URBAN HYDROLOGICAL RESPONSE UNIT PARAMETER CALIBRATION AND VERIFICATION FOR CONCEPTUAL HYDROLOGICAL MODEL METQ

Inga Grinfelde[1], Anda Bakute[2]
[1]Latvia University of Agriculture; [2]Expertisecentrum Regelgeving Bouw, Netherland
Inga.grinfelde@llu.lv

Abstract. The growing urbanization level significantly impacts the hydrological regime of streams and rivers. Land use is changed and natural areas are transformed to living areas or industrial parks. The conceptual hydrological model METQ is developed by the Latvia University of Agriculture to calculate total run-off for different purposes. However, it was developed for rural areas and is missing the urban hydrological response unit. The aim of this research is to calibrate and verify the urban hydrological response unit parameters of the conceptual hydrological model METQ. In Latvia, there is no hydrometric station with urban catchment area and in Europe there was not possibility to get enough long run-off and meteorological data set. Free access run-off and meteorological data from the United States Geological Surveywere used in this research. The calibration was made using MonteCarlo simulations. To evaluate the calibration results Nash–Sutcliffe efficiency index (NSE), determination coefficient R^2, percent bias (PBIAS), ratios the root mean square error to the standard deviation of measured data (RSR) in addition to the graphical method were used. The calibration and validation results of the urban hydrological response unit parameters were satisfactory and achieved the recommended limits NSE > 0.5; R2 > 0.75; RSR < 0.70 and PBIAS +/- 25 % for all six catchments. There is variation of the parameter values between catchments, which is related with the urbanization level and hydrogeological conditions of the catchment. This paper gives recommendations for hydrological response unit parameter application for the conceptual hydrological model METQUL2012.

Keywords: urbanization, discharge, METQUL2012.

Introduction

More than half of the world population live on urban areas and according to the United Nations migration projections in 2030 more than 80 % of the population will live in urban areas [1]. Growing population and increasing urbanization rate force more and more to think about sustainable resource management, including water management [2; 3]. The change of land use and especially urbanization have significant impact on hydrological processes [4]. Urban areas, on the one hand, increase pollution pressure and deplete water resources, on the other hand, increase the amount and quality of water supply and sewerage infrastructure, as well as develop a flood protection system [5; 6]. Heavy rainfall in urban areas causes local flooding, which is becoming more and more intensive and repeats more and more often [7-10]. In flood events the most vulnerable social groups of societies suffer, as well as material losses during the flood events each year are several billions [11; 12]. The European Union flood risk mitigation measures are regulated by the Flood Directive (2007/60/EC), which entails an obligation to the Member States to organize a flood risk assessment and risk areas mapping [13]. At the scientific level, the understanding of the urban area hydrological regime is currently being designed and developed using monitoring data and modeling of the opportunities offered, but there is a need for a longer monitoring period at least two decades, during which to accumulate data of hydrological regimes in urban areas [14-17]. Modelling of urban catchment hydrological regime is difficult because of the fragmented environment with specific hydrological response, and so far, there is no clear understanding of the rain circulation cycles of the urban environment [18]. Bach et al.[19] highlighted the need to classify urban watershed integrated models and recommended to develop the model classification according to the degree of integration. However, there are ongoing discussions about the universal concept of the water cycle at watershed level and development of common methodology.

In Latvia, there was developed a conceptual hydrological model METQ [21; 22] with very good precision. Previous versions of models were developed for natural areas[22]. However, by growing urbanization of natural areas there is a need to integrate this hydrological response unit in hydrological models. The previous experience of integration of the hydrological response unit in the existing conceptual hydrological models shows good results [22-24]. Many researchers prefer manual calibration to increase the model performance [25-29]. The newest version of the METQ model is METQUL2012 where friendly interface and separated hydrological response units calculation modules are used [30].The aim of this research is to calibrate and validate the urban hydrological response unit parameters of the conceptual hydrological model METQUL2012 and to give recommendations of the parameter integration in the model.

Materials and Methods

In Latvia, there are no data of discharge from the urban catchment areas. In the Northern part of Europe there was not a possibility to get enough long run-off and meteorological data set. In this research free access run-off and meteorological data from the United States Geological Survey (USGS) were used. Catchments with area from 9.76 till 183.63 km^2 from the cold climate zone where chosen. The location of the urban catchments is presented in Table 1. The smallest catchment is Valley Stream in New York City 9.76 km^2 and the largest catchment is Paint Creek in Detroit 183.63 km^2. The highest density of waterproof areas is in Valley Stream 95 % and Ecorse River 92 %.

Table 1

Characteristics of urban catchments

USGS Number	US State	Name	Latitude	Longitude	Density of waterproof areas, %	Drainage area, km^2	Shortening
01302020	NY	BRONX RIVER	40°51’44”	73°52’27”	74 %	99.45	NY_BO
01311500	NY	VALLEY STREAM	40°39’49”	73°42’16”	95 %	9.76	NY_VA
04168580	MI	ECORSE RIVER	42°16’10”	83°17’23”	92 %	25.90	MI_EC
04161540	MI	PAINT CREEK	42°41’18”	83°08’35”	56 %	183.63	MI_PA
12113346	WA	SPRINGBROOK CREEK	47°25’53”	122°13’35”	71 %	21.86	WA_SP
12113349	WA	MILL CREEK	47°25’49”	122°14’31”	86 %	14.58	WA_MI

Table 2

Climate of calibration and validation period of urban catchments

Station	Parameters	Calibration period				Validation period			
		2008	2009	2010	2011	2012	2013	2014	2015
NY_BO	Annual average temperature, °C	11.1	10.7	11.9	11.9	12.7	11.4	10.7	11.4
NY_VA		11.1	10.7	11.9	11.2	12.6	11.3	10.7	11.4
WA_SP		9.2	9.8	10.4	9.3	10.0	10.1	10.9	11.5
WA_MI		9.2	9.8	10.4	9.3	10.0	10.1	10.9	11.5
MI_EC		8.3	8.1	9.5	9.0	10.5	8.2	6.9	9.0
MI_PA		8.3	8.1	9.5	9.0	10.5	8.2	6.9	9.0
NY_BO	Annual sum of precipitation, mm	1382.2	1402.0	1068.3	1143.9	1104.3	1044.2	1224.7	899.3
NY_VA		1382.2	1402.0	1068.3	1143.9	1104.3	1044.2	1224.7	899.3
WA_SP		653.4	1228.6	1800.6	1327.1	1785.8	704.8	1435.5	1230.0
WA_MI		653.4	1228.6	1800,6	1327.1	1785.8	704.8	1435.5	1230.0
MI_EC		720.0	714.9	635.4	1085.0	527.3	1318.8	712.4	569.1
MI_PA		720.0	714.9	635.4	1085.0	527.3	1318.8	712.4	569.1
NY_BO	Annual minimal run-off, m^3·s^{-1}	0.566	0.510	0.340	0.481	0.340	0.280	0.397	0.340
NY_VA		0.000	0.000	0.000	0.000	0.000	0.002	0.003	0.000
WA_SP		0.034	0.054	0.082	0.099	0.127	0.108	0.110	0.014
WA_MI		0.006	0.016	0.024	0.040	0.025	0.037	0.028	0.000
MI_EC		0.005	0.011	0.018	0.014	0.007	0.014	0.010	0.012
MI_PA		0.425	0.538	0.283	0.397	0.249	0.397	0.623	0.368
NY_BO	Annual maximal run-off, m^3·s^{-1}	21.637	23.562	31.718	62.587	13.650	26.054	30.302	18.068
NY_VA		1.529	1.218	2.322	3.257	0.595	1.359	2.322	0.736
WA_SP		3.030	3.285	4.191	2.605	2.209	3.993	1.926	3.257
WA_MI		3.767	4.475	4.843	3.512	3.144	4.050	3.597	4.729
MI_EC		5.296	4.588	7.335	6.542	3.342	3.852	7.477	3.653
MI_PA		16.709	12.433	7.307	11.328	7.392	15.859	10.563	7.816

The air temperature, precipitation and humidity data were used from the closest meteorological station in USGS data base.The air temperature, precipitation and humidity of calibration and validation periods are presented in Table 2. All six catchments represent cold climate with different continentality. The annual average air temperature is higher in New York City (NY_BO and NY_VA) and lower in Detroit (MI_EC and MI_PA). The annual precipitation varies from 527.3 in Detroit to 1785.8 (MI_EC and MI_PA) mm in Seattle (WA_SP and WA_MI).The calibration of the parameters of the urban hydrological response unit was made according to the flowchart presented in Figure 1.

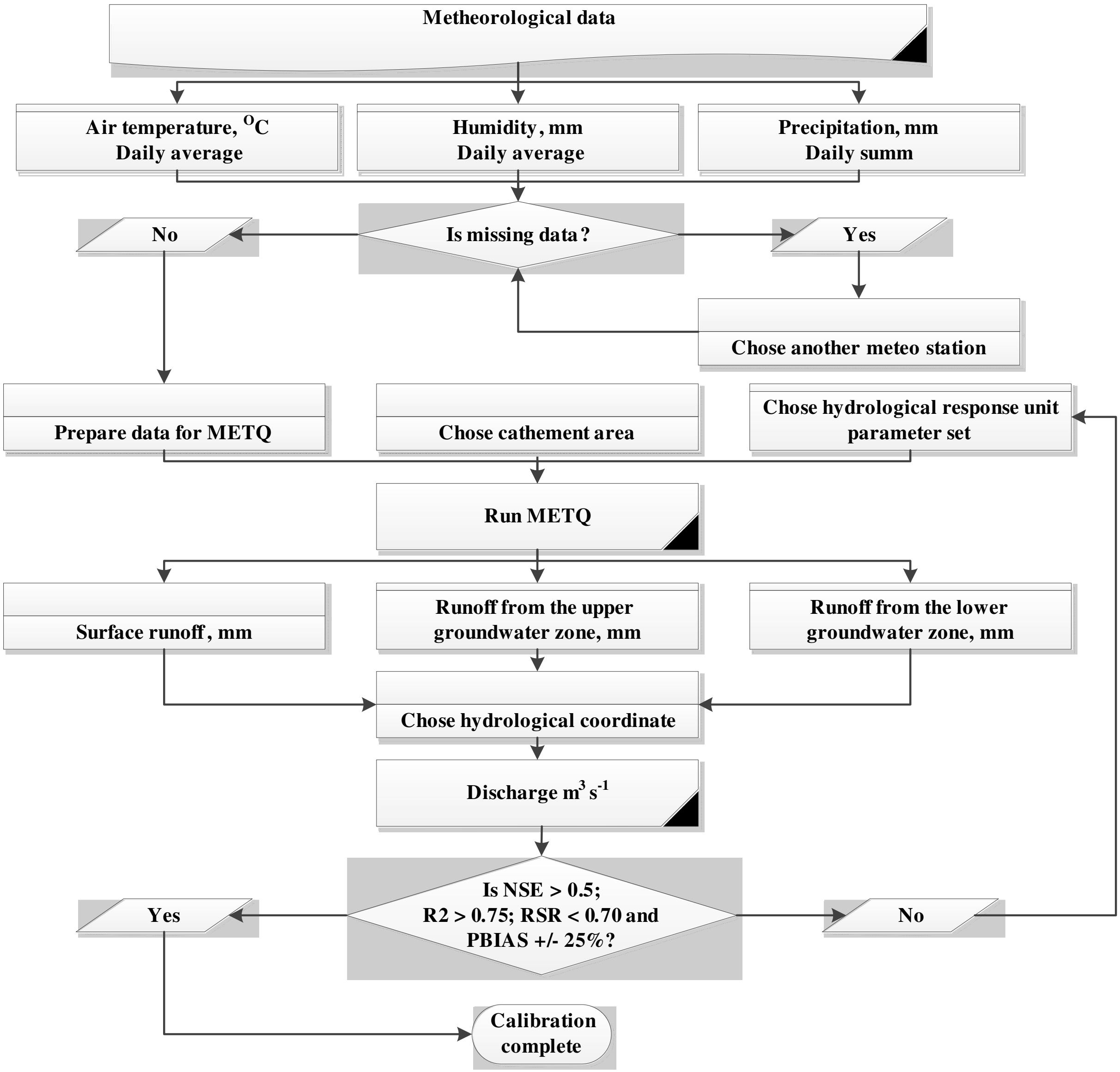

Fig. 1. **Flowchart of urban hydrological response unit calibration steps**

The conceptual hydrological model METQUL2012 calculates discharge of each hydrological response unit using the daily temperature, precipitation and humidity data. The calculation algorithm consists of 23parameters: WMAX; ALPHA; ZCAP; A2; A3; KU; KL; CMELT; T1; T2; KS; DZ; PZ; RROB; RROBZ; RROB2; RROBZ2; ROBK; WHC; CFR; DPREC; AMCOR; BETA[20;21].The model METQUL2012 does not accept missing data, the meteorological data from the United States Geological Survey (USGS) were tested for the missing values. The Meteorological data set was uploaded in the model. All catchments are in urban areas, this means the catchment area is the urban hydrological response unit area. The hydrological response unit parameters were calibrated using MonteCarlo simulations and manual calibration of the parameters. To evaluate the calibration results the Nash–Sutcliffe efficiency index (NSE) [31], which is commonly used in hydrology, determination coefficient R^2[32], percent bias (PBIAS) [33], ratios the root mean square error to the standard deviation of the measured data (RSR) [34] in addition to the graphical method were used. The recommended limits by Moriasi [35] is NSE > 0.5; R2 > 0.75; RSR < 0.70 and PBIAS +/- 25 %.

Results and Discussion

For all catchments, totally 30240 simulations of discharge were done. The best calibration results and verification results are presented in Table 3. The Nash–Sutcliffe efficiency index (NSE) is acceptable [35]and varies from 0.69 to 0.96 for the calibration period and from 0.67 to 0.91 for the validation period. The R^2 is acceptable for all catchments for all periods [35]and varies from 0.81 to 0.98 for the calibration period and from 0.79 to 0.95 for the validation period.

Table 3

Results of calibration of model METQUL2012

Catchment	Calibration period				Validation period			
	NSE	R2	RSR	PBIAS	NSE	R2	RSR	PBIAS
NY_BO	0.69	0.81	0.69	-23.63	0.67	0.79	0.70	-24.87
NY_VA	0.78	0.91	0.47	11.67	0.79	0.91	0.44	10.18
WA_SP	0.82	0.93	0.31	-3.03	0.80	0.92	0.30	-3.48
WA_MI	0.96	0.98	0.21	-1.07	0.91	0.95	0.24	-2.11
MI_EC	0.76	0.87	0.43	14.86	0.73	0.84	0.49	16.36
MI_PA	0.72	0.84	0.40	17.01	0.75	0.87	0.42	15.28

The NY_BO shows better modelling results at the calibration period, however, MI_PA shows to be better fit for the validation period than for the calibration period. Several factors influence the model fit: the precision of the precipitation data; the discharge measurement precision and the conditions of the riverbed.

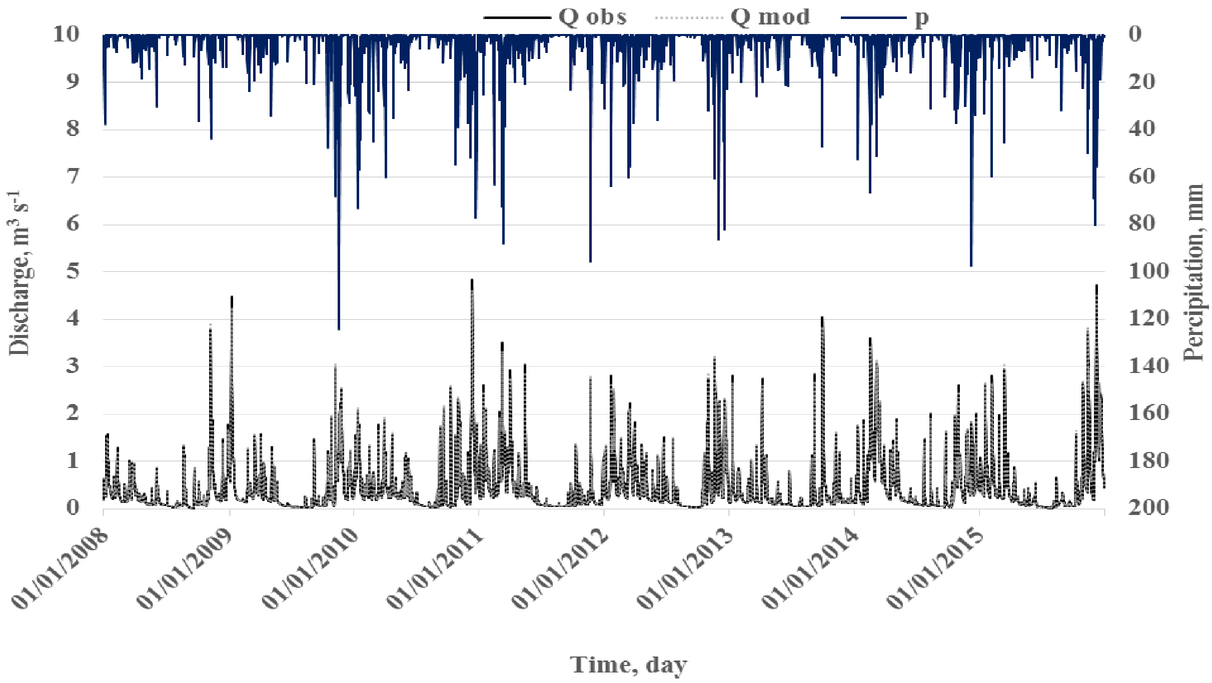

Fig. 2. **Modelled and observed discharge and percipitation of WA_MI cathement**

The conceptual hydrological model METQ parameters (A2; A3; CMELT; DZ; PZ; RROB; RROBZ; RROB2; RROBZ2; ROBK; DPREC; AMCOR; BETA) can be calibrated for rural catchments [21] and other parameters are constant. During calibration of the urban hydrological response unit parameters there was made a decision to calibrate additional parameters (WMAX; ALPHA; ZCAP; KU; KL; T1; T2; KS; WHC; CFR; AMCOR). In urban areas, there is high heterogeneity of the surface and disturbed stream formation as well as different microclimate [36]. The best fit of the modelled and observed discharge is presented in Figure 2. The modelled and observed discharges show good fit, however there are underestimation or overestimation of discharge. This uncertainty is related with measurement precision and rain event distribution in the catchment area.The parameters WMAX, ALPHA, ZCAP, T1, T2, KS, DZ, PZ, DPREC, BETA show significant variance - larger than 20 % between the catchments and in some cases more than 40 %. The variation is related with heterogeneity of the land cover, historical development of the storm water collection system and urbanization density [36]. There is a need to classify urban catchments by covered areas and develop at least three urban hydrological response unit parameter sets and integrate the calculation algorithm in the conceptual hydrological model METQUL 2012.

Conclusions

1. The calibration and validation results of the urban hydrological response unit parameters weresatisfactory and achieved the recommended limits NSE > 0.5; R2 > 0.75; RSR < 0.70 and PBIAS +/- 25 % for all six catchments.
2. There is variation of the parameter values between the catchments, which is related to the urbanization level and hydrogeological conditions of the catchment.
3. It is recommended to classify urban catchments by covered areas and develop at least three urban hydrological response unit parameter sets and integrate additional calculation algorithms in the conceptual hydrological model METQUL 2012.

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