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HYDRAULIC MODEL OF STORMWATER DRAINAGE SYSTEM USING DIFFERENT METHODS FOR DEFINING THE CATCHMENT AREA

The stormwater drainage system is an infrastructure facility that accumulates the rainwater, protecting the urban areas from flooding. An important parameter for stormwater drainage systems in urban areas is the size, shape and type of the catchment area. According to current practice the catchment area can be determined by several methods: classical methods where the catchment area can be defined using a roof symmetry by links or by distributing it in equal parts at all nodal points of the hydraulic model and modern methods in which the definition of the catchment area is made by taking into account additional parameters such as the slope of the terrain, the position of node points, the distance of the connection points to the future sewage, the size of the catchment area, etc.

Subject of this hydraulic analysis is to apply the classical and modern methods for defining the catchment area in order to show the advantages and disadvantages of the methods with a further comparison and recommendations for designing the stormwater drainage system.

Keywords: hydraulic analysis, stormwater drainage systems, catchment areas

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 quite 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 [1].

According to previously stated, the water flow in the stormwater drainage system depends on various parameters, giving a lead role to the size and type of the catchment area due to creating a hydraulic model and its analysis.

2. RATIONAL METOD

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 maximum, or peak, of the hydropraph is sufficient for design and analysis of the hydraulic model of the stormwater drainage system, which can be easy calculated using the Rational method [1,2,3].

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 13 km^2. The equation is:

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

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 [4].

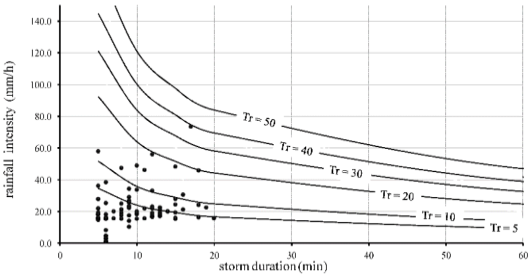

Figure 1. Example for IDF-curves

Time of concentration of a catchment area is often defined to be the time required a parcel of runoff to travel from the most hydraulically distant part of a watershed to the outlet. This parameter also depends of the size and type of the catchment area.

3. CATCHMENT AREA

Catchment areas are hydrologic units of land whose topography and drainage system elements direct surface runoff to a single discharge point. They are divided into pervious and impervious subareas. Surface runoff can infiltrate into the upper soil zone of the pervious subarea, but not through the impervious subarea. Runoff flow from one subarea in a catchment area can be routed to the other subarea, or both subareas can drain to the catchment outlet. The other principal input parameters for catchment areas include: assigned rain gage (using an IDF-curve); outlet node (subarea); assigned land uses; area size; imperviousness; slope; characteristic catchment width; Manning’s n for overland flow on both pervious and impervious areas, etc.

While making a hydraulic model, the size of the catchment area and its parameters can be defined using the two methods:

- classical method - where the catchment area can be defined using a roof symmetry by links or by distributing it in equal parts at all nodal points of the hydraulic model

- modern methods - where the definition of the catchment area is made by taking into account additional parameters such as the slope of the terrain, the position of node points, the distance of the connection points to the future sewage, the size of the catchment area, etc.

4. CLASSICAL METHOD

To define the catchment area using the classical method mean that the boundary conditions will be determined by the method of roof symmetry by links or by distributing it in equal parts at all nodal points of points of the hydraulic model, also named as a method of Thiessen polygon [4].

In the areas of hydraulics and hydrology, the measurement of rainfall is one of the most important elements in modelling or dimensioning of storm water drainage, as well as the amount of rainfall that fell on a particular surface.

The Thiessen polygon method is created by American scientist Alfred H. Thiessen (1872-1956). For distribution of the water (fecal, storm water, etc.), Thiessen’s polygon in modeling is used to quickly and clearly define the catchment areas on the nodes of a system, individually. There are two types of defining the Thiessen polygon method:

- Method for determining of Thiessen polygons with circles

- Method for determining Thiessen polygons with triangulation

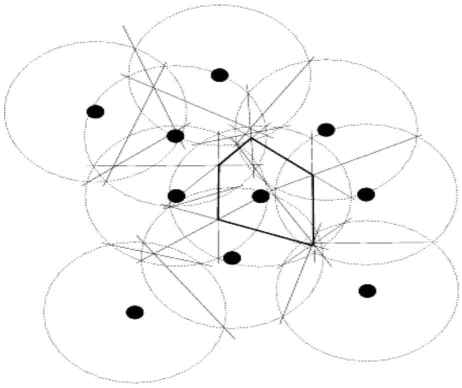

Figure 2. Method for determining of Thiessen polygons with circles

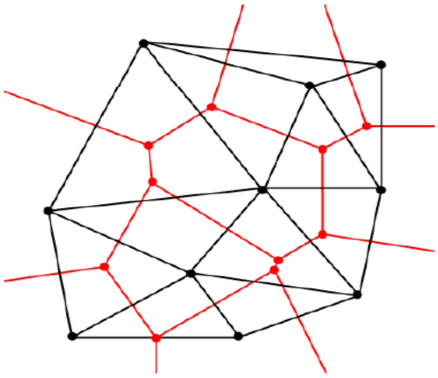

Figure 3. Method for determining Thiessen polygons with triangulation

In Figure 2. and Figure 3. are given the graphical presentation of the two methods of the Thiessen polygon, were the boundaries and size of the catchment area are presented.

In order to obtain greater accuracy in the determination of catchment areas, a so-called method is used that is named "Roof symmetry method". This method makes a two - dimensional distribution of rain amounts depending on the length of the links and the location of the nodes in the system. Graphically this method is executed as presented on Figure 4.

Combining the Thiessen polygon method and the Roof symmetry method, the Classical method of defining the catchment area size and boundaries is defined.

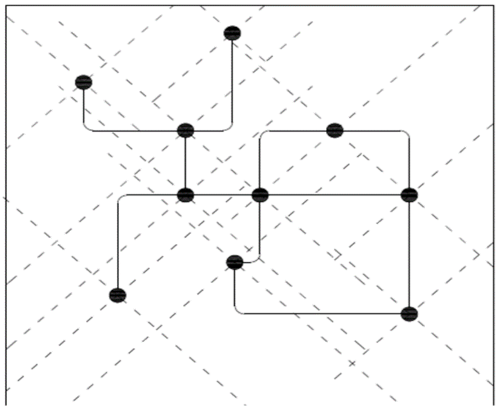

Figure 4. Roof symmetry method

5. MODERN METHOD

Defining the catchment areas using the Modern Method generates the topography of the terrain, with a main note on its: slope, groundwater, its use, elevation, geometric change, embankments, etc.

Once the boundary of the urban area has been defined, it is necessary to define the catchment areas separately. 2D modeling of stormwater drainage systems begins with 2D modeling of catchment areas. The amount of rainfall that the systems generates in 2D modeling by modern methods depends largely on the size of the catchment areas. Each of the created 2D catchments must belong to the already defined boundary of the urban surface. 2D catchments serve to control surface runoff and direct that flow to the final drainage point - realistic as the field or to the next closest drainage point. (Figure 5.)

5.1 BREAK LINES

The boundary elements defining these surfaces are called "break lines" (or break points). They are plotted in places where the 3D model of the terrain has significant topographies and geographical variations or in places where there are significant elements. Also, they can be placed as bisector lines on the links that connect the nodes. They are placed at each location where there is a break (barrier) to the free flow.

Connecting the break lines, within them self they create a polygon in the already defined urban boundary area, which represent the 2D catchment areas.

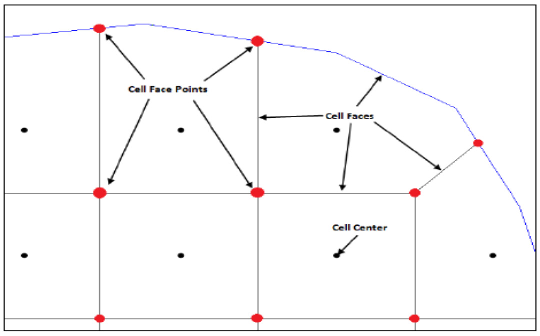

Figure 5. 2D catchment areas and their properties

5.2 CHARACTERISTIC CATCHMENT WIDTH

An initial estimate of the characteristic width is given by the catchment area divided by the average maximum overland flow length. The maximum overland flow length is the length of the flow path from the outlet to the furthest drainage point of the subcatchment. Maximum lengths from several different possible flow paths should be averaged. These paths should reflect slow flow, such as over pervious surfaces. Adjustments should be made to the width parameter to produce good fits to measured runoff hydrographs.

6. HYDRAULIC MODEL

In the modelling of stormwater drainage systems, defining the catchments is considered as a key element for the output data. Due to the hydraulic analysis, the main parameters of the elements are predifined, so the accuracy and operation of the system is ascertained by defining the catchment areas. Depending on the boundaries of the urban surface from where the runoff is drawn, the dimensions of the catchment areas play big role on the peak flow from where the system is designed. The rainfall is governed by the intensity of the rain (IDF-curves), with a note that a bigger catchment area generates greater amount of flow (rainfall concetration), and vice versa smaller catchment area- less amount of flow.

For the purpose of the hydraulic analysis, a hydraulic model has been developed that will simulate the runoff conditions of the stormwater drainage system, using the SWMM (Storm Water Management Model) software package. While developing the model, first the parameters of the main elements are examined, such as: manholes and catch basins; channels; links (pipes); outfalls; main collector; urban surface border and catchment areas.

Furthermore, for the developing of the hydraulic model analysis, a certain calibration needs to be done for the input: terrain and elevation points, maximum flow, flow velocity, links diameters, IDF-curves, concentration time and catchment areas. By varying this input data, the hydraulic model is generated, where the peak flow of the hydrogram is used as a corrective output parameter to validate the model.

Using the SWMM software package, the creation of different scenarios for a case study for the variable parameters was simplified. The return period from the inserted IDF-curves was chosen for 2 years to be in accordance with the designing law for stormwater drainage systems. The study of this hydraulic model is validated with a real situation for the two already created methods of defining catchment areas – the classical and the modern method. The analysis works on the principle of the “Rational Method”, with already defined runoff coefficient C=0.450, the impervious percent of the surface is 25%, the impervious coefficient is 0.011, and the pervious is 0.03 (Manning’s). Infiltration was calculated experimentally by Horton's method.

The purpose of this hydraulic model is to prove the accuracy and functionality of a stormwater drainage system in hydraulic analysis, by defining the catchment area sizes at different calculated characteristic catchment widths including two different analysis for the both methods (classical and modern).

7. RESULTS

To make a comparison between the accuracy of the two analysis of the hydraulic model, one can see the difference in the flow rate of the links, depending on the amount of water they receive from the catchment areas. This is further illustrated by means of hydrograms that are examinating the dependence between the Q flow and the T time. The flow Q is expressed in [l/s], and the time T is expressed in [min].

The following hydrograms provide a detailed overview of the maximum peak flow that occurs after a certain time: at the upstream links, at the intermediate collecting links and at the downstream links at the outlets, which occures a separation in to three groups.

7.1 UPSTREAM LINKS

On Figure 6. are presented the hydrograms for the upstream link shown on Figure 7. and Figure 8., with total lenght of 208.8 m, which includes 6 manholes and 5 pipes. According to the classical method, one catchment area is defined for this link and six catchment areas according to the modern method. Because of the separation of the catchment areas due to using the modern method, is enabled to make an optimization of the diameter of the pipes that generate less peak flow according to its hydrograms.The maximum peak flow is Q=162.9 l/s.

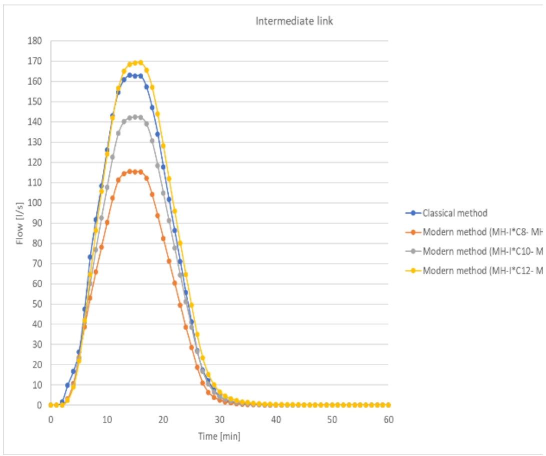

Figure 6. Hydrograms for upstream link

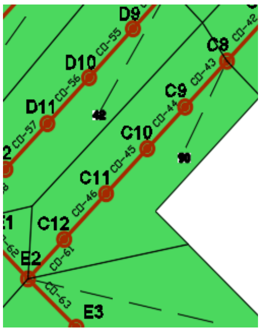

Figure 7. Classical method

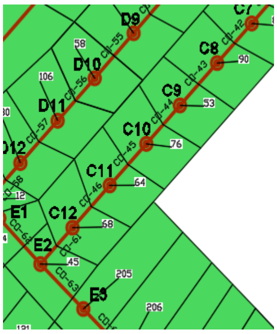

Figure 8. Modern method

7.2 INTERMEDIATE LINKS

On Figure 9. are presented the hydrograms for intermediate link shown on Figure 10. and Figure 11., with total lenght of 212.45 m, including 6 manholes and 5 pipes. According to the hydrograms of the classical and modern method, their peak flows are almost equivalent. With the classical method only one catchment area is defined and using the modern method – for each manhole there are six catchment areas. In this case scenario both, the classical and modern method of defining the catchment areas can be used for analysis and desgning the stormwater drainage system. The difference between the peak flows is Q=52.25 l/s.

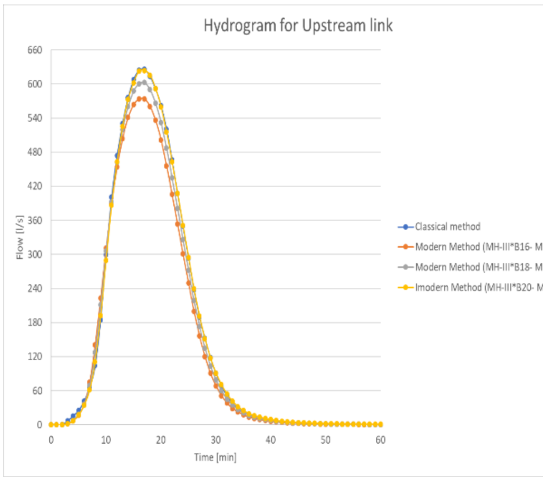

Figure 9. Hydrograms for intermediate link

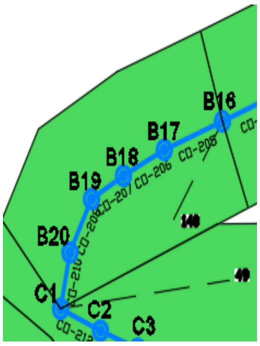

Figure 10. Classical method

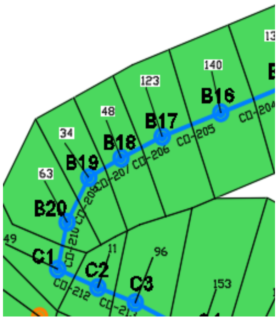

Figure 11. Modern method

7.3 DOWNSTREAM LINKS

On Figure 12. are presented the hydrograms for the downstream link shown on Figure 13. and Figure 14., with total lenght of 172.8m, including 1 manhole, 1 outfall and a pipe between them. Using the classical and modern method it can be concluded that using the classical method there is a bigger peak flow because of the larger catchment area defined. According to the hydrogram from the modern method, the peak flow is less that the other, due to smaller catchment area size, with difference of Q=57.81 l/s. In this case scenario it can be concluded that both of the methods can be used for its analysis and designing, with a note that the modern method generates a smaller peak flow.

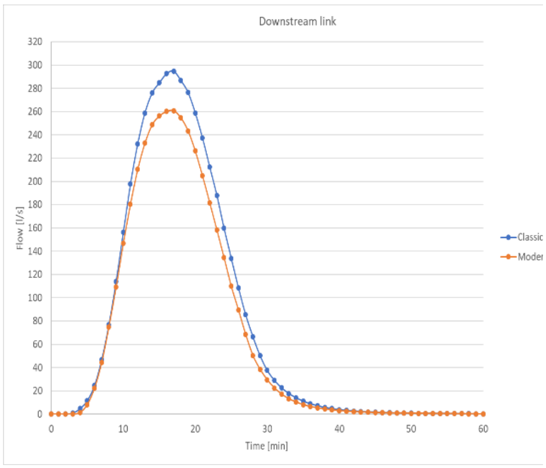

Figure 12. Hydrograms for downstream link

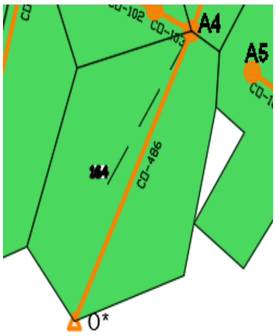

Figure 13. Classical method

Figure 14. Modern method

8. CONCLUSION

The different approaches to defining catchment areas at the upstream links of the system give a larger difference in the peak flows of the hydrograms. When analyzing a stormwater drainage systems, the second method of defining the catchment areas - the modern method (distribution of rainfalls on catchment areas depending on the topography of the terrain, with a main note on its: slope, groundwater, terrain use, elevation, geometric change of terrain, embankments,etc.) can be said to be better for upstream parts of these kind of systems because they allow optimization of the pipe diameters (due to its peak flows). With the help of diametric optimization, lower economic cost of current projects would be obtained. In the case of the intermediate and downstream parts of stormwater drainage systems, it can be said that both the classical and modern methods are suitable for the use of catchment area definitions, as the difference in hydrograms is minimal, thus proving their validity. These recommendations would apply to urban, predominantly plain areas.

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