II Hydraulic Engineering and Environmental Impact

# HYDRAULIC CAPACITY ANALYSIS OF AN EXISTING COMBINED SEWER SYSTEM USING STORM WATER MANAGEMENT MODEL

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**Abstract**

Most of the sewerage systems in N. Macedonia is said to be separation, but in reality, they are most often combined systems where in the fecal sewerage system there are large number of connections from the storm sewer system, which practically in case of heavy rain with low intensity occurs overflow of the fecal sewage system. Also, with the increasing investment in the construction of wastewater treatment plants, the problems with mixing the sewage water are problems for the functioning of the treatment plants themselves.

The subject of this paper is to make a hydraulic model using the software package SWMM to determine the hydraulic characteristics of a combined sewer system at the appropriate intensity of rain from where will be defined: the maximum amount of water that will come to the wastewater treatment plant, bottlenecks of the existing network, amount of water that will flow through the overflows, points of overflow of the sewerage, etc. The case study that was used to create the hydraulic model is for the city of Bitola.

There are various methods for determining the amount of atmospheric water - the authoritative rain that will be used for analyzing the existing sewerage or will dimension the future sewerage, and in our country the most commonly used method is method of prof. Gorbachev because it is quite useful when the analysis does not use a sophisticated mathematical model. However, in this paper a comparative analysis will be made where besides the method of prof. Gorbachev will use the Rational Method.

**Keywords:** sewer network; Method of Prof. Gorbachev, Rational Method, hydraulic analysis, SWMM.

## 1. Introduction

The amount of water flow that appears in the stormwater drainage system is highly variable throughout the year. During dry periods, it is equal to zero, while during heavy rains its value can be very high. The maximum flow which occurs as surface runoff, depends on: hydrometeorological conditions, urban surface relief, slope, type and size of the catchment area, hydrogeological composition of the soil, groundwater etc. The stormwater drainage system collects the water flows from the natural water processes such as: rainfalls, melting snow, ground water, etc.

Accurate determination of the amount of water to be accepted by the sewer is important from a functional and economic point of view. If the network is undersized, it will not be able to fully accept surface water which would lead to water spills on the streets and the formation of watercourses that could in the worst case couse loss of human life. Whereas if sewage network is oversized, then we would have unjustifiably spent funds for its construction. That is why it is very important to accurately determine the amount of water for sizing the sewer. For that purpose, in this paper will be made comparison the results of two methods for defining amount of stormwater.

First method is method of Prof. Gorbachov. In Macedonia, it is most commonly used method because it is quite useful when the analysis does not use a sophisticated mathematical model and we have data of average annual rainfall.

Second method is Rational Method. In the SWMM software a hydraulic model of the sewerage network is made, and then the amount of atmospheric water is determined according to the Rational Method.

This comparison of the obtained results will be made on the existing sewerage system for the city of Bitola.

## 2. Methods

### 2.1. Method of Prof. Gorbachov

The method of prof. Gorbachov is an empirical form for determining the intensity of rain.

$$Q_{ATM}=\Sigma F \bullet q_r \bullet \varphi \bullet \Psi \text{ [l/s]}$$

where:
$Q_{atm}$ – amount of atmospheric water flowing into the canal [l/s]
$\Sigma F$ – total catchment area for the corresponding move [ha]
$q_r$ – authoritative rain for channel sizing [l/s/ha]
$\varphi$ – delay coefficient
$\Psi$ – leakage coefficient
It is used in cases when we do not have data on the amount of rain and duration, but when we have only information of the average annual rainfall. This method uses the equation for technical intensity of rain

$$q=166{,}7 \bullet i$$

It expresses the dependence between the height of the rain and the duration through the intensity of the rain.

$$\Delta=\sqrt{h * i}$$

if $i=\frac{h}{t}$, then the expressions can be written: $\Delta=\frac{h}{\sqrt{t}}$ or $\Delta=i \bullet \sqrt{t}$
If the intensity is expressed from the last equation, it will be seen that it is inversely proportional to the square root of the duration.

$$i=\frac{\Delta}{\sqrt{t}}$$

The intensity of the rain for a given locality is determined with the help of the average annual precipitation ($H_{cp}$) according to the equation of prof. Gorbachev.

$$\Delta=\mu \bullet \sqrt[3]{p};\ \mu=\alpha \bullet \sqrt[3]{H_{cp}^2};\ \Delta=\alpha \bullet \sqrt[3]{H_{cp}^2} \bullet \sqrt[3]{p}$$

where:
$\alpha$ – geographical constant (correction coefficient) which for Macedonia is 0.046
$\mu$ – climatic constant that depends on the average annual rainfall
$H_{cp}$ – average annual precipitation [mm]
$p$ – probability of rain

$$\varphi=\frac{1}{\sqrt[n]{\Sigma F}}$$

## 2.2. Rational Method

A hydrograph is a graph showing the rate of flow (discharge) versus time past a specific point in a river, channel or conduit carrying flow. The peak of the hydrograph is sufficient for design and analysis of the hydraulic model of the storm water drainage system, which can be easy calculated using the Rational Method.

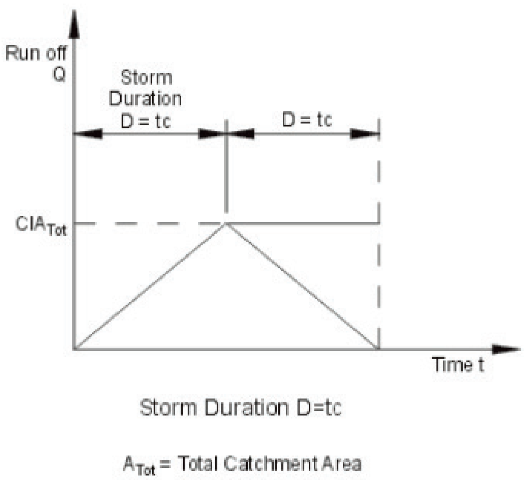


**Figure 1**. Rational Method runoff hydrograph

The rational method was developed about 130 years ago by Kuichling (1889). This method is applied to urban areas up to 15 $km^2$ and uses a simple equation that determines the maximum surface runoff (peak of the runoff hydrograph) in a given profile. The equation is

$$Q = C \bullet I \bullet A \qquad [m^3/s]$$

C is a dimensionless runoff coefficient intended to indicate the amount of runoff generated by the catchment area. The value of this coefficient varies between 0.05-0.95, depending on the type of the catchment area.

Storm intensity i [mm/min], depends of duration of the rain and the return period. The relation between the three components – storm duration, storm intensity and storm frequency (return interval) is presented by a family of curves called the intensity-duration-frequency curves, or IDF curves.

Time of concentration Tc is the time required for rainfall landing on the farthest point of the watershed to reach the watershed outlet. Tc depends of the size, type and shape of the catchment area.

In Rational Method, storm duration is equal to time of concentration. Therefore hydrograph has triangular shape.

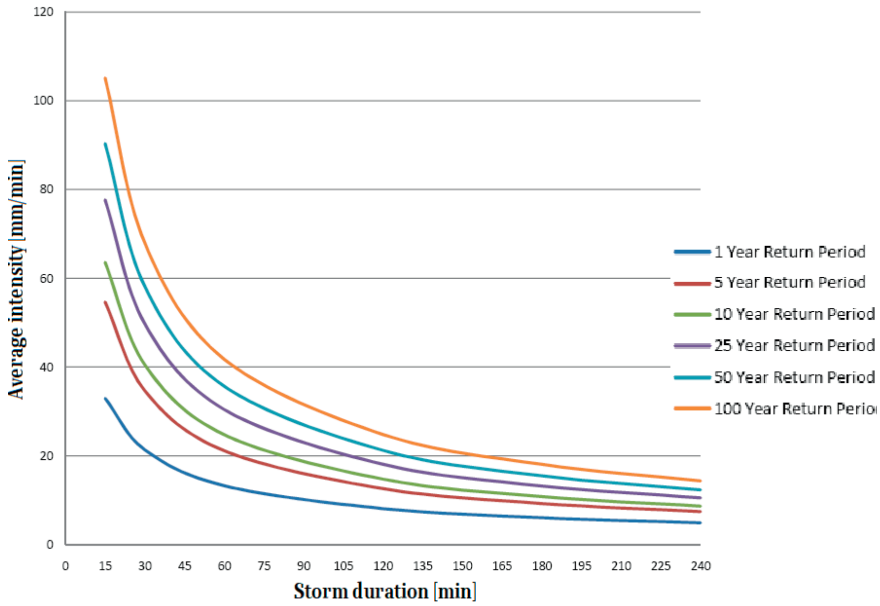


**Figure 2.** Example for IDF curves

Time of concentration Tc is the time required for rainfall landing on the farthest point of the watershed to reach the watershed outlet. Tc depends of the size, type and shape of the catchment area.

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## 3. Hydraulic model

As a case study that is analyzed is existing combined sewer network for the city of Bitola. The terrain in the city of Bitola consists of both steep and flat parts, which is quite convenient to see the differences in the results of the methods that will be compared.

The hydraulic model of existing sewerage network was created in the software package "Storm Water Management Model" (SWMM).

The data for the manholes and pipes were obtained from the public utility company Niskogradba. 4215 manholes were imported. The pipes diameter varies from 200mm to 500 mm for secondary network, while it varies from 500mm to 2200mm for collectors. The sewerage network consists of 7 main collectors with a length of about 21 km.

The total catchment area is 1025 ha and it is distributed over 32 catchment areas. The 32 catchment areas have a relatively large area, each catchment area is divided by the Thiessen method into a subcatchment area for each manhole, i.e. each manhole has its own catchment area to which atmospheric water flows.

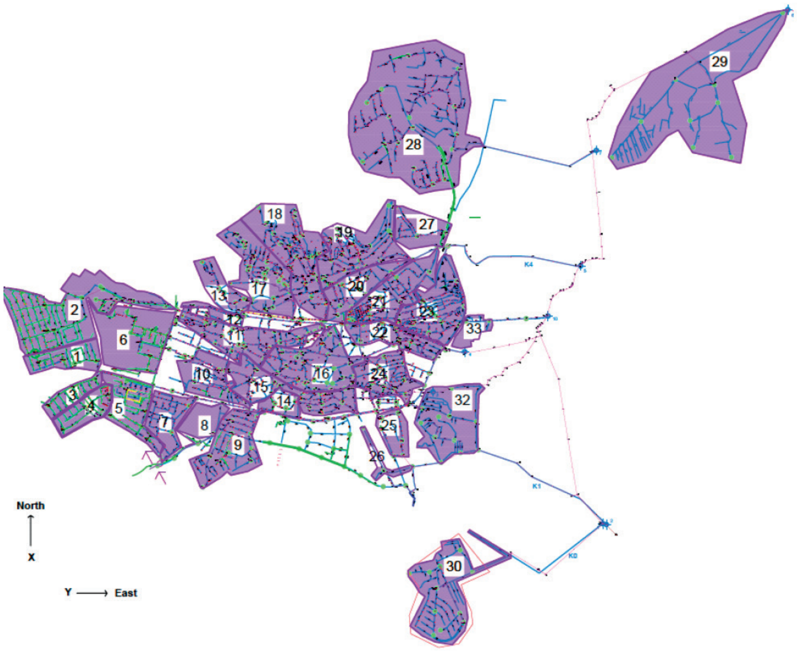


**Figure 3.** Hydraulic model of the sewerage network in the city of Bitola

The leakage coefficient for each catchment area is determined separately, depending on the percentage of greenery, roof, asphalt and concrete. The following leakage coefficients are adopted depending on the type of surface:

- 0.90 – leakage coefficients for roofs
- 0.80 – leakage coefficients for asphalt surface
- 0.70 – leakage coefficients for concrete surface
- 0.25 – leakage coefficients for parks

After previously received information from the public utility, three overflows were inserted in the model, two of which were placed on the collector 4, one placed on the collector 3.

The maximum amount of sanitary wastewater for each catchment area is obtained from public utility and it varies from 0.2 l/s/ha to 2 l/s/ha.

During the hydraulic analysis, rain with a return period of 2 years, intensity of 93.02 l /s/ ha and duration of 20 minutes was used.

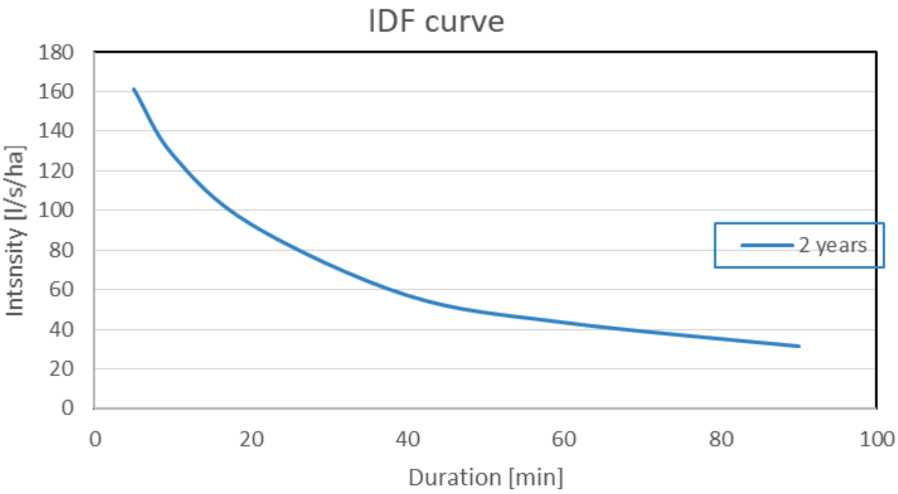


**Figure 4.** IDF curve used in SWMM

## 4. Results and discussion

The amount of atmospheric water obtained by the method of prof. The Gorbachev and SWMM methods differ due to the different complexity between these two methods and the number and nature of the input data required for input into these two methods. Namely, the SWMM method considerate the slope of the pipes and the topography of the catchment areas, while that data in the method of prof. Gorbachev is contained in the formula for the coefficient of delay with article n, which indirectly considerate the influence of the slope, the shape, the size of the catchment area and the slope of the pipe on the size of the runoff. Therefore, for small, steep and elongated catchments, this article, although according to the recommendations should be a maximum of 10 in certain parts. The same in this hydraulic model is provided with values up to 15, while for larger and developed catchments this is adopted between 4 and 8 in depending on the type, shape, slope and size of the catchment area. For article n values above the recommended ones are adopted, in order to get as close as possible to the runoff quantities obtained according to the Rational Method

**Table 1**. Runoff Quantities

| **Method** | **Prof. Gorbachov** | | | | | | **SWMM** | **Compare** |
|---|---|---|---|---|---|---|---|---|
| Collector | Manhole | Catchment | Specific Runoff l/s/ha | Area | ϕ | Quantities l/s | Quantities l/s | SWMM – Prof. Gorbachov |
| K00 | S30 | O-K00 | 93.02 | 49.97 | 0.61 | **97.5** | **112** | **14.5** |
| K01 | S26 | S26 | 93.02 | 5.29 | 0.89 | **11.8** | **18** | **6.2** |
| | S25 | S25 | | 11.24 | 0.74 | **72.6** | **82** | **9.4** |
| | S32 | S32 | | 40.30 | 0.63 | **189.7** | **221** | **31.3** |
| | S32 | O-K01 | | 56.83 | 0.36 | **169.5** | **169** | **–0.5** |
| K02 | S07 | S07 | 93.02 | 17.59 | 0.70 | **239.7** | **295** | **55.3** |
| | S08 | S08 | | 22.64 | 0.68 | **204.6** | **226** | **21.4** |
| | S10 | S10 | | 20.23 | 0.47 | **336.3** | **382** | **45.7** |
| | S09 | S09 | | 30.84 | 0.65 | **364.1** | **465** | **100.9** |
| | S07 | S08 | | 17.59 | 0.70 | **273.7** | **330** | **56.3** |
| | S08 | S10 | | 40.23 | 0.63 | **444.8** | **563** | **118.2** |
| | S10 | S09 | | 60.46 | 0.60 | **857.2** | **908** | **50.8** |
| | S09 | MH-1801 | | 91.30 | 0.57 | **1130.7** | **1195** | **64.3** |
| | S14 | S14 | | 7.62 | 0.78 | **289.9** | **345** | **55.1** |
| | S15 | S15 | | 28.79 | 0.66 | **936.9** | **1268** | **331.1** |
| | S14 | S15 | | 7.62 | 0.78 | **289.9** | **318** | **28.1** |
| | S15 | MH-1801 | | 36.40 | 0.64 | **1154.5** | **1457** | **302.5** |
| | MH-1801 | O-K02 | | 127.71 | 0.55 | **2108.5** | **2499** | **390.5** |
| K03 | S12 | S12 | 93.02 | 13.12 | 0.53 | **333.5** | **361** | **27.5** |
| | S11 | S11 | | 22.37 | 0.68 | **752.7** | **905** | **152.3** |
| | S16 | S16 | | 38.06 | 0.59 | **1122.5** | **1133** | **10.5** |
| | MH-3154 | O-K03 | | 91.36 | 0.57 | **2253.0** | **2464** | **211.0** |
| K04 | S13 | S13 | 93.02 | 13.96 | 0.84 | **344.7** | **385** | **40.3** |
| | S17 | S17 | | 36.55 | 0.79 | **844.1** | **929** | **84.9** |
| | S18 | S18 | | 45.53 | 0.78 | **1067.7** | **1255** | **187.3** |
| | S19 | S19 | | 37.27 | 0.79 | **834.2** | **921** | **86.8** |
| | S21 | S21 | | 29.00 | 0.71 | **741.8** | **810** | **68.2** |
| | S23 | S23 | | 33.01 | 0.50 | **503.2** | **557** | **53.8** |
| | S27 | S27 | | 16.88 | 0.83 | **68.0** | **75** | **7.0** |
| | S13 | S17 | | 13.96 | 0.84 | **344.7** | **373** | **28.3** |
| | S17 | S18 | | 50.51 | 0.77 | **493.3** | **611** | **117.7** |
| | S18 | S19 | | 113.62 | 0.73 | **1130.2** | **1444** | **313.8** |
| | S19 | S21 | | 150.90 | 0.72 | **1841.3** | **2176** | **334.7** |
| | S21 | S27 | | 167.78 | 0.71 | **2326.2** | **2902** | **575.8** |
| | S27 | S23 | | 184.66 | 0.71 | **2683.2** | **2948** | **264.8** |
| | S23 | O-K04 | | 217.67 | 0.51 | **2086.6** | **2483** | **396.4** |
| K05 | S28 | O-K05 | 93.02 | 143.96 | 0.19 | **170.8** | **191** | **20.2** |
| K06 | S29 | O-K06 | 93.02 | 129.84 | 0.30 | **89.6** | **27** | **–62.6** |

From the obtained results it can be concluded that in the places where we have steep terrain, according to the SWMM method we have a higher flow, while in the plain parts we have a higher flow according to the method of prof. Gorbachev. These two cases are significantly more pronounced when we have a steep slope and small and elongated catchments, while large circular catchments and a slight slope produce approximately the same amount of atmospheric water.

## 5. Conclusion

The method of prof. Gorbachev is an old method, in which a simple formula provides the maximum amount of storm water that is needed to dimension the storm sewer. In this method, the topographic characteristics of the catchment area are not taken as a whole, but are expressed through article n of the delay coefficient, so when we analyze storm water for settlements with large variation of slope, size and shape of the catchment area, we will get unrealistic quantities of storm water at certain parts of sewer network.

SWMM is a modern method of determining the amount of storm water, which with the help of the power of computers can very quickly simulate storm water, turning it from rain into canal water, taking into account the topography of the terrain, the slope of the canals, the type of surface, etc. The advantage of this method that can solve very complex sewer networks and in a very easy way to make changes in them. The great advantage of this method is that the model can be calibrated, i.e the input parameters can be changed and thus we can get a model that works approximately the same as the real sewer network.

From the above, it can be concluded that the method of Prof. Gorbachev is an outdated method that can only be used for some preliminary calculations in order to obtain an indicative size of storm water even when we have a smaller number of input data. While the SWMM method is a modern tool that requires large data input, but therefore provides a realistic simulation of the operation of the sewer system.

### References:

[1] Nikola Krstovski, “DIFFERENT ANALYSIS METHODS FOR STORMWATER SYSTEM MODELING” Master thesis, Skopje, Macedonia, 2022.

[2] Шкоклески Ж. “Врнежи во Република Македонија”.

[3] Rossman LA. Storm water management model user’s manual, version 5.0, EPA. United States. 2009; p. 233.

[4] David B. Thompson “The Rational Method”, September, 2006, Civil Engineering Department, Texas Tech University.

[5] Junaidi, A.; Ermalizar, L.M. (2018): “Flood simulation using EPA SWMM 5.1 on small catchment urban drainage system”.

[6] Waikar, M.L.; Undegaonkar Namita, U. (2015): “Urban Flood Modeling by using EPA SWMM 5”.