APPLICATION OF SWMM FOR CAPACITY ANALYSIS OF COMBINED SEWER SYSTEM

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A sewer system is an underground infrastructural facility that is designed to receive storm and sanitary water and safely distribute it within urban areas. The distribution of this water can be accomplished through separate and combined sewer systems. In separate sewer systems, sanitary and stormwater flow through different pipes, while in combined sewer systems, they flow through the same pipe.

In the past, designing a sewer system was a tough and complex task due to all calculations being done by hand. However, with the advancement of technology and computers, numerous software programs have been developed for flow simulation in sewer systems. These software applications can now be utilized to create hydraulic models for planned sewer networks, enabling calculations of pipe dimensions, as well as to assess the flow capacity of existing sewer networks.

The objective of this topic is to assess the flow capacity of the existing sewer network in the city of Bitola using EPASWMM (Storm Water Management Model).

Keywords: combined sewer system, hydraulic model, rational method, SWMM

1. INTRODUCTION

The flow rate in a combined sewer system can vary significantly throughout the year. During dry periods, the flow rate is zero, whereas during heavy rainfall events, it can reach very high values. It is crucial to accurately determine the volume of water that the sewer system can accommodate, considering both functional and economic factors. If the network is undersized, it won't be able to handle the surface water, resulting in water overflow on the streets and the formation of watercourses, which could potentially lead to loss of life. On the other hand, if the sewer network is oversized, it would mean unnecessary expenditure on construction. Hence, accurately determining the water volume is of utmost importance for sizing the sewer system.

2. RATIONAL METHOD

The Rational method was developed approximately 130 years ago by Kuichling (1889). The rational method is based on a simple formula that relates runoff- producing potential of the catchment area, the average intensity of rainfall for particular length of time (time of concentration) and the catchment area. This method is applied when the size of the catchment area is less than 15 km2. The equation is:

$$Q = F \cdot C \cdot i \qquad (1)$$

- F – catchment area [ha]
- i – rainfall intensity [l/s/ha]
- C – runoff coeficient

The runoff coefficient C, is a dimensionless ratio intended to indicate the amount of runoff generated by the catchment area, given an average intensity of precipitation for a storm. The value of this coefficient varies between 0.05-0.95, depending on the type of the catchment area.

Storm intensity i is a function of geographic location and design exceedence frequency (or return interval). The relation between the three components - storm duration, storm intensity, and storm return interval, is presented by a family of curves called the intensity-duration-frequency curves, or IDF curves. They can be determined by analysis of storms for a particular site (Figure 1)

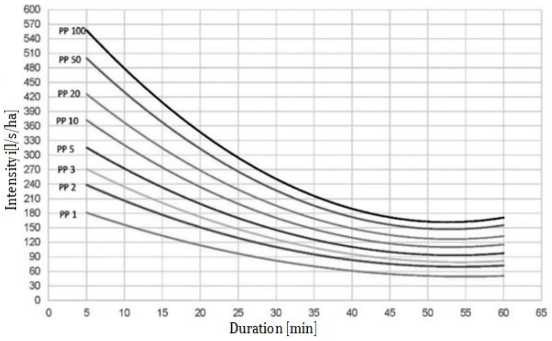

Figure 1. IDF curve

Two key parameters on which peak flow depends are the time of concentration (tc) and the duration of rain (td).

The runoff hydrograph obtained by the rational formula has a triangular shape (Figure 2).

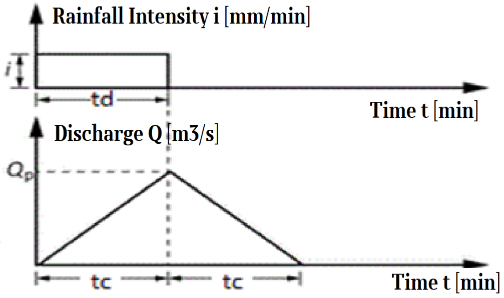

Figure 2. Hydrogram obtained using the Rational Method

The time of concentration (tc) is defined as the time it takes for water drops from the furthest point in the catchment to reach the specified profile. When the duration of rainfall (td) is less than tc (td < tc), the maximum flow will be lower because the entire catchment area does not contribute to flow formation (Figure 3a). On the other hand, when td > tc, the flow will increase up to a maximum value and then gradually decrease (Figure 3b). The maximum flow occurs when td = tc because the entire catchment area actively participates in flow formation, and the rainfall duration is shorter compared to previous cases. Shorter-duration rains have higher intensities, resulting in higher maximum runoff.

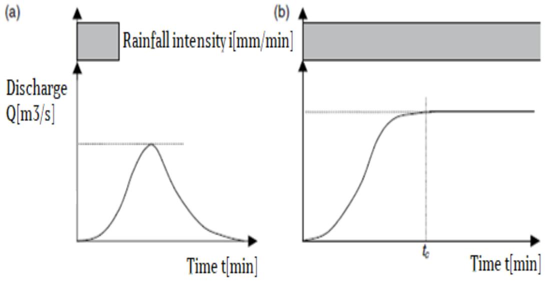

Figure 3. Runoff hydrograph (a - td<tc; b – td>tc)

The time required for water to reach the analyzed profile (tc) can be divided into two components:

$$t_c = t_1 + t_2 \qquad (2)$$

- t_1 – time required for water to reach the channel
- t_2 - time of water flow through the channel itself

The time of water entering the sewer network depends on various factors such as the slope of the terrain, the type of surface, the distance to the drain, the infiltration characteristics of the soil, and more. A common approach to estimating this time is as follows:

- t_1=5 [min] - for impervious surfaces, particularly in densely populated cities with closely spaced catchments
- t_2=10-15 [min] - for densely populated urban cities with low terrain slope
- t_3=20-30 [min] - for residential zones with widely spaced sinks

3. EPA SWMM

EPA SWMM is a dynamic, physically based model that simulates the process of transformation of precipitation into runoff. It can be used for a single event or a longer-term simulation of the quantity and quality of runoff water, most often from urban areas.

This software was developed by the US EPA (Environmental Protection Agency) in 1971. It is very often used in the stages of planning, analysis and design of sewage systems for the acceptance of atmospheric and waste waters, culverts under the road, open channels, etc. SWMM allows data input in a virtual environment and then based on that data input makes hydrological, hydraulic and water quality simulations, as well as reviews the obtained results in different formats.

The SWMM takes into account the various hydrological processes that affect runoff, such as:

- irregularity of rainfall
- snow melting
- water retention in surface depressions
- evaporation
- infiltration of the rain in the unsaturated layers of the soil
- interaction between collectors and groundwater

The capabilities of SWMM for hydraulic modeling of flow through pipes, channels, reservoirs or through flow distribution facilities are as follows:

- Collector network of unlimited size
- Possibility of using various forms of open and closed channels
- Modeling of special facilities such as reservoirs, water treatment facilities, flow distribution facilities, pumps, overflows, etc.
- Application of kinematic and dynamic wave methods for calculation of flow in pipes
- Modeling of different flow regimes, such as free water mirror flow, pressurized flow, reverse flow, surface water retention, etc.
- Modeling the operation of the pump, the openings and the crown level of the spillway

The working concept of SWMM is based on the interaction of several main components of the environment, which are modeled as objects. Those components and objects are:

- Atmosphere, from which rain or snow falls and pollutants that settle on the surface of the land. SWMM uses the Rain Gage tool to represent precipitation as an input to the system.
- Land surface, which is represented through one or more Sub-Catchment objects. It receives precipitation from the atmosphere, which can be in the form of rain or snow. From the land surface, a part of the runoff goes into the groundwater through infiltration, and the rest into the transport system as surface runoff and pollution
- Groundwater receives infiltration from the Land Surface and transfers a part of this inflow to the Transport systems. This is modeled using Aquifer objects
- The transport system contains a network of transport elements (channels, pipes, pumps and stoppers), collection elements and treatment elements that transport the water to an outlet in a recipient or a treatment facility. Inflows to this component can come from surface runoff, groundwater interflow, sanitary dry weather flow, or from user-defined hydrographs. The components of the Transport system are modeled with Node and Link objects.

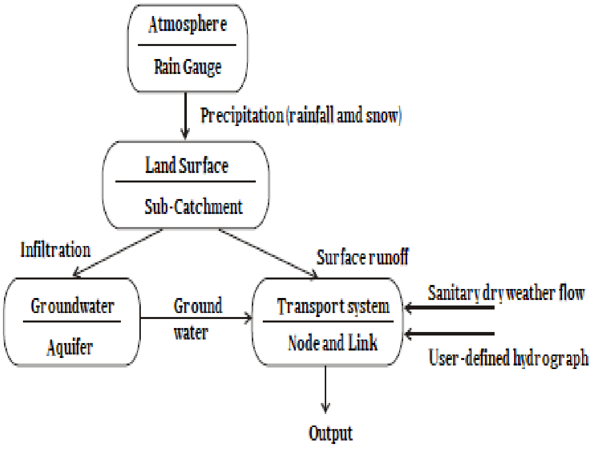

Figure 4. SWMM conversion of precipitatiton to flow

4. HYDRAULIC MODEL

The case study being analyzed involves the existing combined sewer network in the city of Bitola.

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

The data for the manholes and pipes used in the hydraulic model were obtained from the public utility company 'Niskogradba'. A total of 4215 manholes were imported into the model. The pipes in the secondary network have diameters ranging from 200 mm to 500 mm, while the collectors have diameters varying from 500 mm to 2200 mm. The sewerage network is composed of 7 main collectors with a total length of approximately 21 km.

The total catchment area for the sewerage network in Bitola is 1025 hectares, which is distributed across 32 separate catchment areas (Figure 5). These catchment areas are relatively large in size. Using the Thiessen method, each catchment area is further divided into sub-catchment areas assigned to individual manholes. This means that each manhole has its own designated catchment area, where atmospheric water flows and contributes to the overall drainage system flow rate.

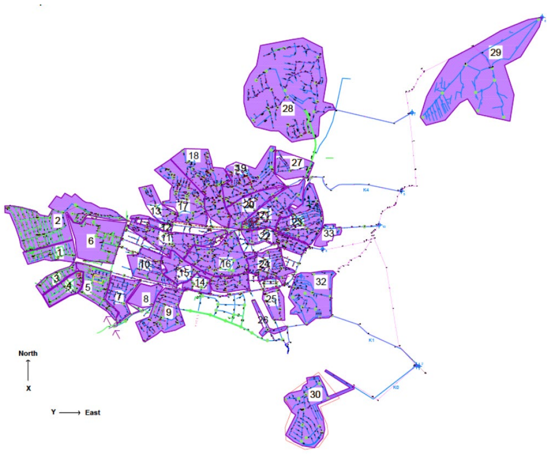

Figure 5 Hydraulic model of the sewerage network in the city of Bitola

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

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

Based on the information provided by the public utility company, three overflow points were incorporated into the hydraulic model. Specifically, two overflow points were placed along collector 4, and one overflow point was placed along collector 3. These overflow points serve as outlets for excess water in the event of high flow conditions in the sewer network.

The maximum amount of sanitary wastewater for each catchment area is obtained from the public utility company and it ranges 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.

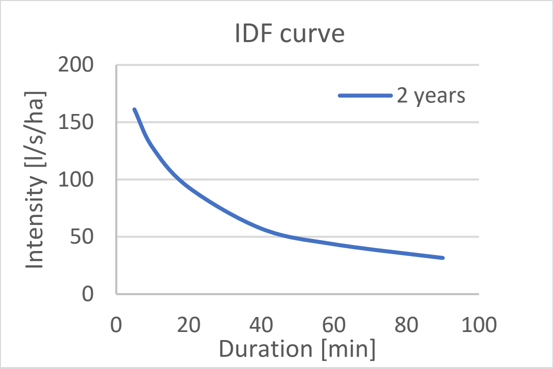

Figure 6. IDF curve used in SWMM

5. ANALYSIS OF THE RESULTS FROM THE HYDRAULIC MODEL

The results obtaioned from the hydraulic model are shown in the Figures 7-9. The hydraulic analysis of the sewage network in Bitola reveals the presence of bottlenecks in a specific section of the network, resulting in water spills during rain events with an intensity of 93.02 (l/s/ha). Additionally, a significant portion of the sewerage network exhibits underutilization of pipe cross-sections, indicating the presence of oversized pipes.

Table 1 shows the length of the pipes and utilization of the capacity of the pipes expressed in %.

Figure 7. Catchment flow (Total out)

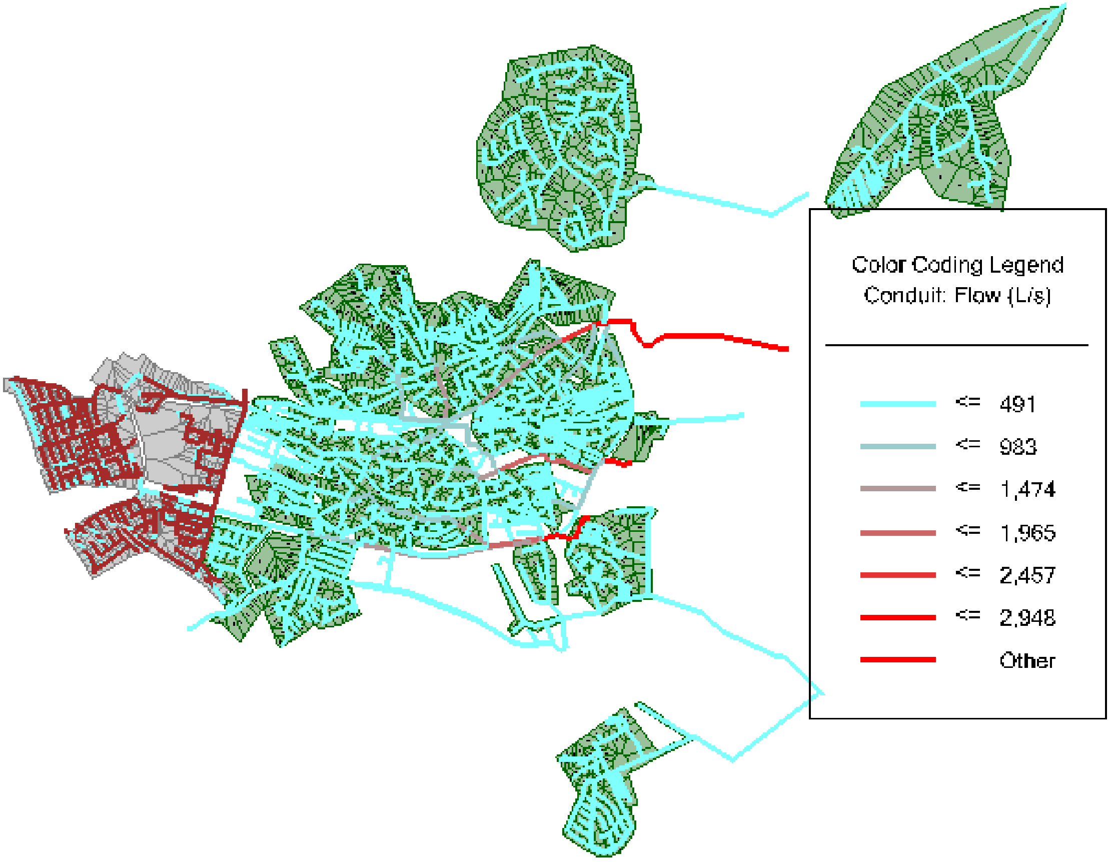

Figure 8. Conduit flow

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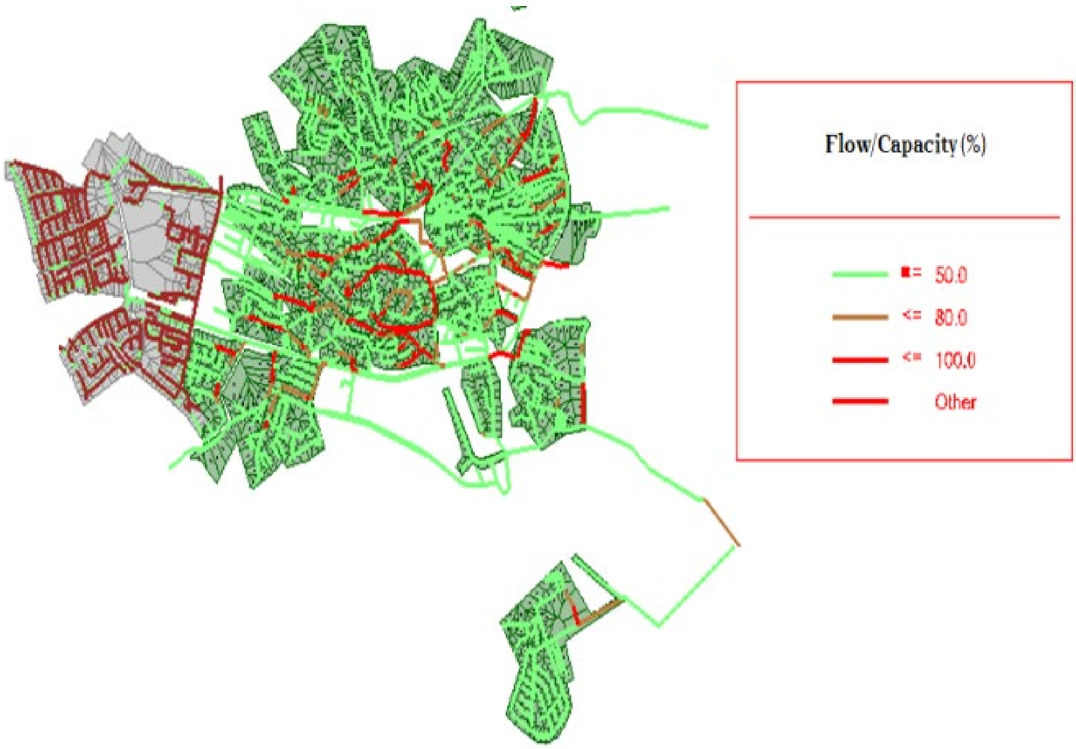

Figure 9. Flow/Capacity of the sewer system

Table 1. Utilization of the capacity and pipe length

Flow/Capacity [%]	Pipe length [km]
<50	141.4
50-80	11.1
80-100	4.3
>100	7.6

6. CONCLUSION

SWMM is a modern method of designing sewer network, which with the help of the power of computers can very quickly simulate stormwater, turning it from rain into canal water, taking into account the topography of the terrain, the slope of the conduits, the type of surface, etc. The advantage of this method is that can solve very complex sewer networks and in a very easy way 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.

With the application of such software, sewerage networks can be designed in which the utilization of the cross-section of the pipe will be within the allowed limits, that is, we will not even have an oversizing of the sewerage network, which would mean unreasonably spent finances for the construction of that network or undersizing on the pipes, which would lead to spillage of water from the sewers even during minor rains.

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