Microwave links potential for runoff prediction: Case study Letnany

Le potentiel des ondes cellulaires pour la prévision des rejets de temps de pluie : étude de cas de Letnany

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RÉSUMÉ

La gestion des eaux pluviales en milieu urbain nécessite des données pluviométriques d'une résolution spatiale et temporelle élevée, qui ne sont souvent pas disponibles. Des données intégrées sur les taux de pluviométrie provenant d'ondes cellulaires (MWL) permettraient potentiellement de remédier à cette situation puisque le réseau MWL est très dense dans les zones urbaines. Cet article étudie le potentiel du système MWL en termes de prédiction du ruissellement en zone urbaine. Il compare la performance du modèle de ruissellement en utilisant les données pluviométriques dans six scénarios différents de suivi des précipitations dérivés de champs de précipitations générés à partir de modèles stochastiques : informations pluviométriques complètes (référence), taux de précipitations mesuré par le réseau MWL et taux de pluviométrie mesuré par quatre installations différentes de pluviomètres. L'article met l'accent sur la description de la variation spatiale des précipitations plutôt que sur les incertitudes de l'instrumentation proprement dite. Les données pluviométriques (150 chutes de pluie) pour les six scénarios, ont été dérivées de champs de précipitations générés à partir de modèles stochastiques utilisés comme données de base pour un modèle calibré de ruissellement. La performance du modèle est évaluée en fonction des formes hydrographiques, des volumes de ruissellement, des pics de rejet et du décalage temporel des pics de rejet. Les résultats montrent le potentiel considérable de la méthode MWL qui, pour tous les paramètres intéressants, présente une similitude très étroite avec le scénario de référence.

ABSTRACT

Urban storm water management requires rainfall data of high spatial and temporal resolution which is often not available. Path-integrated rain rate information from cellular microwave links (MWL) has a great potential to improve this situation as the MWL network is very dense in urban areas. The paper investigates the MWL potential in terms of urban storm runoff prediction. It compares the rainfall-runoff model performance when using rain rate input from six different rainfall monitoring scenarios derived from stochastically generated rainfall fields: complete rainfall information (reference), rain rates as measured by MWL network and rain rates as measured by four different rain gauge layouts. The paper focuses on effect of rainfall spatial variation description rather than uncertainties in instrumentation itself. Rainfall data (150 rainfall events) for six scenarios were derived from stochastically generated rain fields used as an input to a calibrated rainfall-runoff model. Model performance is evaluated with respect to hydrograph shapes, runoff volumes, peak discharges and time shift of peak discharges. Results show a high potential of the MWL method which in all metrics of interest exhibit a very close similarity with the reference scenario.

KEYWORDS

Telecommunication microwave links, quantitative precipitation estimates, rainfall monitoring, storm runoff prediction, urban hydrology

1 INTRODUCTION

Rainfall is the main driver for urban runoff, and represents thus a crucial input for urban hydrology modelling. Uncertainties in rainfall measurements propagate directly to the predicted runoff (Fencl et al., 2013; Stransky et al., 2007). Runoff response in urban catchments is extremely sensitive to spatio-temporal rainfall dynamics on very fine temporal and spatial scales (Berne et al., 2004; Schilling, 1991). Actual state of national and regional rainfall measurement networks (even those specifically designed for urban hydrology tasks) is usually one order of magnitude sparser than optimal. A solution might be searched for in radar rainfall estimates, however, they are still affected by substantial errors (Berne and Krajewski, 2013) and the required high-resolution radar information is not always available. Recently, commercial microwave links (MWLs) from telecommunication networks have been suggested as a novel source of rainfall information (Leijnse et al., 2007; Messer et al., 2006), which could provide quantitative precipitation estimates (QPEs) on the radar-pixel scale or even finer resolutions. MWLs are point-to-point radio systems, which connect two remote locations, mostly at line-of-sight. They operate usually at millimetre wave lengths and rainfall drops represent a major source of the signal attenuation, and can provide path-average QPEs.

The goal of this paper is to analyse (apart from instrumentation uncertainties) if using MWLs is a viable method compared to traditional methods using individual rain gauges (RG) or a network of them. A question raised is: Are path-average QPEs from MWLs comparable to point measurements from traditional network of RGs?

2 MATERIAL AND METHODS

2.1 Experimental catchment

A district of Prague called Letnany (134 ha) was selected as an experimental catchment. The catchment is a mixture of residential (a housing estate), commercial and industrial areas. The catchment is drained by separate sewer system of the length of 18.2 km. There are no RGs permanently placed within the catchment. The nearest RG Ladvi is situated about 2 km west from the centre of the experimental catchment. The catchment is covered by 19 MWLs (Figure 1).

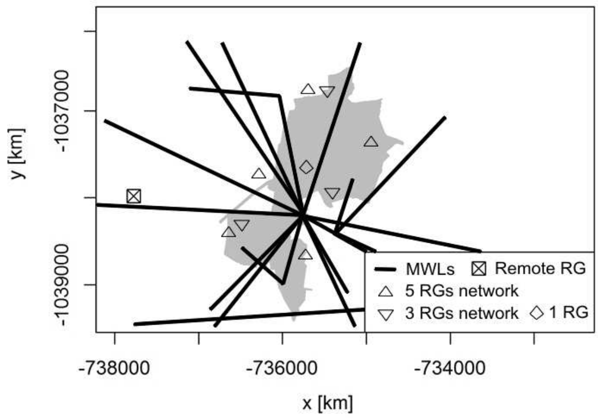

Figure 1: Experimental catchment Letnany with MWL and different rain gauge layouts

For purposes of presented study the experimental catchment was divided to 188 sub-catchments of average size 0.7 ha.

2.2 Rainfall data

One hundred fifty artificial rain events were generated by stochastic simulation of intermittent drop size distribution fields in time (Schleiss et al., 2012) with a pixel size of 100x100 meters (Figure 2) and time resolution 1 min. All scenarios described in chapter 2.3 are based on this data.

2.3 Scenarios

Six hypothetical scenarios with different rainfall information were studied (Table 1).

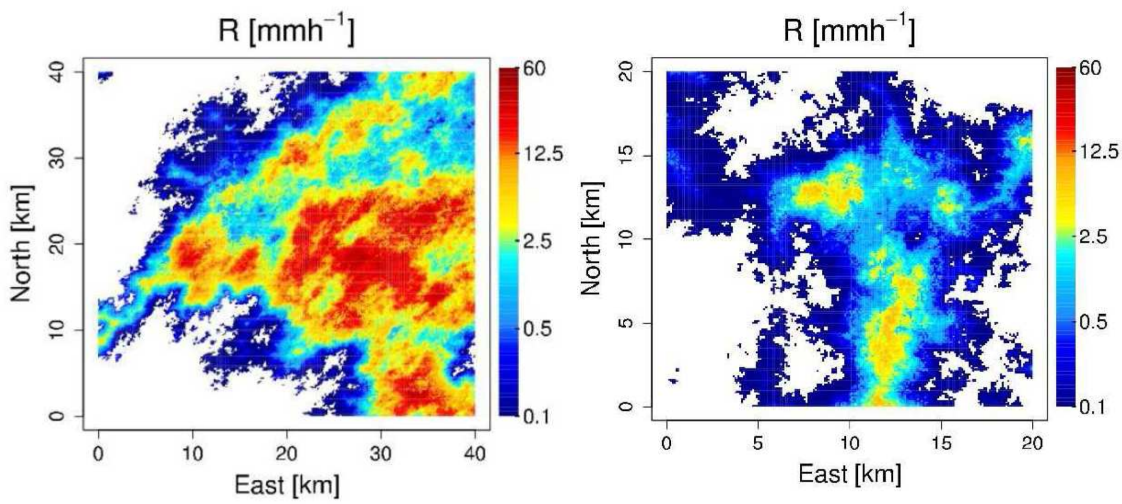

Figure 2: Example of stochastically generated rain fields

Table 1: Scenarios studied

SCENARIO	SCENARIO NAME	SOURCE OF RAINFALL DATA
A	Reference	188 RGs placed in individual sub-catchments
B	MWLs	19 MWLs
C	Five RGs	network of five rain gauges placed within the catchment (or in a close vicinity)
D	Three RGs	network of three rain gauges placed within the catchment (or in a close vicinity)
E	One RG	one rain gauge placed in the centre of catchment (as used for the rainfall-runoff model calibration)
F	Remote RG	one rain gauge placed in the location of closest permanent RG Ladvi

2.4 Simulations

A calibrated rainfall-runoff model MIKE URBAN was used to simulate the scenarios described. In case of scenarios C and D, calculations were made for several different settings of RG network. Averaged values from these calculations (discharge Q, water depth h and velocity v) were used for further analysis. More than 2000 simulations were done in total.

2.5 Performance criteria

Simulation results were analysed at three cross sections (upper, middle and downstream part of the system). Comparison to reference scenario was done with respect to:

- shape of the hydrograph:
  - correlation coefficient,
  - coefficient of determination,
  - least square method.
- surcharge ratio (length of surcharged sewers related to the total length of the sewer system, in %) (Stransky and Fatka, 2005),
- runoff volume V,
- peak discharge Q_{max} and
- time shift of peak discharges ΔT.

3 RESULTS

Results of the runoff simulations in the downstream profile of the sewer system are presented in Table 2 and are similar with the results from the middle and upstream profiles. Average values of the correlation coefficient, coefficient of determination and least square method, are presented. For the surcharge ratio, runoff volume and peak discharge, a number of runoff events (out of the total number of 150) exhibiting less than 10% error is given. Similarly, the number of runoff events with the time shift of Q_{max} less than 2 minutes is shown.

Table 2. Comparison of the scenarios for the downstream profile

SCENARIOS→	A Reference	B MWLs	C Five RG	D Three RG	E One RG	F Remote RG
Correlation coefficient *Q*	1.000	0.985	0.977	0.973	0.938	0.813
Coef. of determination *Q*	1.000	0.971	0.957	0.952	0.898	0.736
Least square method *h*	0.000	0.137	0.295	0.310	0.408	0.578
Surcharge ratio	150	150	147	144	138	121
Runoff volume *V*	150	111	102	102	58	35
Peak discharge Q_{max}	150	104	98	99	45	31
Time shift ΔT	150	111	112	110	83	35

The runoff calculations based on MWLs (scenario B) exhibit the highest similarity with the reference scenario A (with exception of the time shift, where the five RGs scenario C performs slightly better). Scenarios B, C and D give very similar results, whereas using one RG within the catchment (scenario E) or in a remote location (scenario F) lead to a substantial error in the runoff prediction.

4 CONCLUSIONS

- using only one RG leads to substantial errors in runoff prediction even in a small catchment,
- MWLs have a great potential to predict runoff with the same or a better performance than a network of RGs,
- instrumentation uncertainties (especially relation between the signal attenuation and rainfall intensity) must be further studied to enable the full exploitation of the theoretical potential of the MWLs method.

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