Mitigation of Surface Runoff and Erosion Impacts on Catchment by Stone Hedgerows

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Abstract: This paper presents the results of a study on the influence of hedgerows on the process of the surface runoff in the experimental catchment Verneřice 1, Ústí n. L. region, the Czech Republic. The influence of hedgerows on the surface runoff was simulated using the KINFIL rainfall-runoff model. The model parameters were assessed from the field measurements of the soil hydraulic parameters, in particular the saturated hydraulic conductivity and sorptivity. The catchment area is characterised by stone hedgerows constructed by land users throughout the past centuries, using stones collected from the adjacent agricultural fields. Presently, the hydraulic properties of these hedgerows reflect the characteristics of the mixture of stones, deposited soil, and vegetation litter, and they are more permeable than soil on the areas between them. Due to this fact, the permeability of the hedgerows produces a higher infiltration and a lower surface runoff. Therefore, the overland flow vulnerability and impact of water erosion decrease if they are situated in parallel to the contour lines system. The model was applied for two scenarios in the catchment – with and without hedgerows – to assess their effects on extreme rainfalls with a short duration. The surface runoff caused by extreme rainfall was simulated in order to show how hedgerows can mitigate the resultant flood and erosion. This paper provides relevant hydrological data and summarises the influence of man-made hedgerows on the overland flow control, i.e. on long and steep slopes surface runoff.

Keywords: extreme rainfall; infiltration intensity; rainfall-runoff model; soil erosion; stone hedgerows; surface runoff

Landscape structures are significant factors affecting biodiversity and spatial variety, and they represent an important ecological value for the countryside (Langlois *et al*. 2001). Landscape structures change in time and in space by natural influences and by agricultural practices of the land users.

In many parts of the Czech Republic, especially in the boarder regions, the landscape is characterised by systems of linear field margins, which at present are usually overgrown with hedgerows. Many of these systems date back to the late Middle Ages, when these highland areas were first colonised (Löw & Míchal 2003). They are called remnants of medieval "pluzina" (i.e. ploughed land) (Sklenička *et al.* 2009), and can be recognised by a characteristic comb-like or radial pattern of fields and field margins, radiating from a village, or a former village. The fields of a pluzina often have the characteristic shape of a flat letter S.

The earthworks of field margins can be of three types: a mound, a step, or a terrace (Černý 1973). Mounds (about 0.3–2.0 m in height and 2–4 m in width) are typical for milder slopes and were created by piling up stones collected from the fields. Steps (1.0–1.5 m in height and 1.5–3.0 m in width) are found in slightly hilly terrains, where the margins run horizontally or diagonally and were created by long-term ploughing. These two types of margins separated the fields of different

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land owners. Horizontal terraces (1.0–2.5 m in height) were usually created on steep slopes and several of the narrow fields were farmed by only one land owner.

Occasionally, systems of the field margins of a younger origin than Medieval can be found in the landscape. Unlike pluzinas, these margins often cannot be found in the Stable Cadastre maps system that was established in the 30's of the 19th century (Molnárová *et al.* 2008). They usually have different structures and do not have the characteristic spatial relationship to the settlement. Mounds are usually defined by stone hedgerows, composed of wood and herbs.

Extensive agriculture has had a long lasting tradition in North-Western parts of Bohemia. Whether a stone hedgerows axis was parallel to contour lines or down slope, or in any direction between, was not very important for growing crops or for animal husbandry. Constructing hedgerows was obviously part of good practice in cultivation. Of course, from the hydrological point of view, the longitudinal axis of stone hedgerows is very important as a stabilising factor in the direct runoff formation (Mérot 1999; Marshall & Moonen 2002). The best positioning is in the contour line direction. This can mitigate overland flow as an effective belt. This belt transforms part of the flow, and allows it to infiltrate. A description of differently situated stone hedgerows is given in Figure 1, where the well situated hedgerows have number 1, while those having numbers 2 and 3 are orientated down slope, without any runoff control effect. A detailed view of a typical stone hedgerow is provided in Figure 2. These hedgerow forms are effective obstacles to the overland flow, offering high water permeability and usually also a high diversity of vegetation species (Machová & Elznicová 2009, 2010). These landscape studies analyse the development of stone hedgerows from 1938 to the present days, with reference to their slopes, lengths, longitudinal and cross-section profiles and botanical diversity. The most frequent vegetation growing on these stone hedgerows belong to woody species (trees and shrubs), specifically *Fraxinus excelsior* (up to 60%), *Acer pseudoplatanus*, *Tilia cordata*, *Acer campestre*, *Corylus avellana*, *Prunus avium*, *Prunus spinosa*, and *Carpinus betulus.* The dominant herbs (59 species found) include mainly *Impatiens parviflora* and *Geranium robertianum* (Machová & Elznicová 2010). Figure 3 describes the scheme of contour line orientated hedgerows with protective flood and erosion control on a mild slope catchment. A number of these landscape forms are characteristic for the area of the Ore Mountains (Krušné hory) (Adolfov, Fojtovice, Knínice, Libouchec) and for the northern part of the Central Bohemian Uplands (Oblík, Verneřice). Our case study is focused on the territory of Verneřice, and analyses the hydrological and erosion control functions of stone hedgerows as a biotechnical measure of historical importance. This case study follows up a paper, which has been published by Štibinger (2011).

Figure 1. The Verneřice region with different axis directions of stone hedgerows (1 – well situated, 2 and 3 – non effective, GPS 50°40'42.7''N, 14°14'24.9''E)

Figure 2. Typical hedgerow made of stone deposition with three levels of vegetation (trees, shrubs and herbs)

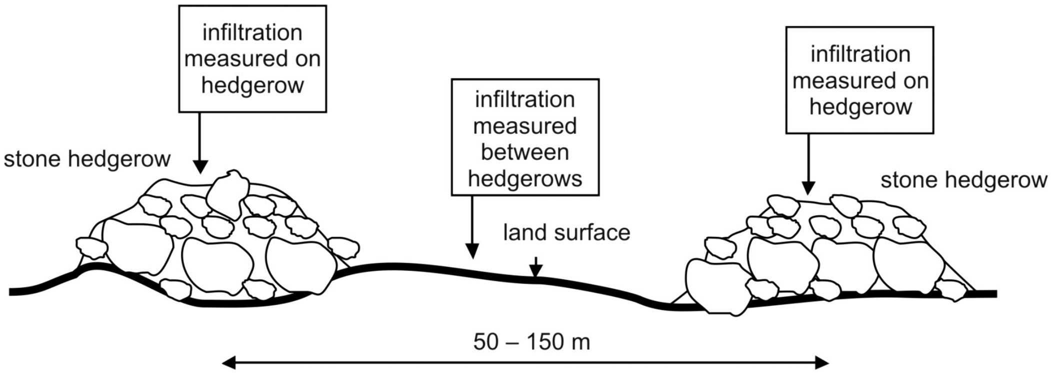

Figure 3. The scheme of contour lines orientated hedgerow protecting soil against surface runoff impact; infiltration intensity is measured on hedgerows and also on land between them

MATERIAL AND METHODS

The protective hydrological function of contour lines orientated stone hedgerows mitigates the negative impacts of extreme intensity rains, i.e. their runoff and soil erosion effects on the catchments. By using infiltrometer measurements, it has been determined that hedgerows and their subsoil are usually more permeable than the upper soil layers between them. Hence, a stone hedgerow can be considered as a biotechnical measure resulting in excellent infiltration properties. It has favourable deep-infiltration properties, which reduce the overland flow and replenish groundwater storage. It can operate as "a linear infiltration belt". When directed parallel to the contour lines, it can be considered as a land management element and one of the catchment characteristics in Figure 4. However, the goal of our study is more pertinent. We want to find an answer to the question, to what extent can we mitigate the surface runoff from extreme rainfalls to prevent the damage caused by flooding and soil erosion.

Experimental area

Our experimental area is situated in the catchment area Verneřice 1 (Figure 1) in the Central Bohemian Uplands, district Ústí n. L. It is an ungauged catchment with the upper water divide on the southern side of the Verneřice 1 area. This catchment is 14 km from the raingauge station Ústí n. L.-Kočkov, where the data used in our study have been collected. The catchment altitude is about 410 m a.s.l. and does not differ significantly from the raingauge altitude (the difference is about 160 m). The catchment does not end with one outlet profile, but with an open contour line profile which is 475 m wide, transferring the sur-

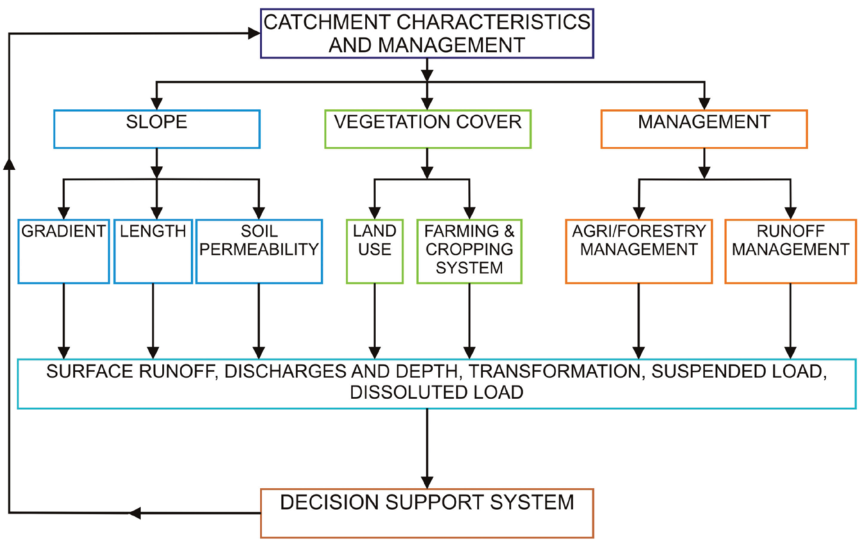

Figure 4. Catchment and management characteristics affecting surface runoff and sediment transport

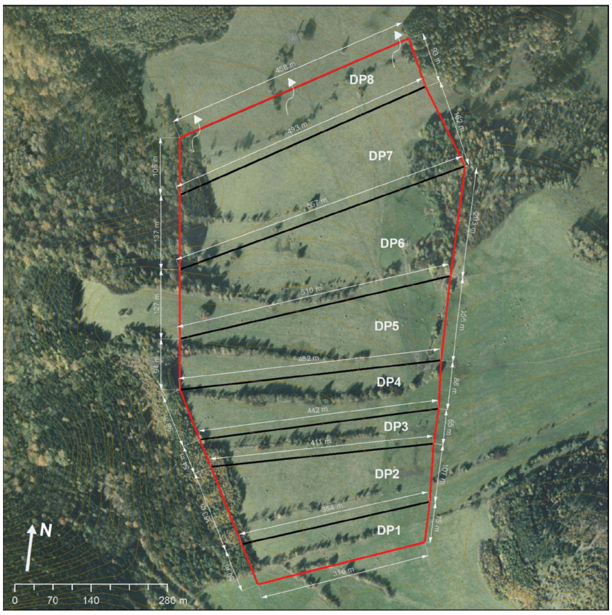

Figure 5. The catchment area Verneřice 1 with stone hedgerows

face runoff down to the rest of the catchment. For practical reasons, the lower part of the catchment is not part of our analysis. The catchment area has a form of a non-regular hexagon, spreading over an area of 40.1 ha. The average slope is 0.08 (8%) with eight sub-catchments (DP1 to DP8), and with the same number of stone hedgerows. The width of the individual sub-catchments varies from 335 to 534 m, their length from 70 to 165 m, with permanent grassland use. The margins are composed of forested areas, the rest are hedgerow areas. More detailed information is given in Table 6; the overall situation is shown in Figure 5. The climate of the catchment area is mild-warm and humid. The average annual temperature is between 7.0 to 7.5°C, the long-term annual precipitation varies between 600–700 mm. The catchment geological structure is made of outcrops of tertiary basalt and partially also sandstone sediments of the secondary geological formation. Soil types are mostly mesotrophic to eutrophic Cambisols and haplic Luvisols. These soil categories can be characterised as water permeable silt loam and sandy loam. The catchment Verneřice 1 covers the upper part only, where all eight hedgerows are situated. Therefore, it has no one point outlet. The lower margin of eight hedgerow form the "line outlet", transferring the overland flow to its lower part. Figure 5 represents the experimental area Verneřice 1 (A = 40.1 ha), which has been fragmented into eight sub-catchments. These sub-areas are naturally divided by eight stone hedgerows with an average width of 5.0 m. The lengths of the individual hedgerows vary: their total length is 3 338.0 m, their widths vary from 3.6 to 7.1 m, the average slope is 0.08, the average distance between the hedgerows is 94.0 m, and the average angle between the hedgerow axes and contour line is about 7°. Table 1 provides the areas of the sub-catchments DP1 to DP8 (including the hedgerow areas).

Field measurements

The field measurements of the infiltration intensity in the catchment area Verneřice 1 were taken four times in the period from 2009 to 2010. The results were analysed statistically within the research project NAZV QH 82126/2008 "Harmonisation of landscape-stabilizing, hydrologic and production function of stone hedgerows and terraces for diversification activities in rural areas". The purpose of these measurements was to determine the values of the infiltration parameters and the soil hydraulic characteristics in the areas between the hedgerows, and also within these hedgerows. Such measurements have not yet been taken in this area, and thus our study offers unique findings (Cílek 2009). One of the specific outcomes of this study is the evaluation of the Richards' equation (Kutílek & Nielsen 1994) and the Philip's solution of non-steady infiltration (Philip 1957). The shortened Philip equation for the vertical cumulative infiltration, V (m), into homogeneous soil with water ponded on the surface was applied for the determination of the saturated hydraulic conductivity K_s (m/s) and sorptivity S (m/s$^{1/2}$), which has the form:

Table 1. The sub-catchment areas of the Verneřice 1 catchment (see Figure 5)

	Area No. DP							
	DP1	DP2	DP3	DP4	DP5	DP6	DP7	DP8
Area (ha)	2.524	4.840	2.419	4.210	5.959	8.167	7.608	4.345

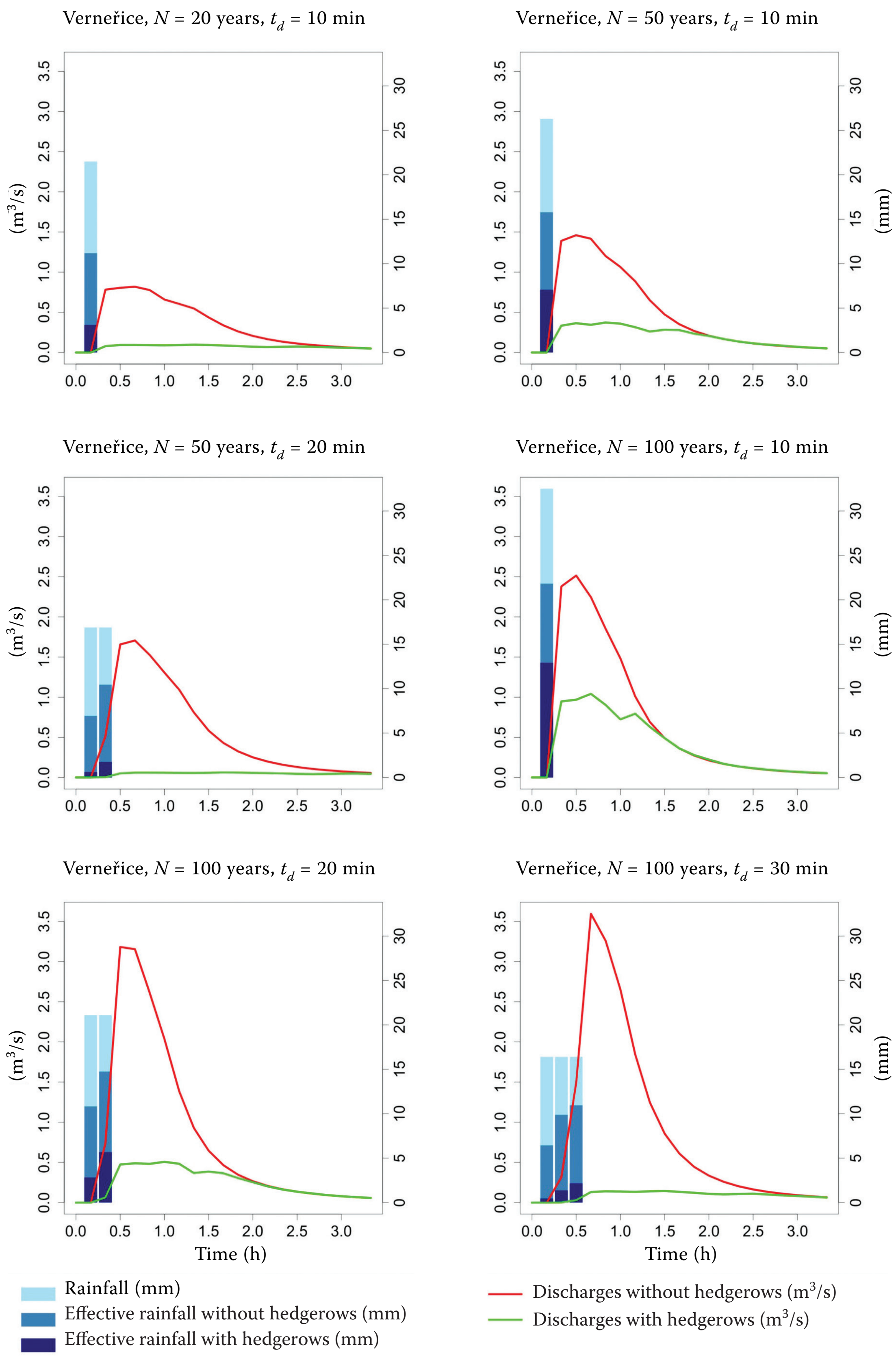

Figure 6. The hydrographs comparison on the Verneřice 1 catchment with a hedgerow infiltration function and without it, for extreme rainfalls of various return periods *N* and duration periods *t*

$$V = S \times t^{1/2} + A_t \times t \qquad (1)$$

where:
A_t – soil parameter (m/s$^{1/2}$)

A_t is related to the saturated hydraulic conductivity K_s, and for the saturated soil surface is equal to it. Then, it can be written:

$$V = S \times t^{1/2} + K_s \times t \qquad (1a)$$

The infiltration intensity $v(t)$ can be obtained by derivation of Eq. (1a) in time, when:

$$v(t) = \frac{1}{2} S \times t^{-1/2} + K_s \qquad (2)$$

The non-linear regression was computed and, in order to collect the values by the field measurement in the Verneřice catchment area (Figure 1), the two-cylinder method of infiltration was used and all data were analysed. The measurement technique as well as its statistical analysis have been described in detail elsewhere (Štibinger 2011).

Subsequently, both parameters S and K_s were computed, applying the method of non-linear regression.

The correlation coefficient R showed the best fit of the data series, when $R = 0.999$ and 0.970.

The final parameter values are given in Table 2. On the basis of the analysis of the data collected in the Verneřice 1 catchment, it became clear that the K_s permeabilities values of the hedgerows lines were about 4.5 times higher ($K_s = 3.58 \times 10^{-5}$ m/s) than those in the empty spaces lying between them ($K_s = 8.10 \times 10^{-6}$ m/s).

Table 2. Values of saturated hydraulic conductivity (K_s) and sorptivity (S) on the Verneřice 1 catchment

	Between hedgerows	On hedgerows
K_s (m/s)	8.10×10^{-6}	3.58×10^{-5}
S (m/s$^{1/2}$)	2.16×10^{-4}	2.38×10^{-4}
R	0.997	0.999

Extreme rainfall assessment

The catchment Verneřice 1 has a rainfall gauge in close vicinity, which provides daily rainfall data with a return period N = 2, 5, 10, 20, 50 and 100 years, as shown in Table 3. The length of the data record was 90 years (1901 to 1990). These data were used for a shorter duration than one day (24 h), as the catchment area is relatively small (0.40 km^2). Therefore, the periods of critical rainfalls duration were selected for time t = 10, 20, 30, 60, 90, 120 and 300 min. For this computation, the RAIN_red procedure (Kovar & Hradek 1994) was used, according to the relations (Hrádek & Kovář 1994):

$$P_{t,N} = P_{1d,N} \times a \times t^{1-c} \qquad (3)$$

$$i_{t,N} = P_{1d,N} \times a \times t^{c} \qquad (4)$$

where:
$P_{t,N}$ – maximum extreme rainfall depth (mm) of duration t and return period N
$i_{t,N}$ – maximum extreme rainfall intensity (mm/min) of duration t and return period N
$P_{1d,N}$ – maximum extreme rainfall depth (mm) of one day duration and return period N
t – time
a, c – regional parameters

The regional parameters for the extreme rainfall reduction a and c were derived by means of the methodology used by Hrádek and Kovář (1994). The return period (N years) for extreme rainfall is assumed to be the same as the return period for runoff. These extreme rainfalls are used also for the design purposes, with planning flood or erosion control measures. Such "design" rainfalls were used with a constant intensity. Table 4 provides the $P_{t,N}$ rainfall depth values needed for the design in-

Table 3. One day extreme rainfalls $P_{1d,N}$ at the Ústí n. L.-Kočkov station*

	Return period N (years)					
	2	5	10	20	50	100
Daily extreme rain $P_{1d,N}$ (mm)	30.6	41.8	49.0	56.5	65.7	79.2

*Distance 14 km from the Verneřice 1 catchment, altitude difference is 160 m a.s.l.

Table 4. Maximum extreme rainfall depths $P_{t,N}$ of short duration for the station Ústí n. L. (in mm)

N (years)	$P_{1d,N}$ (mm)	t (min)						
		10	20	30	60	90	120	300
2	30.6	10.1	12.4	14.0	16.3	17.6	18.6	22.4
5	41.8	14.7	18.2	20.7	24.8	26.9	28.4	32.8
10	49.0	17.6	22.4	25.7	30.7	33.3	35.2	39.8
20	56.5	21.5	27.4	31.6	38.0	41.1	43.5	47.9
50	65.7	26.3	33.8	39.2	47.5	51.5	54.6	58.5
100	79.2	32.5	42.1	49.1	59.4	64.4	68.1	72.0

put hydrograph computation, using the RAIN_red procedure, as already mentioned. Similarly, Table 5 gives the $i_{t,N}$ rainfall intensity values of a short duration, as estimated from daily values. These short duration extreme rainfalls were tested using the KINFIL rainfall-runoff model in the experimental catchment, to simulate the runoff. Due to the small catchment area and thus a short concentration time, a particular expectation was put on the short time extreme rainfall of duration t = 10 to 30 min.

KINFIL rainfall-runoff model

The KINFIL model is based on the combination of infiltration (1st part) and direct runoff transformation processes (2nd part). This model (2D) is physically based and it has been used for the reconstruction of many historical rainfall-runoff events and also for various scenario simulations on gauged or ungauged catchments (Kovář 1992; Heřman *et al.* 2001; Kovář *et al.* 2002). It requires physiographical parameters of the catchment, which can be determined from maps and field survey. It is often used for the design discharge determination and also for scenario situations, e.g. when the effects of the climate change are simulated. The first part of the KINFIL model computes infiltration rates $v_f(t)$ for each interval of duration t and subtracts them from the extreme rainfall intensities $i(t)$ (of return period N) in order to get the effective rainfall hyetograph $r_e(t)$:

$$r_e(t) = i(t) - v_f(t) \tag{5}$$

This infiltration part of the KINFIL model is based on the infiltration theory of Green and Ampt applying the concept of the ponding time and storage suction factor S_f by Morel-Seytoux and Verdin (1981) and by Morel-Seytoux (1982):

$$v_f = (\theta_s - \theta_i)\frac{dz_f}{dt} = K_s\left[\frac{z_f + H_f}{z}\right] \tag{6}$$

The left side of Eq. (6) expresses the Darcy principle of an infiltration process, while its right side reflects the Green-Ampt theory (Rawls & Brakensiek 1983). It has been used by many authors (e.g. Morel-Seytoux & Verdin 1981).

Table 5. Maximum extreme rainfall intensities $i_{t,N}$ of short duration for the station Ústí n. L. (in mm/min)

N (years)	$P_{1d,N}$ (mm)	t (min)						
		10	20	30	60	90	120	300
2	30.6	1.01	0.62	0.47	0.27	0.2	0.16	0.07
5	41.8	1.47	0.91	0.69	0.41	0.3	0.24	0.11
10	49.0	1.76	1.12	0.86	0.51	0.37	0.29	0.13
20	56.5	2.15	1.37	1.05	0.63	0.46	0.36	0.16
50	65.7	2.63	1.69	1.31	0.79	0.57	0.45	0.19
100	79.2	3.25	2.11	1.64	0.99	0.72	0.57	0.24

The ponding time is expressed as:

$$t_p = \frac{S_f}{i(\frac{i}{K_s} - 1)} \tag{7}$$

and the storage suction factor as:

$$S_f = H_f \ (\theta_s - \theta_i) = \frac{S^2(\theta_i)}{2K_s} \tag{8}$$

where:

θ_s – saturated soil water content (–)
θ_i – initial soil water content (–)
z_f – depth of infiltration front (m)
z – vertical ordinate (m)
H_f – capillary suction on infiltration front (m)
K_s – saturated hydraulic conductivity (m/s)
i – constant rate of design rainfall (m/s)
S_f – storage suction factor (m)
$S(\theta_s)$ – sorptivity at initial soil water content ($m/s^{1/2}$)
t_p – ponding time (s)

When we know the parameters such as the saturated conductivity K_s and sorptivity S, we can use the equations needed for the KINFIL model to compute Eqs. (5) to (8) and to receive the effective rainfall ordinates $r_e(t)$ to be further used for the surface runoff component computed in the second part (KIN).

The second part of the KINFIL model is the surface runoff component, using the kinematic equation of flow over a catchment (Kibler & Woolhiser 1970; Beven 2006):

$$r_e(t) = \frac{\partial y}{\partial t} + \alpha \times m \times y^{m-1} \times \frac{\partial y}{\partial x} \tag{9}$$

where:

$r_e(t)$ – effective rainfall intensity (m/s)
y, t, x – ordinates of depth, time, and position (m, s, m)
α, m – hydraulic parameters

This equation describes the non steady flow, approximated, after neglecting the velocity terms of St. Venant's equation, by kinematic wave on a plane or a cascade of planes or segments.

Eq. (9) is computed, using the finite differences method and implementing the explicit numerical scheme (Lax & Wendroff 1960). The upper boundary condition of the Lax-Wendroff scheme is $y(x, 0) = 0$ for all x. For the practical application of the KINFIL model, the catchment was divided into a cascade of planes, with the same slopes and different lengths and widths.

The present version of the KINFIL model assumes that the individual small subcatchments are substituted by a system of planes, arranged according to the flow direction, i.e. from 1 to 8. This system puts emphasis on the geometry of planes, their slopes and roughness conditions. Therefore, the KINFIL model requires geometric parameters of planes, slopes, soil hydraulic parameters K_s and S, Manning roughness n, and flow pattern system.

Table 6. Fragmentation of the Verneřice 1 catchment area for the KINFIL model

Sub-catchment DP	Area (ha)	Average slope (–)	Average width (m)	Average length (m)	Land use: grassland (%)	Land use: forest (%)	Land use: hedgerow (%)
DP1	2.524	0.080	335	70	90.2	3.2	6.6
DP2	4.840	0.080	383	130	91.3	4.8	3.9
DP3	2.419	0.080	426	60	87.5	3.7	8.8
DP4	4.210	0.080	462	93	93.4	0	6.6
DP5	5.959	0.080	496	125	96.2	0	3.8
DP6	8.167	0.080	534	165	87.1	9.6	3.3
DP7	7.608	0.080	525	150	85.8	12.5	1.7
DP8	4.345	0.080	475	99	91.0	3.5	5.5

Table 7. Major rainfall parameters and runoff hydrograph peaks on the Verneřice 1 catchment without hedgerows and with hedgerows as computed with the KINFIL model

Design rainfall			Effective rainfall (mm)		Peak discharges (m^3/s)	
Return period N (years)	duration time t (min)	depth P (mm)	without hedgerows R_e	with hedgerows R_{eh}	without hedgerows Q	with hedgerows Q_h
2	10	10.1	1.26	–	–	–
2	20	12.4	0.33	–	–	–
2	30	14.0	–	–	–	–
2	60	16.3	–	–	–	–
2	120	18.6	–	–	–	–
5	10	14.7	4.93	0.12	0.206	–
5	20	18.2	2.85	–	0.086	–
5	30	20.7	1.60	–	0.032	–
5	60	24.8	0.27	–	–	–
5	120	28.4	–	–	–	–
10	10	17.6	7.54	0.85	0.419	0.011
10	20	22.4	6.52	0.14	0.329	0.001
10	30	25.7	4.77	–	0.192	–
10	60	30.7	1.43	–	–	–
10	120	35.9	–	–	–	–
20	10	21.5	11.24	3.09	0.818	0.096
20	20	27.4	11.20	0.22	0.813	0.001
20	30	31.6	10.11	–	0.681	–
20	60	38.0	5.06	–	0.215	–
20	120	43.5	–	–	–	–
50	10	26.3	15.8	7.05	1.460	0.373
50	20	33.8	17.40	2.37	1.706	0.060
50	30	39.2	12.78	0.12	1.010	0.003
50	60	47.5	12.14	–	0.900	–
50	120	54.6	3.53	–	–	–
100	10	32.5	21.83	12.91	2.514	1.041
100	20	42.1	25.58	8.49	3.182	0.489
100	30	49.1	27.29	3.96	3.595	0.144
100	60	59.4	23.62	0.66	0.496	0.007
100	120	68.1	11.98	–	–	–

RESULTS AND DISCUSSION

The topographic fragmentation of the experimental catchment Verneřice 1 was implemented through GIS ArcInfo with respect to the hedgerows system. The topology-vector data ZABADEG 1:10 000, including planimetry and hypsography, was the basis of the study. The demarcation of the experimental catchment and partial sub-catchments DP1–DP8 were designed from the geographic data, using the ArcInfo programme in the ESRI system. The land slope is almost the same for all sub-catchments (0.08). The fragmentation of the experimental catchment is presented in Figure 5, the geometric and land use data are given in Table 6. Its use had been tested in several locations, i.e. in catchments with rainfall and overland flow observation (Kovář *et al*. 2002, 2006). The determination of the Manning roughness *n* value is usually difficult. In our study, we used the values recommended in relevant literature (Fread 1989; Maidment 1992), i.e. n = 0.100 for grassland, and n = 0.150–0.200 for forests. The value for hedgerows was estimated at n = 0.300. We assume that for extreme discharge from extreme rainfall events with a return period N = 20–100 years, the roughness and turbulent flow correspond to reality. Due to the short runoff lengths (see runoff lengths in Table 6: 60.0–165.0 m) and the homogenous slope of a meadow, it was not necessary to subdivide the partial catchment into more detailed cascades of planes for simulation by the KINFIL model.

One of the important contributions of this paper was the comparision of the function of hedgerows during extreme rainfall-runoff events in various circumstances. A model simulation was implemented for all events of the return periods of extreme rainfalls N = 2 to 100 years and periods of their duration t = 10', 20', 30', 60', 90', 120' and 300' for the basic scenario without hedgerows and with hedgerows to see how much they reduce the surface runoff. By using GIS, the sub-catchment areas DP fragmentation was created, thus reflecting the fact that each DP subcatchment had one protective biotechnical element in the form of a hedgerow. Their geometry dimension corresponded to the real situation.

The surface runoff simulation using the KINFIL model was applied in both scenarios, with and without hedgerows. Infiltration and the hyetographs of the effective rainfalls and their transformation in final hydrographs were then computed. It was assessed that in this particular catchment gross rainfalls, of the return periods N = 2, 5 and 10 years, create only small effective rainfalls. Their depths and rates are quite low, and therefore they can hardly form a significant surface runoff. More heavy rainfalls can create surface runoff only in scenarios without hedgerows, i.e. without their protection, when the return periods are N = 20, 50 and 100 years. Thus, the protection effect of hedgerows is relatively robust. The graphic representation in Figure 6 shows the most critical situations with heavy extreme rains, which cause a significant discharge. In our study, the discharges Q_{20} (10'), Q_{50} (10' and 20'), and Q_{100} (10', 20' and 30') have been found as the highest and they are highlighted in Table 7 and plotted in Figure 6.

Of course, we are aware of the fact that because the experimental catchment Verneřice 1 is ungauged, as is the case with all small catchments with hedgerow systems in the Czech territory, we cannot use the observed runoff data as the feedback for control. However, it is also the fact that the measured data on the infiltration parameters and extreme rainfall data were collected meticulously. Furthermore, the KINFIL model has been implemented successfully many times in other catchments, with acceptable degree of fit with the observed and computed discharges as the criterion of reliability. This fact seems to be a major source of uncertainty.

CONCLUSIONS

Following the previous analyses of the measurement results, obtained *in situ*, of infiltration and computational simulation by the KINFIL model in the Verneřice 1 catchment, the following conclusions may be drawn.

Hedgerows possess distinct hydro-physical characteristics which are different from the characteristics of permanent grassland growing between them. In particular, the latter have much higher infiltration intensity. As a result of favourable infiltration characteristics, they act as infiltration and erosion control biotechnical measures for decreasing surface runoff. Their influence on the water regimes may also be significant during dry seasons.

Simulations using the KINFIL model proved that, as a result of the favourable infiltration characteristics of the soils in the Verneřice 1 catchment, the depth of the surface runoff (i.e. the depth of effective rainfall) for gross rainfall with the return periods $N = 2$, 5 and 10 years is insignificant (see Table 5). The discharges caused by rainfall with the return period $N = 20$, 50, and 100 years could be dangerous in the absence of hedgerows. Due to their infiltration capacity and hydraulic roughness, the hedgerows effectively reduce such discharges. In the most critical Q_{100} (10'), the discharge from the extreme rainfall is reduced by hedgerows from a value of 2.5 to 1.0 m^3/s (i.e. by 60%).

Hydraulic variables, which are characteristic for the runoff formation process, i.e. the flow depth, velocity, and shear stress, indicate that for runoff with the return period exceeding $N = 10$ years, hedgerows obviously protect grassland against erosion. Model simulations, for the alternatives without hedgerows and with hedgerows, have shown that the non-scouring velocity and the critical shear stress on grassland are always resistant against water erosion. If these plots were again transformed in arable land for growing field crops (e.g. root crops, maize, sunflower, rape, etc.), this would surely not be the case, because of the changes in critical shear stress of soil that is not covered by permanent grassland. In our present times of hydrological extremes, such as rainstorms, research focusing on land and water regime protection is of course very relevant.

The next step in our research will be to install a pair of rainfall-runoff gauges in this catchment, in order to compare the observed and computed data. We assume that this will generate reliable data, which will highlight the positive hydrological impact of hedgerows in landscape during strong rainfall-runoff events.

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