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COMPARATIVE ANALYSIS OF THE INFILTRATION MODEL IN AN URBAN CATCHMENT

PhD. Stud. I.C. MARŢINCU, PhD. Stud. A. ZABORILĂ, PhD. Stud. I.E. TODIRICĂ, PhD. Stud. PhD. P. STOICA, Prof.PhD. C.R. GIURMA-HANDLEY, Prof.PhD. RALUCA GIURMA-HANDLEY
Technical University "Gheorghe Asachi" of Iaşi, Romania

ABSTRACT: *As urbanization continues to expand due to decreasing of pervious area, there is a need to quantify its negative impacts on the hydrological level. The infiltration properties of the soils and the piezometric level have a direct impact on the hydrological behavior of urban catchments. The variety of these characteristics necessitates the use of appropriate infiltration models and should be included in urban hydrologic modeling. Hence, high accuracy models are a necessity in the management of the urban floods. This paper investigates the variability of the water depth on a urban catchment in Beilen (Netherlands) represented using the GIM. A 2D model was used to simulate the infiltration of water into the ground and model pluvial flows at an urban catchment scale. Water levels were satisfactorily simulated by the model. Comparative analysis reveals soil parameters are very sensitive.*
Keywords: *infiltration; hydrological modeling; urban catchments; drainage; floods;*

1. Introduction

The evolution of human society and the need for water have led to important changes in the water circuit in nature. Currently, humans significantly influence the hydrological cycle, either quantitatively or qualitatively. Local hydrological cycles are influenced by the way human settlements are designed. The impact of urbanisation on the water cycle is essentially linked to the fact that surfaces become impermeable, resulting in a marked reduction in the infiltration capacity of soils and of more vulnerable drainage systems subject to higher and faster water intakes. If urban planning measures are not developed to counter these historic trends, the percentage of rain that is leaking will increase with urban development, inexorably leading to higher flows and drain volumes. This situation, when it happens, will have various repercussions on people and infrastructures, from complaints and complaints to the political and social pressure exerted on the administrators of urban drainage systems, in addition to costs in damages for municipalities.

Infiltration and runoff are significantly processes in the hydrologic cycle. Infiltration is represented by the water movement into the soil terrain from the ground surface downward or the gravitational flow through micro-macro pores and cracks [2]. Infiltration can be limited by restrictions that occur at the surface of the soil or at lower layers. The major factors influencing the rate of infiltration are the physical characteristics of the soil and the cover on the soil surface. The infiltration rate begins when the precipitation event reaches the surface of the land. When the rate of precipitation exceeds the rate of infiltration, the retention and when the surface storage is filled the runoff begins [3]. When the ground surface is impermeable, water can no longer infiltrate the soil, draining very quickly [1].

The catchment basins are classified in different land use types which generate different amount of runoff from the same rainfall event. The runoff process and the infiltration rate directly affected by the land use type [4].

Application and better understanding of hydrological processes are important in order to improve the prediction of magnitude and duration of floods events. The analysis of the water depth requires realistic concepts of Infiltration process and runoff generation and their variation within drainage basins. These concepts need to be refined, developed and formalized [3]. Thus, building accurate models is directly related with the available data needed to describe the system that will be modelled.

The main objective of this study was to perform a sensitivity analysis which include the rainfall, run-off and the infiltration process on the overland flow in order to study the influence of different model parameters and to generate the flood hazard map. Results of the 2D hydrological model of the inundation area were generated. A digital terrain model was needed to create the computerized surface. Aerial images were required to assign surface roughness parameters. The GIM model was created using ICM software.

2. Research location

Beilen village lies in the central-northern part of Midden-Drenthe city administrative area, in Netherlands (as shown in Figure 1). In Midden-Drenthe it rains more often than in the rest of the Netherlands. Due to climate change, rainfall increases in size and intensity, increasing the risk of water on the streets, floods and possible damage. In order to remain a pleasant living environment in the future, the municipality needs a perspective on the effect of precipitation on the environment. Preventing water on the streets is not realistic, but structuring the city in such a way as to reduce inconvenience and prevent damage as much as possible is an important link.

The entire area of the village was modelled and it extends over approximately 3 km2. The village is predominantly urban, with built areas, green zones and vegetated areas evenly distributed. The topography within the catchment varies from 11 to 16 meters above the sea level and the climate is oceanic. The village's yearly temperature is around 11ºC and it is with 0.5% lower than the others Netherlands's averages. Beilen typically receives about 81 millimeters of precipitation and has around 168 rainy days annually.

In general, the impermeable surface of private property in Beilen is high. This is, among other things, the consequence of too

Fig. 1. Location of the study area

few parking spaces in the city, through which homeowners pave their own property to secure a parking space. In addition, private areas are relatively small, through which often a relatively small percentage of the garden is paved. The paved fraction of private property in this research is estimated at 0.3 and is based on observations from the city and aerial images. The value is based on the places in the villagethat have the highest percentage of paved area.

To address these water problems of the study area, efficient drainage systems coupled with technically sound strategies for groundwater management are essential, for which infiltration plays a key role. This study, therefore, focuses on the detailed investigation of infiltration process in the study area.

This study includes a 1D network, consisting of a circular system network with a total of 2190 modes and 2206 conduits. The conduits have the average of the slope of 1% and diameters between 125 mm and 2000 mm, with a total length of 109 km. The surface flow pattern includes 517 subcatchments. The 2D mesh surface contains 3139227 elements.

3. Materials and methods

A) Modelling Methods

To assess the model performance of the proposed GIM model, 4 scenarios were selected. These models were run with different rainfall scenarios (40 mm, 60 mm, 80 mm and 120 mm) to assess the impact of the GIM. Results from models with the highest impact from the GIM are presented, respectively the ones corresponding to the 120 mm rainfall event. This will highlight the importance of the accurate modelling of slow response flows. The hydrodynamic model study the flow from the run-off from the land. The time moment when the peak flow is reached and the volume that reaches the sewerage are important in order to represent a situation that reflects the reality.

The most significantly data necessary for the floods studies are represented by the elevations data. The computational speed of 2D groundwater flow models is largely influenced by the size of the elements in the 2D grid and other software features to represent obstacles, gaps, and interruptions in topography.

The hydrological modelling was performed using the InfoWorks ICM software. For this study a raster file with a high resolution of 0.5 x 05 m was used. This file was preliminary cleared and it contained only the elevations of the terrain. The DTM was formed as a Triangulated Irregular Network (TIN) based on the LiDAR data (fig. 2). The ground model was imported in the ICM model. Heights of generated mesh elements are calculated by interpolation from this ground model. The created mesh was used to model the 2D flows. A dynamic boundary condition has been applied.

Proper discretization of sub-basins is very important in the correct creation of an urban drainage model. They determine the contributing areas to the flow process. Five surface types were defined for the catchment, which are flat roofs, slope roofs, asphalt roads, paved roads and green zones. For their construction, Thiessen polygons were originally created, related to each collection manhole. The subcatchments areas are created based on the land use information (fig. 3). The road fraction was further divided into normal impervious pavement and pervious pavement road. Percentages of impervious surface are generally accounted for by the sum of roof, impervious road and other impervious surface. Creation of subcatchments enables the better comprehension of the distribution of the areas.

B) Hydrology

Impervious and pervious areas were delimitated based on the aerial image. The surfaces for the land use type were created in

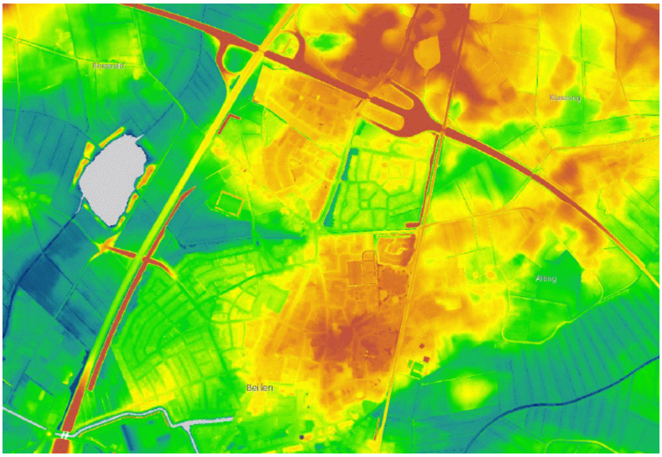

Fig. 2. DEM of the studied area

Fig. 3. Assigned subcatchments within the model

the GIS software. A roughness coefficient and an infiltration loss coefficient was assigned to all surfaces. These are displayed in the table 1. Roads usually have a low infiltration loss, while green spaces would be assigned a higher value. The infiltration capacity of unpaved areas is mainly determined by the nature of the vegetation, the type of soil and the moisture content in the soil.

Four different soil textures were utilized in the model for the green zones. These are displayed in the table 2. The Horton infiltration type was applied for three of the considered scenarios. In these cases the infiltration rate at the beginning of a storm event decreases exponentially with time until it reaches a more or less constant rate. In the second case the infiltration rate is fixed.

The main loads on a mixed or rainwater system are precipitation. The model uses a direct precipitation approach, which consists of applying a precipitation hyetograph to each element inside the 2D surface model. Four uniform rainfall events (40 mm, 60, 80 and 120 mm) with 60 minutes duration and starting at the beginning of the run were aplied with a total simulation of 3 hours to generate the direct surface runoff. The rainfall parameters use for the runs are listed in the below table 3.

Table 1. Roughness coefficient and infiltration loss coefficient applied to the surface

Land use type	Roughness coefficient	Infiltration loss coefficient (mm/hr)
Roads	0.011	0
Parkings	0.02	5
Green zone	0.15	-
Buildings	0.45	0

Table 2. Infiltration coefficient applied to the green zones

Type	Infiltration type	Horton initial (mm/hr)	Horton limiting (mm/hr)	Horton decay (1/hr)
Permeable (medium soil)	Horton	200	12	2
Impermeable	Fixed	-	-	-
Permeable (fine soil)	Horton	125	6	2
Permeable (Coarse soil)	Horton	250	25	2

Table 3. Rainfall parameters modelled

Rainfall event	Intensity [mm/h]	Duration of rainfall event [h]
1	40	3
2	60	3
3	80	3
4	120	3

4. Results

The simulation was applied to a catchment of 3 km2. The model produced results with the flood water depth at regular intervals throughout a simulation. The results of the scenarios was utilized to identify the most sensitive zones to flood where the water depths are significant. The maximum values associated with these outputs were exported and processed in GIS. The results have been processed into flood maps.

The results show that differences appear between all four models even from events with low rainfall. In the figure 4 are displayed the results corresponding to the 120 mm rainfall event. Differences are observed on built surfaces and green spaces. In all cases of precipitation events it is found that the greatest differences occur in the case were no infiltration was considered. Effects of the soil texture type are significant for the water depths and flood extent.

Maximum flood level during the simulation, associated with probability of occurrence, reaches a value of 1.25 m in the narrow areas. Critical water depths are detected in several locations in the studied area. Generally, high velocities were recorded in the zones where roughness coefficient is very small and the infiltration loss coefficient is close to zero.

Differences around 80% in terms of flood extent, 68% in the maximum flood depths and 85% in inundation volume were found. Spatial distribution of inundation flow velocity shows a correlation with the spatial distribution of the elevation within the cathcment. The high values can be accredited to the steep slope of the terrain whiles the low velocities is attributed to the flatness of the terrain.

The results shown variation of moisture content, hydraulic conductivity and soil suction at every time step. Moisture content start to increase when infiltration starts and it continue till to degree of the saturation.

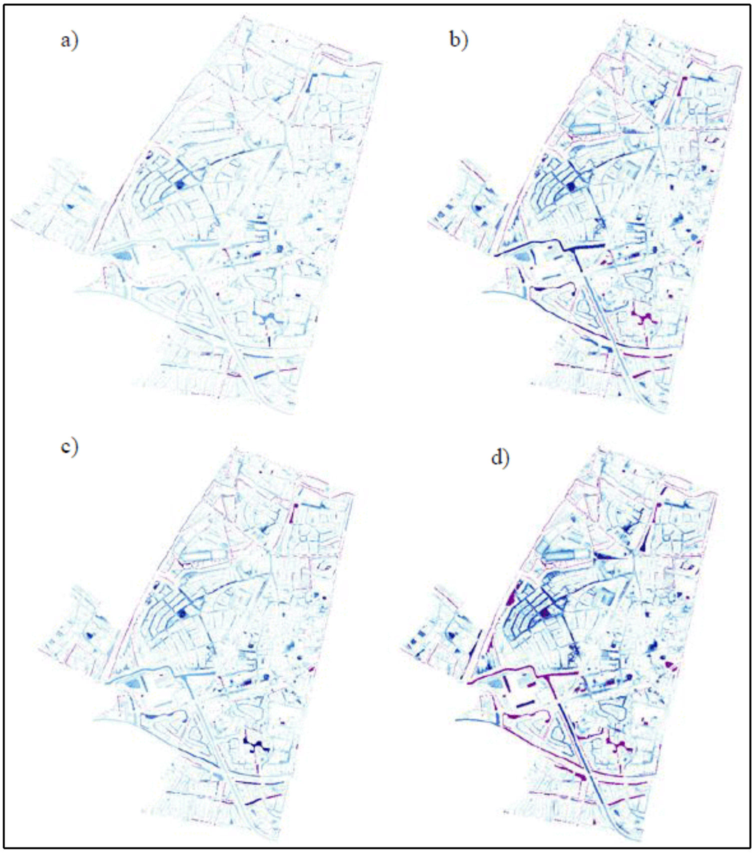

Fig. 4. The extension of the flooded area
a) Coarse soil; b) Fine soil; c) Medium soil; d) Impermeable.

5. Conclusions

Currently, there is no industry standard for implementing the GIM. In order to adequately match the flows, accurate data about the infiltration rate and roughness it is necessary.

The results of the different scenarios have been analyzed and demonstrate the importance of including the infiltration rate in the 2D models. The study has identified that that the variation in the soil texture types affects water depth, the flood extensions and the inundation volume. the It is concluded that developed scenarios performed reasonably well. Comparison suggests the suitability of infiltration model in estimating the cumulative infiltration involving temperature, soil-type, land use and slope of concerned region.

In conclusion, the paper addresses a recently topic, addressing problems related to the assessment of flood zones and the elaboration of a flood hazard analysis. The more models will provide results closer to reality, the more accurate the hazard analysis will be, and the consequences of the floods can be highly reduced, according to the characteristics of the study area.

This field of study opens new perspectives for the development of the urban flood models and has outstanding implications in the analysis and decision-making process for planning. More research is needed to see if this can give appropriate forecast for design events in locations with heavy infiltration.

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