

# Hydraulic calculations of storm sewer networks

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**Abstract.** Surface run-off (SR) produced on the territory of cities and other settlement as a result of atmospheric precipitation is an intensive source of the technogenic pollution of environment, including the waterbodies. In accordance with the existing legislation of the Russian Federation, SR requires organized disposal and treatment according to the standards of regulatory documents. In this article we analyze the European document BS EN 752:2017 with regard to determining the flow-rates of surface (storm-water) run-off, and the calculations are made by the authors, which demonstrate that the application of foreign software products is impossible in Russia, due to the differences between the existing Russian regulatory and methodological documents and the European standards. Nevertheless, for the development of electronic models of hydraulic calculations for a storm-water drainage network, the mathematical relationship, which most adequately characterizes the type of surface run-off hydrograph most frequent for the territory of the Russian Federation as a result of atmospheric precipitation, was found. The relevant algorithm of the hydraulic calculation of storm-water drainage networks was also developed.

## 1 Introduction

The analysis of foreign data [1, 2, 3] revealed that the determination of surface run-off flow-rates for the modeling of run-off hydrographs has several directions.

The hydrological (infiltration) model is based on several calculation methods: SCS method; rational method; Green-Ampt equation and Horton equation.

On the other hand, the empirical model comprises the following: *R*-factor; unit hydrograph; regression method and RTK method. Since the construction of empirical models is based on the construction of surface run-off hydrographs, let us dwell on them in more detail.

### 1.1 R-factor method

This method is based on the supposition that the portion of precipitation entering a storm-water disposal network is relatively constant during rather a long time period and it may be described in the following way:

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$$V = R \cdot V_p \quad (1)$$

Where  $V$  is the volume of inflow/infiltration into a sewer ( $\text{ft}^3$ ,  $\text{m}^3$ );  $V_p$  is the volume of precipitation ( $\text{ft}^3$ ,  $\text{m}^3$ );  $R$  is the portion of precipitation entering the drainage system.

The total design flow-rate, being the total curve of surface run-off flow-rates, and intended for determining the design storm-water flow-rates with respect to time, is closely connected with the soil condition factor and has an impact on the shape of a rainfall graph. This method can be a useful tool for comparing the water catchment areas, which have the rainfall events of similar characteristics with identical initial climatic data.

## 1.2 Unit hydrograph

The transformation of unit hydrographs is carried out either through the application of special methods or is based on obtained measurements.

Moreover, the duration and intensity of precipitation events are uneven. As a result of this, a precipitation event, being an event that takes place in the course of time, is to be subdivided into several intervals and it is necessary to superimpose the obtained hydrographs against each other, in order to obtain the final one, in the long run.

## 1.3 Regression method

In most cases for the determination of surface run-off flow-rates, the method of linear regression at any time interval is used. It may be expressed through the following equation:

$$Q(t) = \sum_{i=0}^t C_i P_{t-i} \quad (2)$$

Where  $Q(t)$  is surface run-off flow-rate ( $\text{ft}^3/\text{s}$ ,  $\text{m}^3/\text{s}$ );  $P_{t-i}$  is precipitation for the  $i - th$  time-step before the  $t$  time (inch, mm);  $C_i$  is regression coefficient, connecting the surface run-off with precipitation for the  $i - th$  time-step before the  $t$  time.

The advantage of this method is the possibility to construct surface run-off hydrographs in the models where the intensity varies in the course of time.

## 1.4 RTK hydrograph method (run-off hydrograph)

The empirical model of *RTK* unit hydrograph most adequately describes the process of a rainfall event and the type of average flow hydrograph most frequent for the territory of the Russian Federation. It is constructed through the application of the Snider method [3], which is based on the construction of unit hydrographs. Fig.1 gives the graphical interpretation of a triangular hydrograph.

Fig. 1 shows an *RTK* hydrograph, where *RDII* is the sum of design flow-rates during the time moment in question. The parameters of design flow-rates are determined through the application of the method of *RTK* unit hydrograph according to the following equation:

$$\frac{1}{2}(T_i + T_i K_i) Q_{pi} = \frac{R_i P A}{3600s/hr} \quad (3)$$

Where:  $T_i$  is time before the peak,  $h$ ;  $K_i$  is the relation between time and the reduction at the peak moment;  $Q_{pi}$  is peak flow-rate ( $\text{ft}^3/\text{s}$ ,  $\text{m}^3/\text{s}$ );  $R_i$  is run-off volumetric coefficient;  $P$  is amount of precipitation (ft, m);  $A$  is water catchment area ( $\text{ft}^2$ ,  $\text{m}^2$ ). *RDII* is the summary

curve of flow-rates intended for determining the hourly flow-rates of storm-water versus the time of event occurrence. It is calculated using the following equations:

If  $t < T_i$ , the flow-rate is calculated according to the following equation:

$$Q = Q_{pi} \frac{t}{T_i} \quad (4)$$

If  $T_i \leq t \leq T_i K_i + T_i$ , the flow-rate is calculated according to the equation:

$$Q = Q_{pi} \left(1 - \frac{t - T_i}{T_i K_i}\right) \quad (5)$$

Where  $Q_{pi}$  is peak flow-rate ( $\text{ft}^3/\text{s}$ ,  $\text{m}^3/\text{s}$ );  $T_i$  is time before the peak flow, h;  $K_i$  is the relation between time and the reduction at the peak moment;  $t$  is time before the beginning of precipitation event (h).

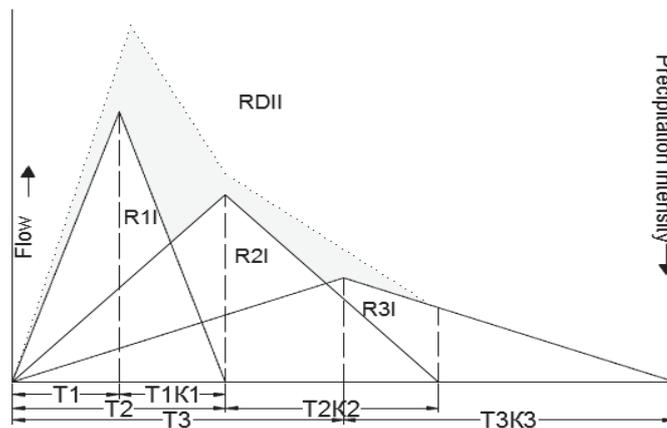


Fig. 1.A triangular hydrograph constructed with the RTK method.

### 1.5 Rational method

According to European legislation, the software algorithm for the calculation of surface run-off disposal systems must comply with the regulatory document BS EN 752:2017 [4]. This document says that storm-water run-off flow-rates must be calculated taking into account the following factors: design rainfall event intensity, the area of water catchment, the area of water-impervious surfaces, some possible losses of storm-water run-off as a result of water infiltration into soil, etc. According to BS EN 752:2017, in the absence of the methods for storm-water flow-rate calculation, and if the water catchment area is less than 200 ha, the following equation is used for the calculation of storm-water flow-rates:

$$Q = C \cdot I \cdot A \quad (6)$$

Where:  $Q$  is storm-water flow-rate, l/s;  $C$  is run-off coefficient (within the range between 0.0 and 1.0);  $I$  is rainfall intensity, l/(s · ha);  $A$  is water catchment area, ha. In the literature [3, 4] the equation 6 is known under the title of a rational method. The rainfall intensity in equation 6 is accepted to be maximal on the basis of the statistical analysis of

the rainfall intensity in the area under consideration. It is evident that the rainfall intensity in equation 6 is a constant value.

### 1.6 Method of limiting intensities

In the Russian Federation, according to the regulatory documents [6,7], the flow-rates in storm-water sewers are calculated through the application of the method of limiting intensities using the following equations:

$$Q_r = Z_{mid} \cdot A^{1.2} \cdot \frac{F}{t_r^{1.2n-0.1}} \quad (7)$$

Where:  $Z_{mid}$  is run-off coefficient;  $F$  is water catchment area, ha;  $t_r$  is the time of storm-water travelling to the cross-section of the collection network in question, this time being accepted to be equal to the rainfall duration, min;  $A$  is design climatic parameter determined according to the equation 8:

$$A = q_{20} \cdot 20^n \cdot \left(1 + \frac{\lg P}{\lg m_r}\right)^y \quad (8)$$

Where:  $q_{20}$  is rainfall intensity for the area in question, the rainfall duration being 20 minutes for the period of a single-fold exceedance of the design rainfall intensity  $P = 1$  year;  $m_r$  is the average number of rainfalls per year;  $y$  is the index of power accepted in accordance with the Table in the Appendix 3 to the “Recommendations for the Calculation of Surface Run-Off Collection, Disposal and Treatment from Residential and Industrial Areas, Including the Determination of Conditions for Run-Off Discharge into Water-Bodies” [5]. It is evident that Russian regulatory documents [6] use power-low relations for the calculation of storm-water flow-rates, including the application of the relation between the rainfall intensity and the storm-water travelling time, this relation is not included in the calculation equation contained in BS EN 752:2017 Standard. This fact may result in considerable differences in determining the pipe diameters of a gravity-flow storm-water disposal system.

## 2 Methods and materials

To estimate the differences in the results of calculations, the storm-water flow-rates were determined both with the rational method, according to BS EN 752:2017 and with the method of limiting intensities, in accordance with the SP 32.13330.2018 Construction Regulations. The calculations were made using the climatic parameters of Moscow and the Moscow Region [7].

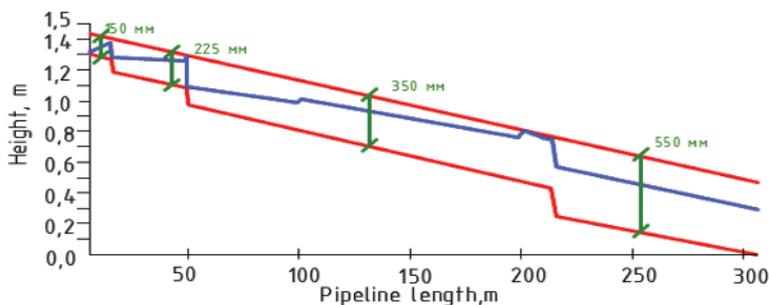
In order to carry out the hydraulic calculations according to SP 32.13330.2018, with the aim of determining the sewer diameter, we developed an algorithm in VBA language. The structure of algorithm operation is represented by the following two blocks: the block for calculating the flow of the surface run-off from the catchment area and the block for the hydraulic calculation of the sewer. The advantage of the algorithm is the fact that it comprises the principles of the hydraulic calculation of networks according to the method of limiting intensities, required by SP 32.13330.2018.

### 3 Results

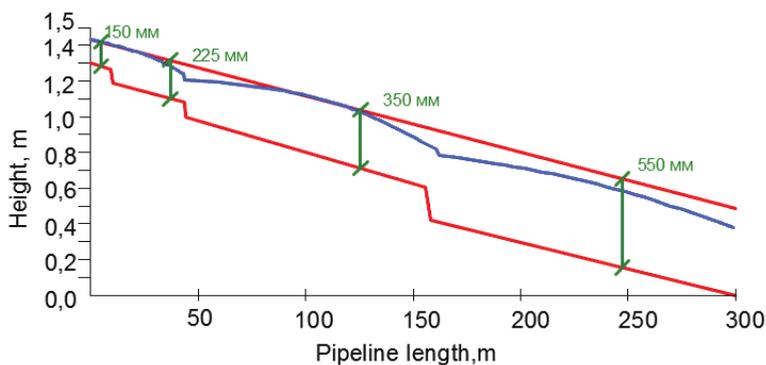
The results of the calculations are given in Table and in Fig. 2 – 3.

**Table.** The results of determining the design surface run-off flow-rates with the rational method and the with the method of limiting intensities.

$F, ha$	Section length, m	Velocity in the section, m/s	$t_r, min$	$Q_{point-source}, l/s$	$Q_{rtot}, l/s$ (SP 32.13330. 2018)	$Q_{rtot}, l/s$ (BS EN 752:2017)
0.000	0.0	0.00	5.00	0.0	0	0
0.120	40.0	0.81	6.00	0.0	25	30
0.240	80.0	0.96	6.80	0.0	46	60
0.360	130.0	1.07	7.80	15.0	78	98
0.480	190.0	1.08	9.00	15.0	90	122
0.600	250.0	1.12	10.0	20.0	106	155



**Fig. 2.** Pipeline longitudinal profile, calculated using the method of limiting intensities (SP32.13330.2018).



**Fig. 3.** Pipeline longitudinal profile calculated using the rational method (BS EN 752:2017).

One may note from Table that the flow-rates calculated using the equation 6, are considerably higher than the flows calculated in accordance with equation 7. This fact indicates the overestimated diameters of the gravity-flow storm-water drainage network, obtained as a result of the rational calculation method usage, resulting, in the long run, in its increased construction cost.

## 4 Conclusions

1. We compared the results of calculating the surface run-off flow-rates, obtained through the application of the regulatory document BS EN 752:2017, and the relevant results obtained according to Russian regulatory and methodological documents, and this comparison revealed the impossibility to apply the equations contained in the European standard BS EN 752:2017 for the development of an electronic software model for the calculations to be made in accordance with the requirements of Russian standards.
2. We developed an algorithm in VBA language aimed at making the hydraulic calculations of sewers for the storm-water drainage networks located on the territory of Russian cities and settlements. The advantage of the algorithm is the fact that it comprises the principles of the hydraulic calculation of networks according to the method of limiting intensities, required by SP 32.13330.2018.
3. It was found out that for the development of software model for the hydraulic calculation of storm-water drainage networks, it was possible to apply the method of *RTK* hydrograph (surface run-off hydrograph), comprising the construction of Snider unit triangles.

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