SIMULATION OF THE IMPACT OF LAND USE ON SIGNIFICANT RAINFALL-RUNOFF EVENTS USING THE KINFIL MODEL

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This paper deals with the analysis of flood events, implementing the KINFIL hydrological model on small catchments where both land use and land management play a significant role, and where these human activities can influence the design discharges. A combination of GIS techniques with the KINFIL model, which is conceived on a physically based infiltration approach (INFIL) and on a kinematic wave transformation of direct runoff (KIN), provides a tool for analysing historical rainfall-runoff events, for assessing design discharges, and for simulating hypothetical flood scenarios. KINFIL is a complex model using the correspondence of Curve Number (CN) with soil parameters and the kinematic wave transformation with the physiographical parameters, and it serves as the implementation example of the Černici experimental catchment in Central Bohemia (Czech Republic). All the topographical and morphological catchment data were analysed and prepared for the KINFIL model, using GIS facilities. Thus the model was first implemented for design discharge assessment and then for simulation scenarios of changes in land use expressed by the model parameters. It has been shown again that land use changes do not affect peak flood discharges by more than 10 percent.

infiltration approach; kinematic wave; GIS; rainfall-runoff models; design discharges; land use changes

INTRODUCTION

Recent trends in sudden weather changes in Central Europe have clearly led to a rise in the frequency of hydrological extremes, i. e., floods and droughts. Catchment management, including land use, plays an important role in rainfall-runoff relationships. Implementation of hydrological models gives an opportunity to make a better analysis of flood situations, with particular reference to direct runoff processes in the context of changes caused by human activities. Simulation of design discharges on small catchments under the influence of these activities is a key task for hydrometeorological institutes. However, in the case of small catchments, the reliability of this data varies, and one possible way to improve it is by applying hydrological models. One such model simulating direct runoff from ungauged catchments is the KINFIL model (Kovář, 1992), which can be utilized by skilled hydrologists.

MATERIAL AND METHOD

Model structure

The KINFIL model uses the Curve Number method (US SCS, 1986), but suppresses its weak theoretical background by substituting physically-based infiltration theory for the common empirical CN approach. The correspondences between CN values and soil parameters, such as saturated hydraulic conductivity (K_S) and sorptivity (S_f), were derived through a correlation technique of these parameters with design rainfalls for the territory of the Czech Republic. These correspondences were used for further simulation of historical rainfall-runoff events, implementing the KINFIL model namely on typical mountainous catchments. The infiltration part of the model is based on the Morel-Seytoux equations (Morel-Seytoux, Verdin, 1981), based on the Green-Ampt concept distinguishing pre- and post-ponding infiltration from constant or variable rainfall.

The second basic component of the KINFIL model is a simulation of runoff. This process is based on a kinematic flow approximation in the model. For the numerical solution, the explicit Lax-Wendroff finite difference scheme was implemented. Three simulation components, a cascade of planes, converging or diverging segments, and channel reaches were used to simulate the topography of a catchment. A more detailed model structure is described elsewhere (Kovář, 1992). A recent innovation in the „geometrization" of a catchment is to take consistently into account the hierarchy of sub-catchments in the flow direction. This version assumes that individual small sub-catchments are substituted by a system of serial/parallel cascades of planes arranged according to flow direction. However, this system should not go into too great topographic detail, but puts emphasis on slopes and roughness conditions.

Model implementation and results

The Černičí experimental catchment (hydrological number 1-09-02-107, located in the Benešov district), with a relatively heterogeneous land use pattern, was used for the KINFIL implementation. The shape of the

Table 1. Catchment characteristics

Catchment area	139.8 ha
River length	2.17 km
Average river slope	4.4%
Minimum altitude	448 m a. s. l.
Maximum altitude	543 m a. s. l.
Middle altitude	489 m a. s. l.
Catchment perimeter	5.9 km

Table 2. Land use

Land use	Area in ha	Area in %
Arable land	88.3	63.2
Permanent grassland	26.3	18.8
Forest	25.0	17.9
Others	0.2	0.1

Table 3. Hydrological soil groups in land use (ha)

Soil groups	B			C		
Land use	ha	%	CN	ha	%	CN
I. Arable land	74.5	53	78	13.8	10	85
II. Permanent grassland	–	–	–	26.3	19	72
III. Forest	25	18	63	–	–	–

Average value of Curve Number (CN) on the catchment:
$CN_{II} = 0.53 \times 78 + 0.18 \times 63 + 0.1 \times 85 + 0.19 \times 72 = \mathbf{75.0}$
$CN_{III} = \mathbf{88.0}$

Černičí catchment is longitudinal, the bulk of land use is arable land (63.2%), and the area of permanent grassland (18.8%) and forest (17.9%) are balanced roughly one to one. The physiographic characteristics of the catchment are given in Table 1, the land use in Table 2, and the hydrological soil groups are presented in Table 3. These groups were selected according to the Curve Number (CN) method, a widely used procedure concerning both agricultural and forested lands (US SCS, 1986; Ritzema, 1994).

The catchment was heavily impacted by a significant torrential rainfall on May 5, 2001, when the arable land was still bare before maize sowing. Besides maps, the following data was used for the KINFIL implementation:

- Hourly rainfall data from the local (Černičí) raingauge recorder
- Hourly runoff data from the water-stage recorder at the Černičí outlet
- Land use data, topographical and physiographical characteristics of the catchment given on maps (as shown in Tables 1, 2 and 3)

Before the sudden five-hour rainfall event with a depth of 16.2 mm, the catchment had been saturated by 60mm precipitation in the previous 30 days. The lack of vegetation cover on the arable land meant that there was almost no surface protection. Thus, the local direct runoff appeared with a depth of 9.3 mm, with a peak of 4.2 $m^3.s^{-1}$, which corresponded to a 2 to 3-year flood. The concentration time was about 40 min.

The topographical structure of the catchment, divided into sub-areas creating the drainage pattern, was analysed using GIS ArcInfo, resulting in a digital elevation map (DEM). All topographical parameters needed for the catchment fragmentation were derived from DEM, and the final form is shown in Fig. 1, with the drainage pattern in Table 4. The water-divides between the cascade-

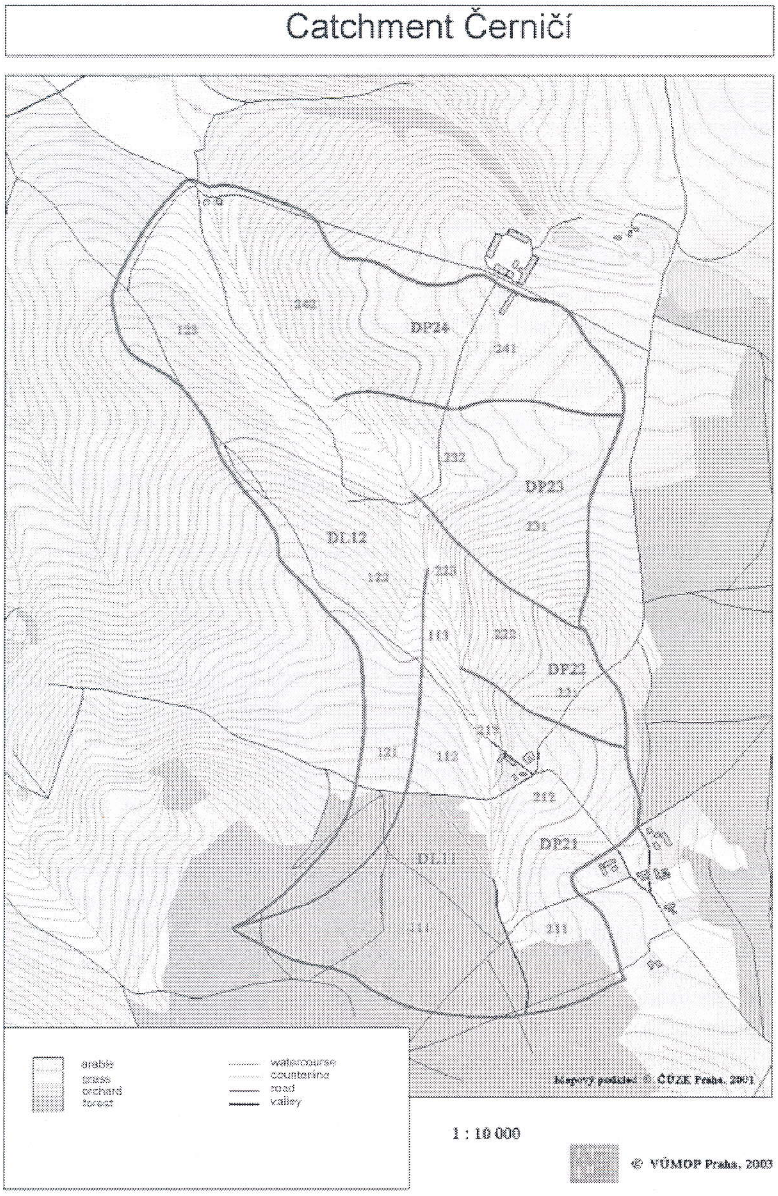

Fig. 1. Černičí map with sub-catchments and land use

Table 4. Drainage pattern of the Černičí catchment (KINFIL)

Cascade	Area (km^2)	Plane	Area (km^2)	Average width (km)	Length (km)	Slope (–)	Arable (%)	Grass (%)	Forest (%)	Urbanized (%)
DL 11	0.252	111	0.183	1.093	0.167	0.051	1	0	99	0
		112	0.053		0.048	0.074	56	30	14	0
		113	0.016		0.015	0.111	0	100	0	0
DL 12	0.396	121	0.079	1.076	0.073	0.057	59	1	40	0
		122	0.127		0.118	0.097	84	16	0	0
		123	0.190		0.177	0.085	41	59	0	0
DP 21	0.189	211	0.105	0.845	0.124	0.032	68	4	28	0
		212	0.071		0.084	0.074	81	18	0	1
		213	0.013		0.015	0.103	32	67	0	1
DP 22	0.109	221	0.049	0.436	0.112	0.056	99	1	0	0
		222	0.038		0.087	0.106	98	2	0	0
		223	0.022		0.050	0.138	32	68	0	0
DP 23		231	0.127	0.284	0.447	0.073	99	1	0	0
		232	0.063		0.222	0.091	56	44	0	0
DP 24		241	0.139	0.604	0.230	0.036	99	0	0	1
		242	0.124		0.205	0.096	78	22	0	0

Table 5. Statistical fit of the observed and computed hydrographs

Flood wave	Determination coefficient RE (–)	Volume error TVOL (%)	Peak error PEAK (%)
05/05/2001	0.75	0.20	0.70

Note: For the best fit: RE = 1.0

plane were derived from the Arc/Info slope and land use-components. All sub-catchments were transformed into area-equal rectangular elements of each cascade (Table 4). The sub-catchment numbering system is well illustrated in Fig. 1, based on the following system (Kovář et al., 2001, 2002):

- 1 x x left side (DL 1 xx)
- 2 x x right side (DP 2 xx)
- x 1 x – x 4 x cascade number
- x x 1 – x x 3 plane number in cascade (downstream numbering)

DISCUSSION AND CONCLUSIONS

The first aim of this paper is to present the KINFIL model for reconstructing a significant rainfall-runoff event and for improving the assistance of GIS in the KINFIL model for a catchment parameter analysis and subsequently for process modelling. A clear visualization of the spatial parameter variability and drainage pattern can also be performed by the interface between the hydrological model and Arc/Info. This reconstruction is illustrated in Fig. 2. The goodness of fit of the observed

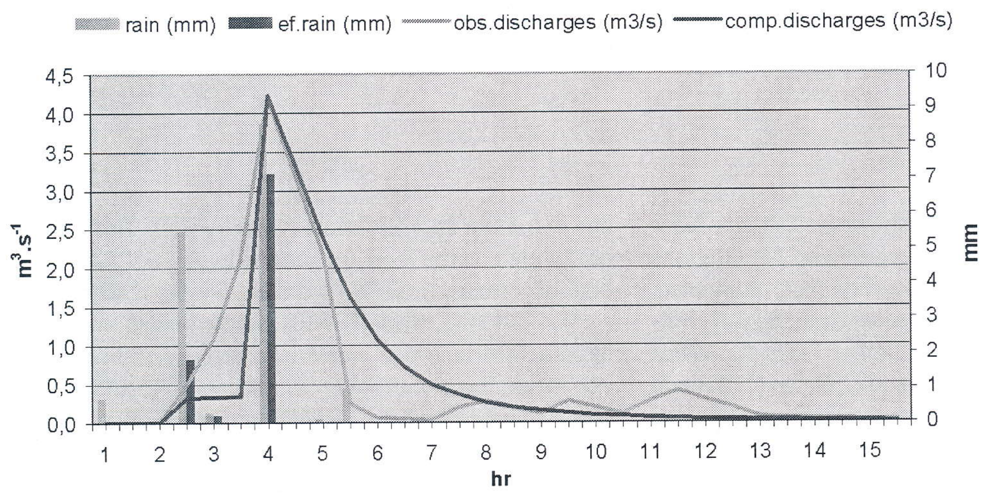

Fig. 2. Observed and computed discharges (KINFIL) Černičí catchment, flood wave 05/05/2001

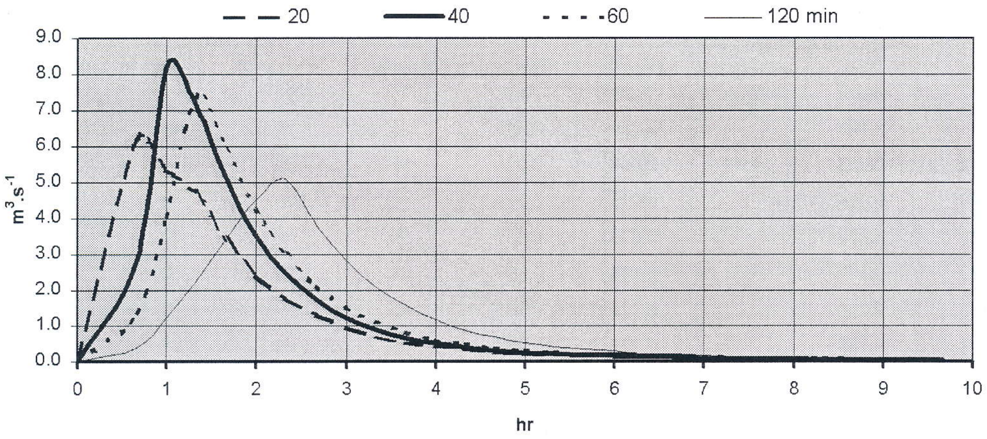

Fig. 3. Design discharges for duration t_d = 20, 40, 60, 120 min and recurrence time N = 10 years

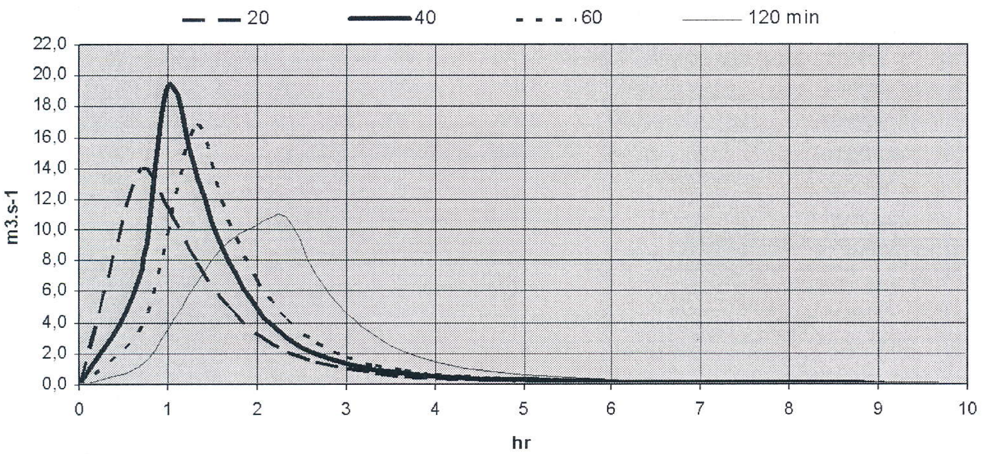

Fig. 4. Design discharges for duration t_d = 20, 40, 60, 120 min and recurrence time N = 50 years

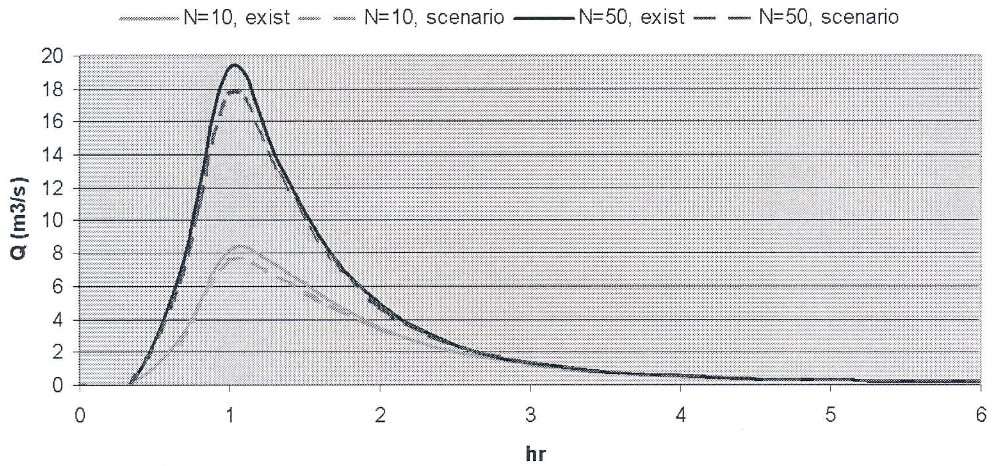

Fig. 5. Scenario simulation of land use for design rainfalls N = 10, N = 50 years; t_d = 40 min

and computed discharge pairs is shown in Table 5. After reconstruction analysis, the design flood simulations from rainfalls of the same probability were computed. This rainfall assessment was computed from the daily values for the nearest rain gauge station at Dolní Kralovice for the rainfall duration t_d = 20, 40, 60 and 120 min (Hrádek, Kovář, 1994). These scenario simulations were computed, and the results are given in the form of hydrographs in Fig. 3 (for H_s = 64.0 mm, N = 10 years) and Fig. 4 (for H_s = 87.8 mm, N = 50 years). Time of concentration t_c is the most dangerous duration of rainfall for both occurrence times N, and it is about t_c = 40 min.

The last step of the KINFIL implementation was the hypothetical land use scenario to discover how much it can affect the flood peak. The scenario of substituting 10% of arable land by permanent grassland was established and implemented. The results for two design floods of N = 10 and 50 years showed that, in general, the influence of this land use change does not affect the runoff peak more than 10% (8.8% for N = 10 years, and 8.2% for N = 50 years) (Fig. 5).

In conclusion, the most important rainfall characteristics are depth and intensity. Well diversified land use with a high percentage of forest and permanent grassland can reduce direct runoff in favour of infiltration, but usually by at most 10%. The KINFIL modelling technique has demonstrated its good applicability and successful performance for use in flood management.

REFERENCES

CHOW, W. T. – MAIDMENT, D. R. – MAYS, L. W.: Applied Hydrology. McGraw-Hill, USA, 1998. 572 pp.

HRÁDEK, F. – KOVÁŘ, P.: Calculation of alternate intensities of rainstorms, Vod. Hospod., *44*, 1994: 2.

KOVÁŘ, P.: Possibilities of determination of design discharges on small catchmenst using the KINFIL model. Vodohosp. Čas., 1992: 197–220.

KOVÁŘ, P. – CUDLÍN, P. – KORYTÁŘ, M. – ZEMEK, F. – HEŘMAN, M.: Comparative study of water balance on the experimental catchments Všeminka and Dřevnice. Rostl. Výr., *47*, 2001: 260–266.

KOVÁŘ, P. – CUDLÍN, P. – HEŘMAN, M. – ZEMEK, F. – KORYTÁŘ, M.: Analysis of flood events on small river catchments using the KINFIL model. J. Hydrol. Hydromech., *50*, 2002: 157–171.

MOREL-SEYTOUX, H. J. – VERDIN, J. P.: Extension of the Soil Conservation Service. Rainfall-Runoff Methodology for Ungauged Watersheds. Colorado, USA, 1981.

RITZEMA, H. P.: Drainage Principles and Applications. ILRI Publication 16, 2nd ed. Wageningen, The Netherlands, 1994. 194 pp.

US SCS: Urban hydrology for small watersheds. U.S. Soil Conservation. Technical Release 55 (13). Service, Washington, 1996.

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Simulace vlivu hospodářského využívání pozemků na srážko-odtokové události modelem KINFIL.

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Příspěvek analyzuje povodňové případy implementací hydrologického modelu KINFIL, používaného na malých povodích, kde hospodářské využití pozemků a antropogenní vlivy hrají podstatnou roli. Záměrem příspěvku je informovat o možnostech využití GIS při fragmentaci malých povodí za účelem zpřesnění vstupních dat pro hydrologický model KINFIL. Kombinace GIS a KINFIL, který je fyzikálně založen na teorii infiltrace a transformace přímého odtoku kinematickou vlnou, poskytuje nástroj pro analýzu jak historických srážko-odtokových případů, tak hypotetických scénářových simulací. Model KINFIL využívá dříve odvozených vztahů mezi hodnotami čísel odtokových křivek CN a „koncepčních" půdních parametrů spolu s parametry transformace na testovaném experimentálním povodí Černičí ve středních Čechách. Model KINFIL využívá prostředků GIS, plně respektuje průběh hydrografické sítě povodí a její členění na subpovodí. Základem pro získání požadovaných parametrů modelu KINFIL 2 je digitální model reliéfu terénu (DEM). Tato verze je geograficky solidně založená, kdy nejprve byly zpracovány historické povodně s odvozením parametrů pro návrhové průtoky a potom simulován vliv změn hospodářského využití povodí na povodňové průtoky. Znovu se prokázalo, že tento vliv obvykle nezpůsobuje změnu větší než cca 10 %.

infiltrační přístup; kinematická vlna; GIS; srážko-odtokové modely; návrhové průtoky; změny hospodářského využití území

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