Simulation of urbanized area impact on runoff by means of fully distributed mathematical model MIKE SHE, the Botič (CZ) case

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1. Introduction

The flood event in June 2013 caused notable damages across several regions of the Czech Republic [1]. A local flood in southern part of Prague city area is focused, which hit rural as well as urban areas. Analysis of land-use changes impact on storm runoff hydrograph was conducted in the upper Botič catchment (Fig. 1). Main aim of the study was to answer a question, whether flood hydrograph entering Hostivař reservoir was affected due to the impact of urbanised area extension across the source catchments in recent period.

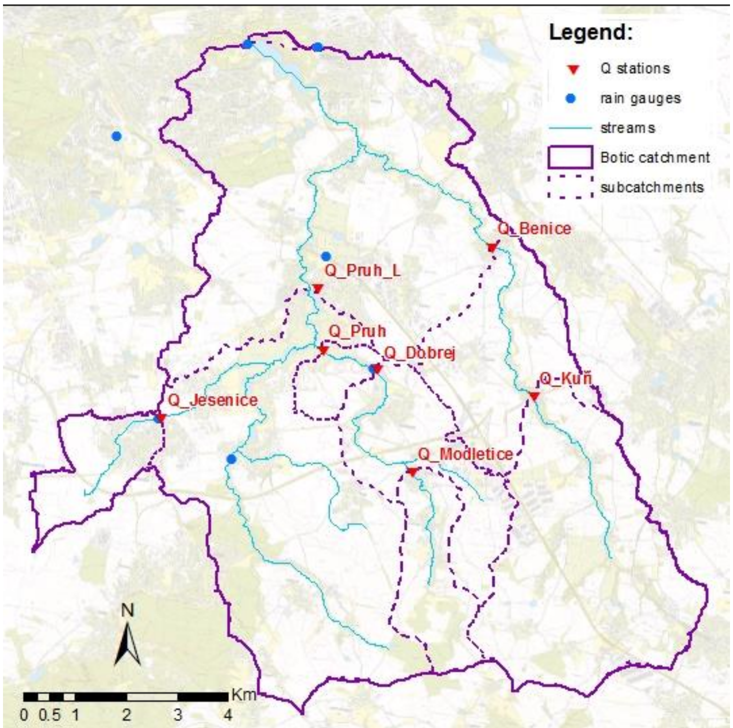

Fig. 1: *The upper part of Botič catchment – modelled area (91 km^2 upstream of Hostivař reservoir)*

2. Botič catchment description and data used

Area of interest is formed by gently undulated landscape at south, transforming to nearly flat terrain at north. Elevation varies between 500 and 250 m a.s.l. Long-term annual precipitation total reaches 565 mm. Maps were collected for two periods: current status (years 2010-2013 denoted here as variant 2013) and for period prior rapid urbanisation (data from 1988-1989 years, denoted here as 1988 variant). Soil map was simplified to 6 main categories. Cambisol prevails (39%). Two main hydrogeological structures were distinguished. Land use was classified (based on aerial photo) using 7 main categories (Fig. 2). For 2013 year, 62% of the area forms arable soil, 11% is paved, 13% are houses with gardens, 13% is covered by forests and shrubs. In most of subcatchments, about 10% of the arable land was converted to urban areas between 1988 and 2013, but in two of them changes reached 14 and 20%. Changes between current status and distribution of 1988 year were approximated by modifications of main properties: soil hydraulic characteristics, hydraulic roughness of surface and vegetation parameters (Leaf area index and root depth).

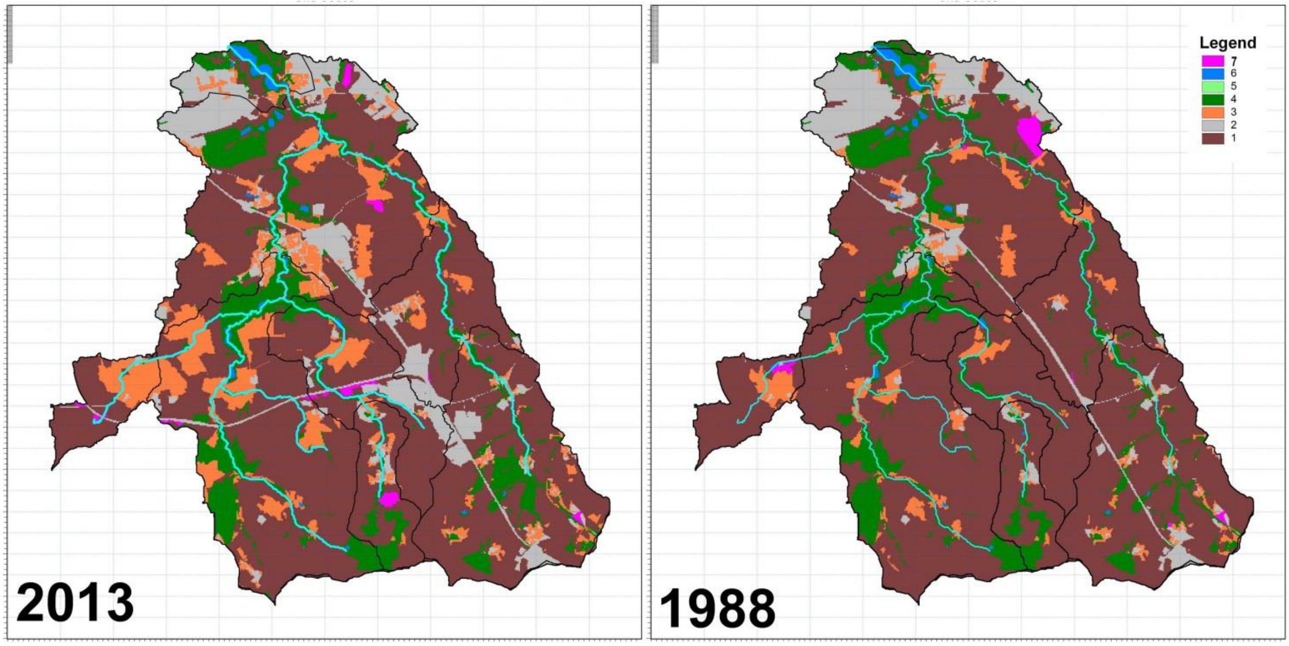

Fig. 2: *Land use map as model input; year 2013 (left) and 1988 (right). 1 and 5 = arable land plus grassland, 2 = paved area, 3 = houses with gardens, 4 = forest and shrubs, 6 = water and wet areas, 7 = other*

Shape of individual stream channels was based on data of Prague Master plan of drainage [2]. Time series used were collected mainly from Czech Hydrometeorological Institute (CHMI) and Lesy hl. m. Prahy databases. CHMI radar data and ground observation formed distributed precipitation field (15 min totals, 1 x 1 km cells). 9 records of water level in flow gauges were converted to discharge. Runoff coefficients calculated for selected subcatchments using observed data are listed in Table 1.

Tab. 1: *Flow gauging stations and subcatchments. Precipitation total and runoff coefficient (6/2013 event).*

Flow gauge	Stream	Subcatchment area	Drained area	Precipitation total	Runoff total	Runoff coefficient
		km^2	km^2	mm	mm	%
Kuří	Pitkovický	17.0	17.0	95	80	84
Benice	Pitkovický	8.4	25.4	81		
Modletice	Chomutovický	4.5	4.5	94	68	73
Průhonice	Dobřejovický	1.7 + 6.8	12.9	82	70	85
Jesenice	Jesenický	3.7	3.7	67	30	44
Pruhonice	Botič	23.5	40.2	76	61	80

3. Distributed mathematical model

Integrated surface - subsurface flow modelling system MIKE SHE 2014 [3] combined with 1D hydrodynamic model MIKE 11 was used as a simulation tool. Main processes focused were: surface overland flow (2D diffusive wave approximation), unsaturated flow (1D Richards equation approximation), groundwater flow (2D Boussinesq equation approximation) and river channel flow (1D fully dynamic approximation), also evapotranspiration calculation was included. The Botič catchment was described in model set up by 25 x 25 m rectangular computational grid network. Basic time step of simulation was set to 10 minutes. Initial conditions were set by water balance simulation of 1 month prior the event (using the same model). Parameter values were pre-calculated based on previous experience; subsurface hydraulic parameters were refined during calibration. Runoff response of model was calibrated using 6/2013 event records in 4 stations, while another 2 records were used for validation. Calibration has been focused on proper simulation of flood peak value and time. Variant simulation, where maps were modified to describe land use across the catchment for 1988 year conditions, was conducted using calibrated model. Further on, model was checked by another event simulation (5/2011, precipitation total about 42 mm), which occurred after monthly dry period. Additional variant simulations (using dry initial conditions for 2013 and 1988) were conducted.

4. Results

Simulation results show, that increase of urbanised area in the model did not lead to notable increase of discharge peak nor flood volume for this particular flood event (example in Fig. 3). Further simulations, taking into account dry initial conditions, showed increase in range of 10-20% for peak discharge as well as flood volume due to the land use changes (example in Fig. 4).

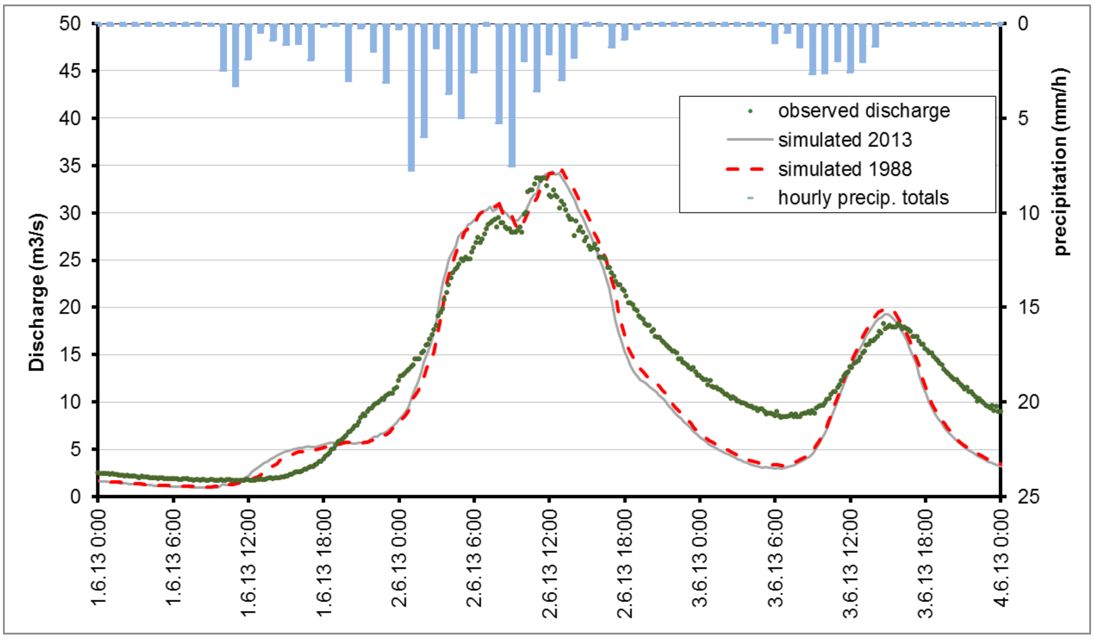

Fig. 3: *Observed (2013, dots) and simulated runoff for 2013 and 1988 conditions, real initial conditions of 6/2013 event (Průhonice station, Botič stream)*

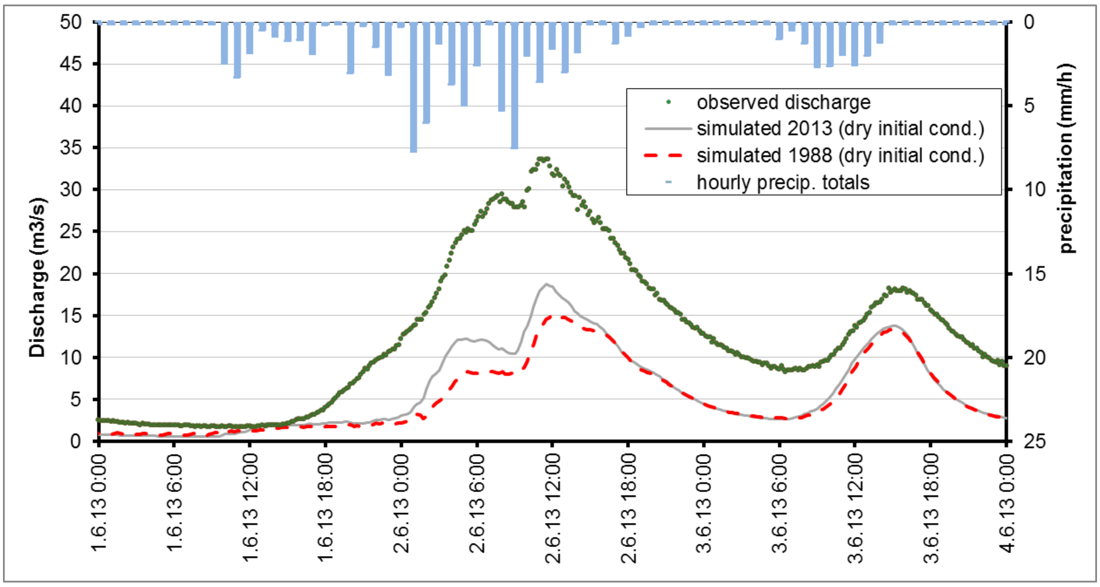

Fig. 4: *Observed (2013, dots) and simulated runoff for 2013 and 1988 conditions, dry initial conditions (Průhonice station, Botič stream)*

Tab. 2: *Summary of simulated results for 3 selected catchments. Percentage of land use changes and simulated runoff coefficients for individual simulation variants*

Catchment		Urban area increase 1988-2013		runoff coefficient simulated			
Q station	drained area	paved	houses + gardens	2013	1988	dry initial 2013	dry initial 1988
name	km^2	%	%	%	%	%	%
Jesenice	3.7	3	14	59	59	22	16
Průhonice - Dobřejovský	13.0	9	4	81	78	52	44
Whole area	95.4	4	6	80	79	46	41

For individual flow gauges and simulation variants were calculated differences in peak discharge, runoff volume, surface runoff and change in subsurface water storage. Examples are given in Tab. 2. Values of runoff coefficient differ from Tab.1 due to the shorter period taken into account.

5. Conclusions

We may conclude that changes in simulated runoff volume and peak discharge were negligible after adopting land use changes to model. This is caused by high saturation of soil at the beginning of 6/2013 event, indicated by extreme values of runoff coefficient. When dry initial conditions applied to the model, difference between 1988 and 2013 variant in runoff volume reaches about 12-14%, peak discharge increased from 29 m^3/s to 35 m^3/s and runoff coefficient about 6%. When comparing wet and dry simulation of 2013 conditions, difference is reasonably higher: peak discharge and runoff volume doubled (73 m^3/s, 46% increase) and runoff coefficient increased about 33%. It is clear, that initial conditions affect storm runoff variables much more than simulated direct impact of land use changes in this particular case of 6/2013 event. But with increase of urbanised (paved) areas percentage, space for rainfall accommodation is reduced, thus higher frequency of high runoff events may be expected in long-term perspective as a kind of indirect impact.

Literature:

[1] ČHMÚ (2013) Předběžná informace o hydrometeorologických aspektech povodní v červnu 2013. ČHMÚ Praha, červenec 2013 (In Czech)

[2] Hydroprojekt (2006) Generel odvodnění Botiče. Koordinátor řešitelského týmu: Hydroprojekt a.s., Praha (In Czech)

[3] Graham, D. N. and Butts, M. B. (2005) Flexible, integrated watershed modelling with MIKE SHE. In: Singh, V. P. and Frevert, D. K. (eds.): Watershed Models, CRC Press

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