conclusions are very similar, i.e. consensual, then averaging operators like the median, arithmetic mean or maximum agreement mean provide almost the same results. Results, however, may differ when the specialists' conclusions lack cohesion (which is quite common in environmental projects). Then the aggregation operator Maximum Agreement Mean *MaxAgM* provides the only possibility to reach the optimal solution. The results obtained by the new *MaxAgM* averaging operator can differ significantly from results produced through common averaging operators.

The team of 11 experts comprised representatives from various professions, whose overall involvement was aimed at satisfying the various requirements of stakeholders. It was therefore expected that hydrological methods used in flood impact mitigation were to be set quite clearly. In other words, they were to be formulated in such a way as to allow a general understanding for all: professionals as well as laymen. The evaluation by specialists was used for setting parameter values (the value of CN), as well as for enabling binary YES/NO decisions in the matter of adopting proper structural measures. The experts answered in the form of fuzzy numbers as well as crisp values. A weighted alternative was also included.

Of course, classical aggregation measures and *MaxAgM* differed significant (e.g. Median = 90, *MaxAgM* = 75, Arithmetic mean = 63.45). The case study confirmed the usefulness of the group decision methodology. This methodology is very useful in any decision making process.

Both the maximum agreement based method of multi-expert decision making under fuzzy conditions, and the application of MaxAgr software, proved to be an optimal solution and an effective tool for solving of any multi-dimensional environmental problems, which are ill-structured, uncertain and vague.

Acknowledgement. This project was supported by the Ministry of Agriculture of the Czech Republic, Grant NAZV MZe Project No. QH92091 Optimization of reclamation and rehabilitation measures, by the Ministry of Education, Youth and Sports of the Czech Republic (Grant No. MSM 604070904 – Information and knowledge support of strategic management, and by the Grant Agency of the Czech Republic (Grant SMEW – Smart Environments at Workplaces).

List of symbols

N	– return period [years],
t_d	– design rainfall duration [minutes],
CN	– Curve Number [–],
K_s	– saturated hydraulic conductivity [m s^{-1}],
S_f	– storage suction factor at field capacity [m],
$v_f(t)$	– infiltration height at time t [mm],
$r(t)$	– design rainfall height at time t [mm],
R_1	– initial surface retention [mm],
$r_e(t)$	– excess rainfall height at time t [mm],
V_f	– infiltration rate [m s^{-1}],
θ_s	– saturated soil moisture content [–],
θ_i	– initial soil moisture content [–],
z_f	– depth of infiltration front [m],
H_f	– capillary suction on infiltration front [m],
y	– ordinate of depth [m],
t	– ordinate of time [s],
x	– ordinate of position [m],
α	– hydraulic parameter of kinematic wave [m^{2-m}/s],
m	– hydraulic parameter of kinematic wave [–],
n	– Manning roughness [–],
MaxAgM	– Maximum Agreement Mean,
MaxAgr	– level of the best achievable agreement,
$\mathbf{X}$	– random variable with probability distribution $p(\mathbf{X})$ on the closed interval [$X_{\min}$, $X_{\max}$],
X_i	– opinion of the i-th expert,
d_X	– width of X ($d_X = X_{\max} - X_{\min}$),
τ	– variable expressing possible collective agreement of all estimates,
$Agr(\mathbf{X}\mid\tau)$	– τ-agreement of the distribution,
$Agr_w(\mathbf{X}\,\tau)$	– weighted τ-agreement of the distribution,
M	– number of specialists,
w_i	– weight coefficient of the i-th expert.

REFERENCES

ARNETTE A., ZOBEL C., BOSCH D., PEASE J., METCALFE T., 2010: Stakeholder ranking of watershed goals with the vector analytic hierarchy process: Effects of participant grouping scenarios. Environmental Modelling & Software, *25*, 11, 1459–1469.

BEVEN K. J., 2006: Rainfall-Runoff Modelling. The Primer. John Wiley & Sons, Chichester, U. K.

GRABISCH M., MARICHAL J.-L., MESIAR R., PAP E., 2011: Aggregation functions: Means. Information Sciences, *181*, 1, 1–22.

KIBLER D. F., WOOLHISER D. A., 1970: The kinematic cascade as a hydrologic model. Hydrology Paper No. 39, Colorado State University.

KOVÁŘ P., 1992: Možnosti stanovení návrhových průtoků na malých povodích modelem KINFIL. (Possibilities to determine design discharges on small catchment using the KINFIL model.) Vodohosp. Čas., *40*, 2, 197–220.

KOVÁŘ P., CUDLÍN P., HEŘMAN M., ZEMEK F., KORYTÁŘ M., 2002: Analysis of Flood Events on Small River Catchments Using the KINFIL Model. J. Hydrol. Hydromech., *50*, 2, 157–171.

MOREL-SEYTOUX H. J., 1982: Analytical results for predictions of variable rainfall infiltration. J. Hydrol., 59, 209–230.

MOREL-SEYTOUX H. J., VERDIN J. P., 1981: Extension of the SCS Rainfall Runoff Methodology for ungaged Watersheds. Report FHWA/RD-81/060, U. S. National Technical Information Service, Springfield, Virginia.

PONCE V. M., HAWKINS R. H., 1996: Runoff Curve Number: Has it reached maturity? J. Hydrologic Engng., 1, 11–19.

REFSGAARD J. C., VAN DER SLUIJS J. P., HØJBERG A. L., VANROLLEGHEM P. A., 2007: Uncertainty in the environmental modelling process – A framework and guidance. Environmental Modelling and Software, *22*, 11, 1543–1556.

SINGH V. P., 1996: Kinematic Wave Modelling in Water Resources. John Wiley & Sons, Inc., New York.

SOULIS K. X., VALIANTZAS J. D., DERCAS N., LONDRA P. A., 2009: Investigation of the direct runoff generation mechanism for the analysis of the SCS-CN method applicability to a partial area experimental watershed. Hydrol. Earth Syst. Sci., *13*, 605–615.

ŠRAJ M., DIRNBEK L., BRILLY M., 2010: The influence of effective rainfall on modeled runoff hydrograph. J. Hydrol. Hydromech., *58*, 1, 3–14.

TASTLE W. J., WIERMAN M. J., 2007: Consensus and dissention. A measure of ordinal dispersion. International Journal of Approximating Reasoning, *45*, 531–545.

U.S. SCS, 1985: National Engineering Handbook, Section 4: Hydrology. U.S. Soil Conservation Service, USDA, Washington, D. C.

U. S. SCS, 1986: Urban hydrology for small watersheds. U. S. Soil Conservation Service, Technical Release, *55*, 13, USDA, Washington, D. C.

VANÍČEK J., VRANA I., ALY S., 2009. Fuzzy aggregation and averaging for group decision making: A generalization and survey. Knowledge-Based Systems, *22*, 79–84.

VÁŇOVÁ V., LANGHAMMER J., 2011: Modelling the impact of land cover changes on flood mitigation in the upper Lužnice basin. J. Hydrol. Hydromech., *59*, 4, 262–274.

VRANA I., VANÍČEK J., KOVÁŘ P., BROŽEK J., ALY S., 2012: A New Fuzzy Group Agreement-Based Approach for Multiexpert Decision Making in Environmental Issues. Environmental Modelling and Software, *36*, 99–110.

WOODWARD D. E., HAWKINS R. H., JIANG R., HJELMFLET A. J., VAN MULLEM J. A., QUAN Q. D., 2003: Runoff Curve Number Method: Examination of the Initial Abstraction Ratio. Conference Proceedings Paper, World Water & Environmental Resources Congress and Related Symposia, 2003, 1–10.

ZIMMERMANN H. J., 1996. Fuzzy Set Theory – and Its Applications. Third edition, Kluwer Academic Publishers, Dordrecht.

Received 24 November 2011
Accepted 17 October 2012