IMPACT OF TOPOLOGY AND MAP PRECISION ON DESIGNED FLOW IN RAIN SEWERS

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Sewer systems are undisputable part of environmental protection system. Design, construction and correct management of sewer systems eliminates or at least mitigates continual infiltration of sewage water to the environment and ground water. Verification of correct function of sewer system is done by the assessments. This study focuses on impact of terrain topology, placement and geometry of structures in area, precision and actuality of maps that serve as input data in calculation of runoff coefficients, creation of sub-catchments and the choice of model hectare. Those values have direct impact on the calculation of the amount of rain water in sewer system and thus help determine possible flooding of system. Study was conducted on existing sewer system in town of Vrable as a part of greater thesis dealing with verification of boundary conditions that serve as data in sewer system assessments.

KEYWORDS

sewer system, rain sewer, assessment, runoff coefficient, catchment

1 INTRODUCTION

Design and assessments of a combined sewer system (SS) is closely associated with the precision of input data used in modelling. Connection of SS with environment is especially observable in combined sewer overflow chambers that form a direct outflows of mixed rainwater and sewage water into the river. Design and assessment of functionality in particular, in case of these objects depends on the correct flow calculation of waste water at the inlet to the chamber which can be determined using computational methods.

This work focuses on the accuracy of map data, topology of area and in particular their impact on the calculation of the amount of rainwater in SS. Studied factors are in particular the geometry of objects located in the area of interest (in the sense of modelling the object such as buildings, roads, urban greenery, etc.), their impact on the design of sewer sub-catchments, choice of model hectares and in particular, their impact on calculation of runoff coefficients (RC).

2 PROBLEMATICS

While designing SS, the value of design flow is crucial given the fact that it directly impacts the size of designed pipes, which in turn has also impact on assessment. The flow rate in combined SS depends primarily on the amount of rainwater because compared to sewage water, it forms vast majority of design flow. The amount of rainwater that gets into the SS is calculated based on the rain curves for the area of interest. In the case of this study, selected are was the village Vrable. Periodicity of rain events on which the thesis was applied was selected to be P = 0.5 (1 rain event for every two years).

3 RUNOFF COEFFICIENT

The first step was to select model hectares based on initial data to be representative for entire area. Seven hectares were carefully selected for which the RC were calculated based on methods closely described in section 'Runoff coefficient'. This was followed by collection of data from the survey, cadastral maps, geographic informational systems (GIS). Then the initial map has been compared with the focus on the terrain topology, area and object geometry (buildings, built up areas, parking lots, etc.) based on collected data.

Determination of average RC Ψ_s (partial coefficients Ψ_i found in STN 75 6101) has been conducted after adjustment of initial model hectares (update based on the collected data), and values were retrospectively compared with the calculated RC from the original data. Finally, the difference in percentage of the total amount of runoff of initial data and adjusted data has been compared.

4 METHODOLGY

When calculating the design surface runoff (furthermore only design rain flow) using simple methods, the description of the runoff process is significantly simplified because application of these methods is focused on designing sewer sections and surface runoff is calculated by equation

$$\boldsymbol{Q_d = q_s * S_{REAL} * \Psi = q_s * S_{RED}} \quad (1)$$

Where Q_d is the design rain flow (l.s^{-1}), q_s – intensity of rain with given periodicity (l.s^{-1}.ha^{-1}), S_{REAL} - the area of catchment of which surface runoff is drained from (ha), Ψ - average peak runoff coefficient (-), S_{RED} - catchment area reduced by runoff coefficient (ha) [1]

The RC includes all the losses in one number. In Eq. 1, the RC proportionally affects the value of the design rain flow. RC complexly includes not only the runoff loss components of the first part of the runoff process - from the creation of surface runoff, but also the concentration of surface runoff itself. The RC effects also include factors such as the type of surface, slope of terrain, hydraulic roughness of surface, rain intensity, duration of rain, rain frequency, temperature, the initial state of moisture of the surface, geology of the upper layers of the terrain and many other factors. Unsaturated catchment area is assumed at the beginning of the rain and temporal or spatial rainfall variability are not reflected.

Currently, there are many methods to determine RC. According to the hydrological definition, the RC represents the share of the total volume of runoff Q_T (m^3) drained from a certain profile and rainfall R (m^3) fallen on the catchment area belonging to given profile. It's called volumetric runoff coefficient. [1]

$$\Psi_V = \boldsymbol{Q_T * R^{-1}} \quad (2)$$

Sewer sections are not designed for the total volume of runoff Q_T but the maximum flow Q_{max} of given runoff hydrograph. Therefore, Eq. 1 uses so called peak runoff coefficient. It represents the portion of volume of the maximum rain flow rate Q_{max} that's drained in time Δt of elemental area ΔS_s with the same surface and volume of rainfall $q*\Delta S_s*\Delta t$ fallen during this time period.

$$\Psi = \frac{Q_{max}*\Delta t}{q*\Delta S*\Delta t} \tag{3}$$

Simple calculation methods for the design rain flow use average runoff coefficient Ψ_s, which is a weighted average of partial RC pertaining to individual subareas with the same surface in the form of

$$\Psi_s = \sum_{i=1}^{n} \Psi_i * S_i * \left(\sum_{i=1}^{n} S_i\right)^{-1} \tag{4}$$

where Si are areas with the same surface (ha), Ψ_i - partial RC corresponding to the surface treatment, depending on the type and density of buildings in the area, the type of surface and slope of surface.[1] The values of coefficients Ψ_s and Ψ_i according to STN 75 6101 are recommended for a) the approximate calculations of sewer network (general development plan), b) for a detailed calculation. For the indicative proposal, a single peak RC Ψ_s for larger urban catchments is considered, which have approximately the same kind of built up and slope of terrain according to Tab. 1.

Table 1. Runoff coefficients Ψ for indicative calculation of sewer system (STN 75 6101) [2]

Type of buildup and surface type		Runoff coefficients Ψ		
		Slope less than 1 %	Slope from 1 to 5 %	Slope higher than 5 %
Buildings	Enclosed blocks (with built up yards)	0.7	0.8	0.9
	Enclosed blocks (with gardens inside)	0.6	0.7	0.8
	Open blocks	0.5	0.6	0.7
	Isolated blocks	0.4	0.5	0.6
Family houses	Connected in gardens	0.3	0.4	0.5
	Isolated in gardens	0.2	0.3	0.4
Industrial buildings	Older type (more dense)	0.5	0.6	-
	Recent type – open with green areas	0.4	0.5	-
Railroad premises		0.25	-	-
Graveyards, gardens, playgrounds		0.1	0.15	0.2
Fields, meadows		0.05	0.1	0.15
Forests		0	0.05	0.1

Based on the detailed design of SS and site layout of street sewers, the drained area is then divided into sub-catchments of the same built up type, surface treatment and slope of terrain. On each selected characteristic sub-catchments, the average RC is calculated using equation 4, with partial RC Ψ_i chosen from the Tab. 2. Sometimes it is preferable to determine Ψ_s for model hectare with are larger than 1 ha.

Table 2. Runoff coefficients Ψ for detailed calculation of sewer system (STN 75 6101) [2]

Type of buildup and surface type		Runoff coefficients ψ		
		Slope Less than 1 %	Slope From 1 to 5 %	Slope higher than 5 %
Buildup areas		0.9	0.9	0.9
Roads, pavements and such	Enclosed bituminous or concrete pavements, drenched with covered joints	0.9	0.9	0.9
	With bituminous cover from penetration macadam	0.7	0.8	0.9
	Cobblestone pavement with sand covered joints	0.5	0.6	0.7
	With a gravel cover	0.3	0.4	0.5
Open spaces		0.2	0.25	0.3
Graveyards, gardens, playgrounds		0.1	0.15	0.2
Fields, meadows		0.05	0.1	0.15
Forests		0	0.05	0.1
*In sense of STN EN 752-4 the runoff coefficient Ψ in steep and sloping roofs can be considered up to value of 1.00: small roof areas (with area smaller than 100m²) having Ψ = 1.0 and large flat roofts (with area larger than 10 000 m²) having Ψ = 0.50				

Peak RC Ψ shown in Tab. 1 and 2 are constant peak RC determined empirically, depending on the type of surface and the inclination for design rain flow calculated according to block rain of given periodicity. If we assume a constant peak RC, we cannot expect the precise result of the maximum rain flow calculation and we also cannot assess the extent to which certain assumptions introduced in the calculation are applied in accordance with the actual runoff conditions. [3, 4]

Values of the peak RC for paved surfaces are slightly smaller than the volumetric coefficients Ψ_V. For unpaved surfaces it is considerably lower, e.g. for some of our river basins, which are surrounded only by forests and fields, the volumetric RC tends to be greater than 0.5 while the value of the peak RC for the fields according to Tab. 2 is only 0.15 in the area with slope greater than 5%. In case of designing of drainage system for the area with new housing with a significant proportion of permeable surfaces, RC value should not be less than Ψ_{min}=0.35 considering the possibility of future intensification of buildings. [5, 6]

5 INTRODUCTION

The first step was the determination of the runoff coefficient using methods according to STN 75 6101 based on the unadjusted data. Seven selected model hectares used in the study are shown in Fig. 1 and 2.

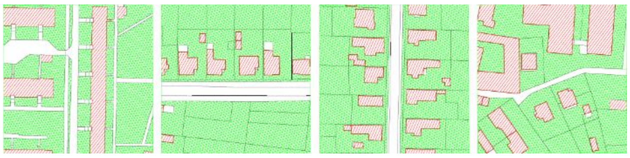

Figure 1. Selected model hectares based on initial data (numbered from left:1, 2, 3, 4)

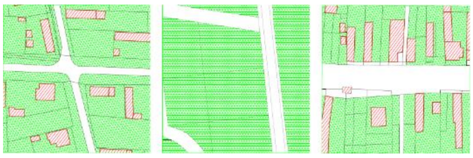

Figure 2. Selected model hectares based on initial data (numbered from left: 5, 6, 7)

The calibration of topology using underlying layers of aerial photographs, focusing on geometry was performed in selected model hectares based on the data obtained from the field survey, cartographic maps and open source GIS resources. Model hectares after the adjustment are shown in Fig. 3 and 4. The creation of more accurate model hectares allowed the detailed calculation of the RC and comparison of differences in percentage of calculated values.

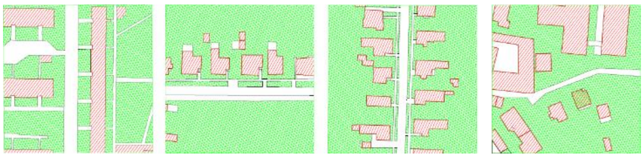

Figure 3. Adjusted model hectares (numbered from left: 1, 2, 3, 4)

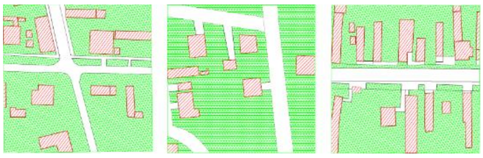

Figure 4. Adjusted model hectares (numbered from left: 5, 6, 7)

The calculated values of RC from both methods before and after the adjustment are listed in Tab. 3.

Table 3. Table 3 Resulting values of runoff coefficients for both methods before and after the adjustment of model hectares

Runoff coefficients based on STN 75 6101									
	Indicational calculation (1st met.)			Detailed calculation (2nd met.)			Calibrated data for detailed calculation (2nd met.)		
ha	Slope of the terrain [%]								
	< 1	1.5	>5	< 1	1.5	>5	< 1	1.5	>5
1	0.50	0.60	0.70	0.49	0.52	0.55	0.51	0.54	0.56
3	0.20	0.30	0.40	0.36	0.40	0.44	0.36	0.40	0.44
4	0.50	0.60	0.70	0.38	0.42	0.46	0.40	0.44	0.47
5	0.50	0.60	0.70	0.46	0.49	0.52	0.49	0.52	0.55
6	0.20	0.30	0.40	0.35	0.39	0.43	0.43	0.46	0.49
7	*0.05*	*0.10*	*0.15*	*0.34*	*0.38*	*0.42*	*0.43*	*0.47*	*0.50*
8	0.20	0.30	0.40	0.50	0.53	0.55	0.47	0.50	0.53

The comparison of differences in percentage of the calculated values is shown in Tab. 4. The values in % are in comparison to the resulting RC after adjusting model hectares. It is important to point out that model hectare no.6 presents extreme values arising from the old geographical data - the southern part of the village at the time included plots on the cadastral map, but was not built up.

Table 4. Comparison of the calculated values for both methods to final values calculated after adjusting model hectares

	Difference in % compared to adjusted data						Areas presented by hectares	
	< 1 % slope		1 to 5 % slope		>5 % slope			
Ha	1st met.	2nd met.	1st met.	2nd met.	1st met.	2nd met.	Area [ha]	% of total
1	1.45	3.65	-10.79	3.20	-19.52	2.79	24.92	11.66
2	82.29	0.31	34.27	0.26	10.27	0.22	14.58	6.82
3	-20.00	4.77	-27.38	4.04	-32.65	3.42	48.88	22.87
4	-1.42	6.75	-13.01	5.87	-21.28	5.09	60.49	28.30
5	112.98	21.26	53.27	17.76	23.42	14.90	33.85	15.84
6	*769.00*	*28.03*	*367.75*	*23.28*	*234.00*	*19.44*	*9.68*	*4.53*
7	136.43	-4.87	67.79	-4.28	33.47	-3.74	21.36	9.99
							213.8	100.00

The final step was to calculate indicative differences of runoff amounts from the entire area. Given the extreme differences in the model hectare no 6., the Tab. 5 includes comparisons that both includes and excludes areas covered by hectare no.6.

Table 5. Percentage comparison of differences in surface runoff for entire area of Vráble

	Difference of runoff amount in % based on weighted average compared to adjusted data					
	< 1 % slope		1 up to 5 % slope		>5 % slope	
	1st met.	2nd met.	1st met.	2nd met.	1st met.	2nd met.
Inc. ha #6	67.2	7.59	23.00	6.41	2.59	5.43
Exc. ha #6	33.9	6.63	6.65	5.61	-8.39	4.77

Thesis will be re-verified by performing simulations of hydrodynamic model based on the calculated values. The next step will be to verify the correlation between the size of area and increase (or decrease) in aberration of total surface runoff from the area of interest.

6 CONCLUSIONS

The goal of the research was to verify the influence of precision of map data on calculation of runoff coefficients and thus total surface runoff calculation. Research has been conducted in the area of the village Vrable. The results of the research shown differences in the calculated RC values compared between the 2 methods before and after adjustment of topology and geometry of objects in maps. The data shown differences in the range of 4-8% of the total amount of surface runoff from the studied area.

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