# MODELLING THE URBAN SURFACE WATER IN THE WESTERLO. CASE STUDY

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***Abstract:*** *Over the past century urbanization has increased even if it has known to have several negative impacts towards hydrological cycle due to decreasing of pervious area and deterioration of water quality in storm water runoff. One of the most serious negative impacts of urbanization is the congestion of the storm water drainage system and this situation leading to flash flood problem and water quality degradation. Hence, high accuracy models are required for informed decision making in urban flood management. The study analyses several GIS layers such as high resolution and accuracy raster, land use (buildings, streets, green areas etc.) This paper demonstrated application of the above breakthrough modelling methodology of surface flow under pluvial flooding conditions in urban areas. The primary objective of the study was to develop a document to be used as guidance for eliminating or reducing flooding within the area in consideration of health and safety.*

***Keywords:*** *urban hydrology; surface water; GIS; raster; flood risk;*

## 1. Introduction

The evaluation of the high intensity flood in small basins and the time finding alternatives solutions of their real time estimation are usual interests for hydrologist not only in Romania but worldwide. Torrential rainfall events have the biggest impact in these basins because of their high intensity are favouring the generation of flash flood. There had been developed a number of stochastique and determinist methods for the estimation of the extreme flood in small basins by some researchers. The G.I.S is commonly used as a primarily environment for preparing the input necessary for the development of the hydraulic models and creating maps with the results.

Urban pluvial flooding comprises flooding from direct runoff, sewers and minor urban watercourses, resulting from heavy or prolonged rainfall. In this case water escapes from or cannot enter in the sewer system or urban water channels, thus it remains on the surface and can enter in the buildings.

The main objective of this study was to develop the 1D/2D model in order to generate the flood hazard map for the management of the future flood in the north of Westerlo city and the strategies that are being applied to restore the performance of the network.. Results of 1D-2D dimensional hydraulic modelling of the inundation area were generated. Remotely sensed data were used to derive a digital elevation model and to assign surface-roughness parameters. Also it was used a ICM system to host the hydraulic model; to calculate the steady water-surface elevation; to visualize the flooded area; and to assess flood hazards. The results of this research could be used for flood mitigation planning purposes, regarding to the historical flood threatens in the study area.

## 2. Research location

The case study is located in the north of Westerloo city, Belgium (Figure 1). In this zone the owner wants to expand its workspace in order to test the current situation of the storm water system in case of some heavy rainfall events and to take into account to what extent the system can drain the runoff. Inside the operational center there are a few bottlenecks that are directly linked to the flood risk. The modeled area covers an area of about 4 ha, an area where both built areas and green spaces predominate. Within the study area, the escarpment achieves its biggest height differences (varying from 17 to 28 m) which, in case of a flash flood will accelerate the run-off.

As can be seen from the figure 2, the completely impervious areas represent almost one third of the total area analyzed. The percentages are the following: fully impervious (buildings, roads): 40%; partially pervious (car parks): 38%; and pervious (green spaces): 22%. Run-off will be partially decreased by vegetation.

This study include a 1D network, consisting of a system network with 147 conduits and 148 manholes. The pipes have an average slope of 1% and diameters ranging from 150 mm to 1200 mm, with a total length of 8493 m. The surface flow pattern includes 115 sub-basins with areas ranging from 0.031 ha to 1.831 ha; slopes range from 0.00 m/m to 0.01 m/m with an average slope of 0.005 m/m, and widths varying from 10 m to 76 m. The 2D surface contains 143058 elements.

The purpose of this paper is to test the current situation of the storm sewer network at a certain rainfall intensity, to observe if the system can drain rainwater and to suggest solutions for improving it and how the sewerage infrastructure should work best, taking into account the current situation, planned extensions and flood risk control on the ground.

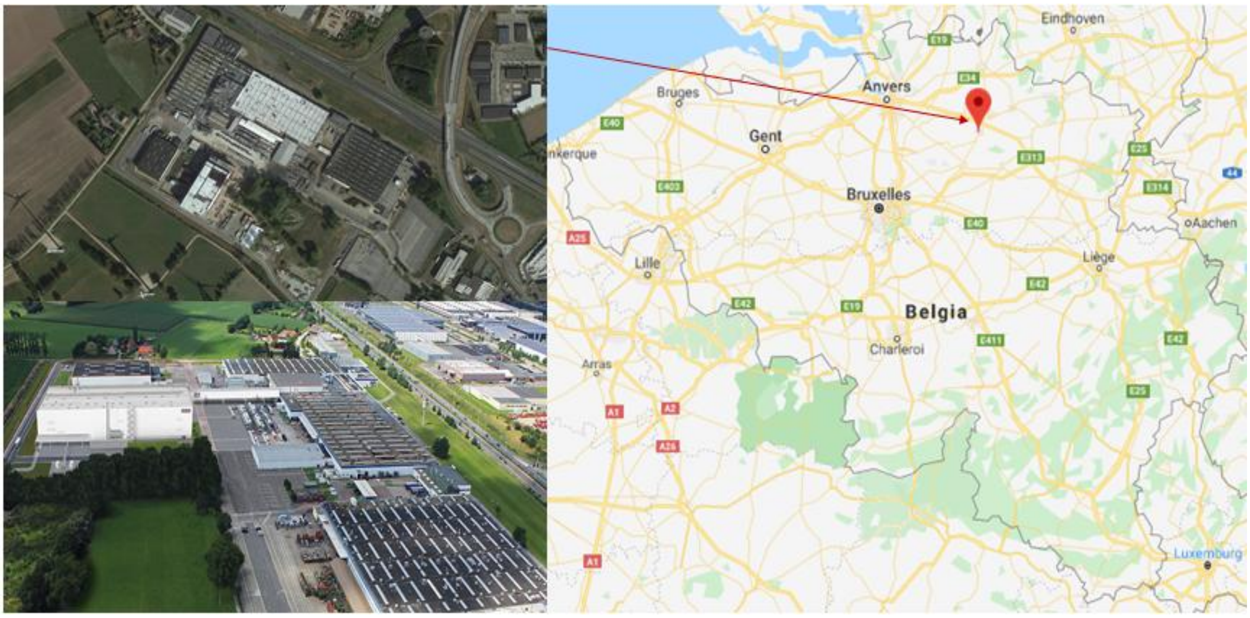


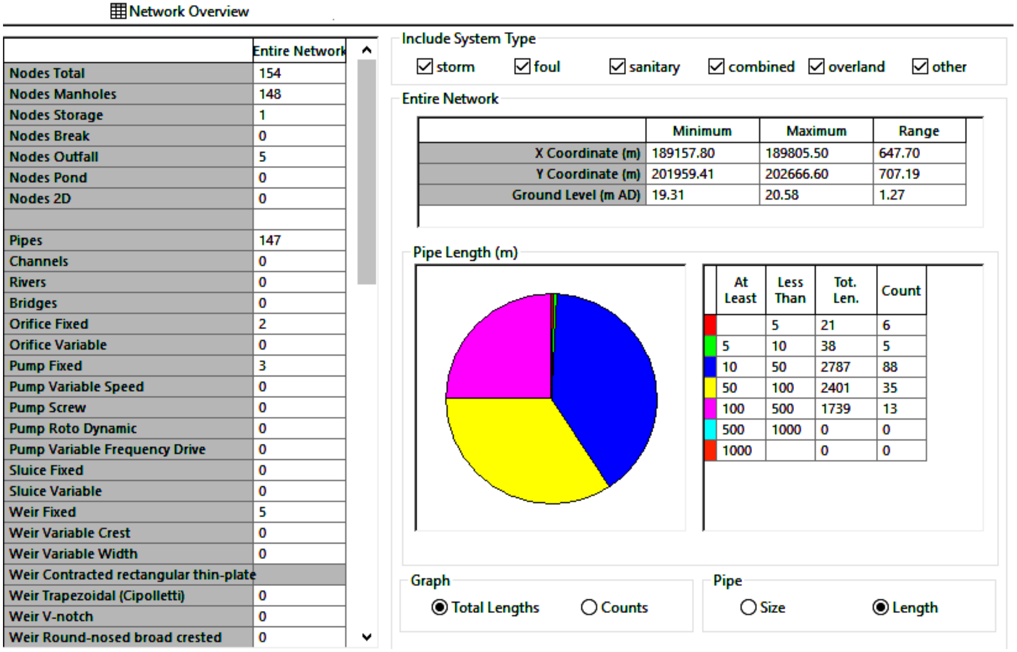
Fig. 1. Location of the study area

## 3. Methodology

### *A) Modelling Methods*

The hydrodynamic modeling study the flow from the run-off from the land to the sewer network simultaneously with the flow coming from the industrial consumer. 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 primary storm water system consists of manholes and pipes that convey flows during the high intensity rains. The conduits were builted based on GIS files that represent the actual situation received from the client and they were included in the ICM model. The schema of this model is represented in the figure 4 and the overview in figure 2.



Network Overview

| | Entire Network |
|---|---|
| Nodes Total | 154 |
| Nodes Manholes | 148 |
| Nodes Storage | 1 |
| Nodes Break | 0 |
| Nodes Outfall | 5 |
| Nodes Pond | 0 |
| Nodes 2D | 0 |
| | |
| Pipes | 147 |
| Channels | 0 |
| Rivers | 0 |
| Bridges | 0 |
| Orifice Fixed | 2 |
| Orifice Variable | 0 |
| Pump Fixed | 3 |
| Pump Variable Speed | 0 |
| Pump Screw | 0 |
| Pump Roto Dynamic | 0 |
| Pump Variable Frequency Drive | 0 |
| Sluice Fixed | 0 |
| Sluice Variable | 0 |
| Weir Fixed | 5 |
| Weir Variable Crest | 0 |
| Weir Variable Width | 0 |
| Weir Contracted rectangular thin-plate | |
| Weir Trapezoidal (Cipolletti) | 0 |
| Weir V-notch | 0 |
| Weir Round-nosed broad crested | 0 |

Include System Type
☑ storm ☑ foul ☑ sanitary ☑ combined ☑ overland ☑ other

Entire Network

| | Minimum | Maximum | Range |
|---|---|---|---|
| X Coordinate (m) | 189157.80 | 189805.50 | 647.70 |
| Y Coordinate (m) | 201959.41 | 202666.60 | 707.19 |
| Ground Level (m AD) | 19.31 | 20.58 | 1.27 |

Pipe Length (m)

| | At Least | Less Than | Tot. Len. | Count |
|---|---|---|---|---|
| 🟥 | | 5 | 21 | 6 |
| 🟩 | 5 | 10 | 38 | 5 |
| 🟦 | 10 | 50 | 2787 | 88 |
| 🟨 | 50 | 100 | 2401 | 35 |
| 🟪 | 100 | 500 | 1739 | 13 |
| 🟦 | 500 | 1000 | 0 | 0 |
| 🟥 | 1000 | | 0 | 0 |

Graph
● Total Lengths ○ Counts

Pipe
○ Size ● Length

Fig. 2. Overview of the 1D model

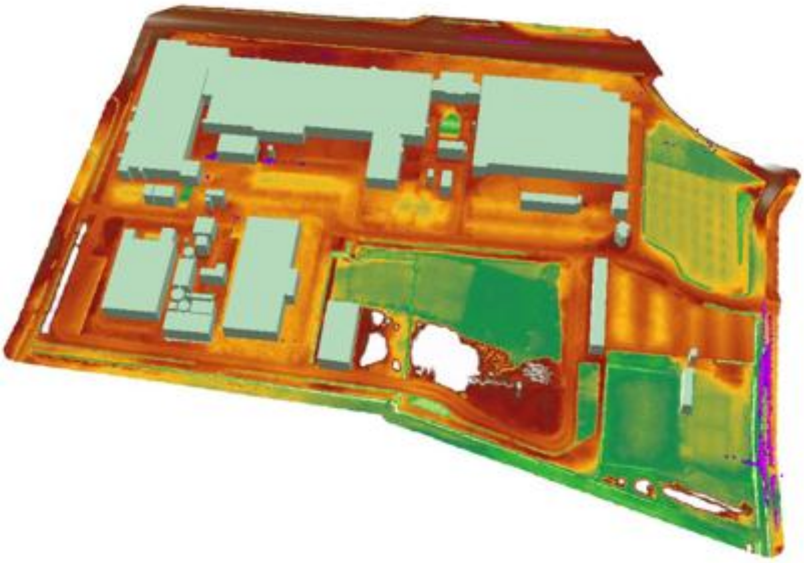


Fig. 3. DEM of the studied area with 3D buildings

The raster file 0.5x05m was cleared and it contain only the elevations of the terrain. The DTM was formed as a Triangulated Irregular Network (TIN) based on the LiDAR data (fig. 3). The LiDAR data are most precise in modelling the ground models that are used for the urban flood modelling. Where the capacity of the modelled storm network is exceeded, flows then spill out onto the 2D surface and are routed overland by the 2D surface model. The flood type of the nodes where set on “Gully 2D” to simulate the interaction between the sewer system into 2D model. A dynamic boundary condition has been applied.

The subcatchments areas are created based on the land use information (fig. 5). As local basins and sinks (the lowest cell in each basin) are found based on the flow accumulation and direction results, the total amount of rainfall for each basin is calculated. Creating subcatchments enables better comprehension of endangered areas and finding the lowest cells (sinks) within them makes the next step possible.

Fig 4. Sewer network model

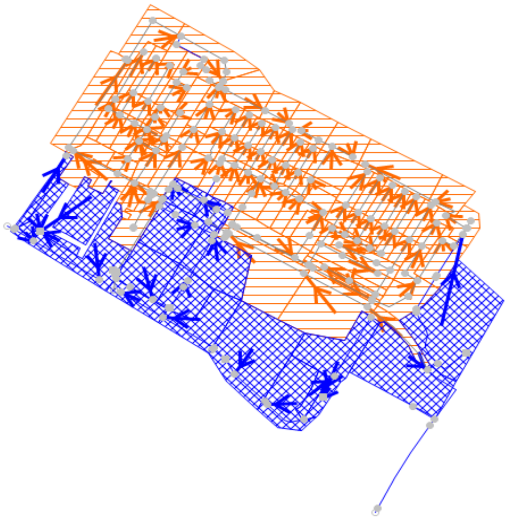


Fig. 5. Assigned subcatchments within the Geoplan

***B) Hydrology***

Impervious and pervious areas were calculated based on planning zones, road parcel boundaries and aerial imagery. The surfaces for the land use type were created using GIS. All impervious areas were assigned a roughness coefficient and an infiltration loss coefficient. These are displayed in the table 1. Tidal areas may in general be expected to exhibit lower roughness than fluvial reaches due to the finer sediments in the channels. Roads usually have a low infiltration loss, while green spaces would be assigned a higher value.

Tab. 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 | 15 |
| Buildings | 0.45 | 0 |

Flood modelling was performed with a simulation driven by 3 storm rainfall events. The rainfall parameters are listed in the above table 1. The rainfall events were used to create output files with the ICM model. The rainfall events are spatially uniform thus the rainfall will fall over the entire modelled area with the same intensity, but not uniform in time due to the peak in the events.

Tab. 2. Rainfall parameters modelled

| Rainfall event | Intensity [mm/h] | Recurrence time [year] | Duration of rainfall event [h] |
|---|---|---|---|
| 1 | 10.5 | 0.25 | 48 |
| 2 | 19.8 | 2 | 48 |
| 3 | 60 | 100 | 48 |

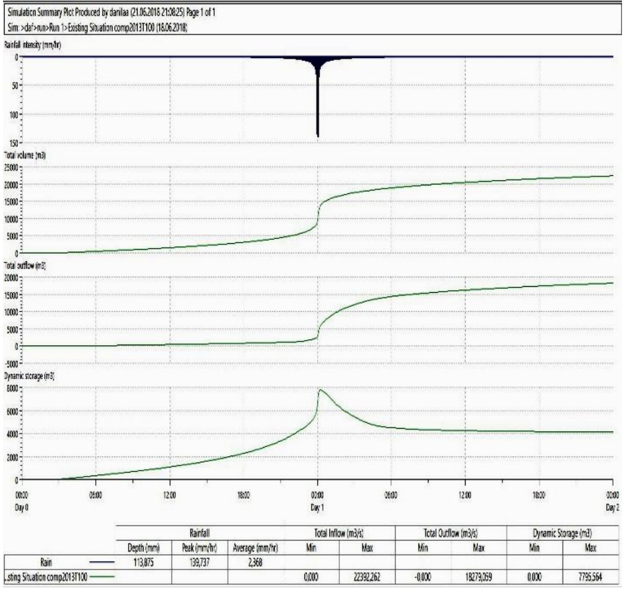
A coarse mesh element size of 669324 m$^2$ is applied on the floodplain. This capture the detail of small channels and other floodplain features such as banks, it allows fast simulation of long time series events whilst maintaining the volume of tidal flows onto the floodplain. The mesh size decreases significantly in the area of the channels, so that individual bank features are captured in the 2D mesh.

The model was calibrated with measured flood depths observed at the site during flood events to ensure that the forecast were realistic. Hydrology data were readjusted to get a good match between the model-predicted flood depth and measured/observed flood depth.

## 4. Results

The hydraulic model realized with InfoWorks ICM can produce both 1D and 2D results. This model has been run for one-in-two year's synthetic rainfall event and compared. The simulation was applied to a catchment of 4 ha. The evaluation of the flooded and unaffected buildings for existing and proposed scenarios at different rainfall events was performed. The results of the scenarios was utilized to identify the most sensitive zones to flood where the water depths are significant.4

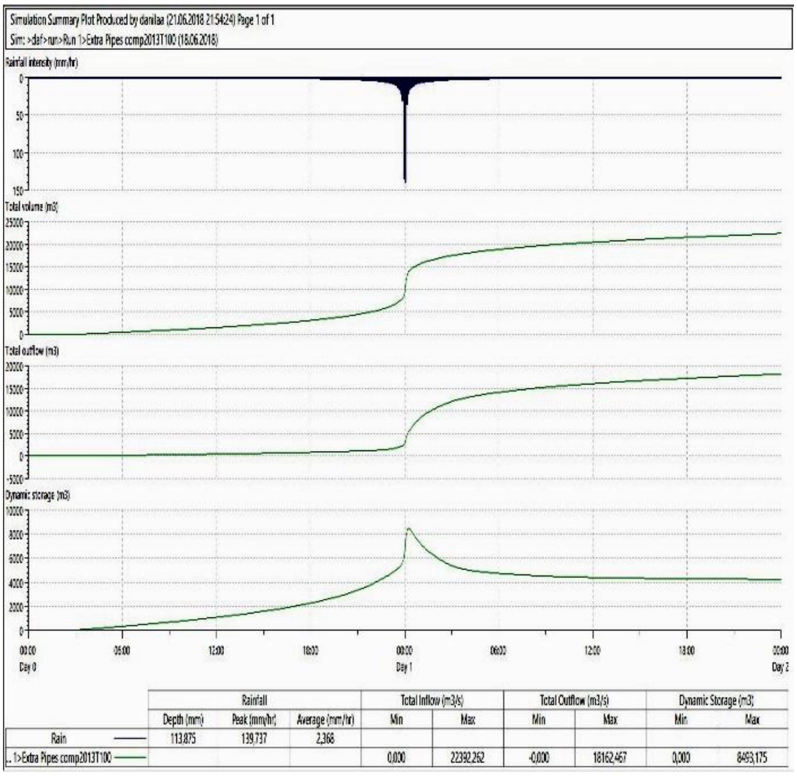
The 1D results are in the form of discharge, velocity and water level time series for each section included in the model. The model can output 2D results, such as flood level, depth, velocity and hazard at regular intervals throughout a simulation. The maximum values associated with these outputs have been produced as 2D grids of 2m resolution. These 2D grids have been processed into flood maps.The modelling summary report of the output parameters for depth, speed and risk for both scenarios are represented below.



Simulation Summary Plot Produced by danilaa (21.06.2018 21:08:25) Page 1 of 1
Sim: >daf>run>Run 1>Existing Situation comp2013T100 (18.06.2018)

| | Rainfall | | | Total Inflow (m3/s) | | Total Outflow (m3/s) | | Dynamic Storage (m3) | |
|---|---|---|---|---|---|---|---|---|---|
| | Depth (mm) | Peak (mm/hr) | Average (mm/hr) | Min | Max | Min | Max | Min | Max |
| Rain — | 113,875 | 139,737 | 2,368 | | | | | | |
| sting Situation comp2013T100 — | | | | 0,000 | 22392,262 | -0,000 | 18279,059 | 0,000 | 7795,564 |

Fig. 6. Modelling report for the existing situation



Simulation Summary Plot Produced by danilaa (21.06.2018 21:54:24) Page 1 of 1
Sim: >daf>run>Run 1>Extra Pipes comp2013T100 (18.06.2018)

| | Rainfall | | | Total Inflow (m3/s) | | Total Outflow (m3/s) | | Dynamic Storage (m3) | |
|---|---|---|---|---|---|---|---|---|---|
| | Depth (mm) | Peak (mm/hr) | Average (mm/hr) | Min | Max | Min | Max | Min | Max |
| Rain | 113,875 | 139,737 | 2,368 | | | | | | |
| .. 1>Extra Pipes comp2013T100 | | | | 0,000 | 22392,262 | -0,000 | 18162,467 | 0,000 | 8493,175 |

Fig. 7. Modelling report for the proposed situation

Hazard maps related to flow depths, velocities and the combination of both flow parameters were generated. For the current scenario these maps were elaborated obtaining the results shown in the figure 8, 9 and 10. It is possible to observe that the depth of the water in most of the areas reach 0.25 m.

Figure 10 shows the extent of peak flood depth for 1:2 years rainfall event frequency across the logistic center. The simulation was run on 2 days. The maximum flood level during the simulation, associated with probability of occurrence, reaches a value of 1.25 m in the narrow areas. The critical water depths are detected at several locations in the project area and can be seen in the figure 8. The total flood area generated by this event covers an area of about 0.78 ha and this represent almost 20% of the entire area and can be considered a significant flooded area.

Fig. 8. Peak flood depth for one-in-two year's probability: a) current situation b) proposed situation

The simulation produced variable flow velocities in the inundated floodplain of the 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. The model results gave a minimum velocity of 0.015m/s to a maximum of 1.25m/s with high velocities occurring mostly in the paved areas (see Figure 9). The spatial distribution of inundation flow velocity of the catchment shows a correlation with the spatial distribution of the elevation. 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.

Fig. 9. Flood flow velocity for one-in-two year's probability: a) current situation b) proposed situation

The flood hazard maps are very important in terms of developing the flood risk map. For this, two basic hydraulic parameters (depth, velocity) are used to calculate the flood risk. From the multiplication of this 2 hydraulic parameters h x v (water depth x water velocity) result the qualitative flood risk. Depending on the value of the multiplication of these 2 parameters, the flood risk can be low, medium or high. In the figures 10 the flood risk maps are illustrated. The maximum reached value for the risk associated with a flood that appears once in 2 years is 1.75.

Fig. 10. Flood risk map for the one-in-two year's probability: a) current situation b) proposed situation

*Solutions to avoid the flood risk – proposed scenario*

The analysis of the causes that produce the failures is of the utmost importance in determining the measures that need to be taken. These causes are multiple and they can occur in different life cycle stages, depending on the type of the material that pipes are made of, on the calculation, execution and technical maintenance conditions, on the flows that they are submitted during their life cycle. Knowing the causes is mandatory in order to be able to take the right correction measures for the remediation of the failures. If the causes are obvious the measures can be taken immediately.

The objective of the considered scenario in the proposal of the technical solution is to reduce the volume of storm water runoff to the surface and must be taken over by the centralized sewerage system. Essentially, with these measures, the storm water flow will be practically reduced and will delay the storm water entering the sewage system.

The technical measure proposed to avoid the risk of flooding is to place a number of pipes in the most vulnerable areas that will facilitate the drainage of storm water in the shortest possible time. The maps with the results for this scenario were putted aside to the maps with the results for the current situation to be observed the differences between the two scenarios. Thereby in the current situation the flood plain covers of about 7865 m$^2$, the volume of the water that stay above ground level is 4419.80 m$^3$ and the maximum peak flood level is 0.75 m. In the proposed situation the flood plain covers an area of about 4797 m$^2$, the volume of the water that stay above ground level is 2702.10 m$^3$ and the maximum peak flood level is 0.5 m. Thus if the solutions that were proposed will be taken into account the flood plains will be reduced even with 60%.

Thus, in the northeast area of the logistics center it is recommended to supplement the existing system by adding a number of 7 pipes with a diameter of 300 mm and a pipe of 400 mm. The first collects the overflow of water that cannot be taken over by the sewerage network in this area during rain events with a probability of 0.02% and introduces it back, through the 700 mm pipe, into another branch of the system. The pipe contain a flange with a retaining flap at the upstream end. The locations where solutions need to be applied is represented in the figure 11.

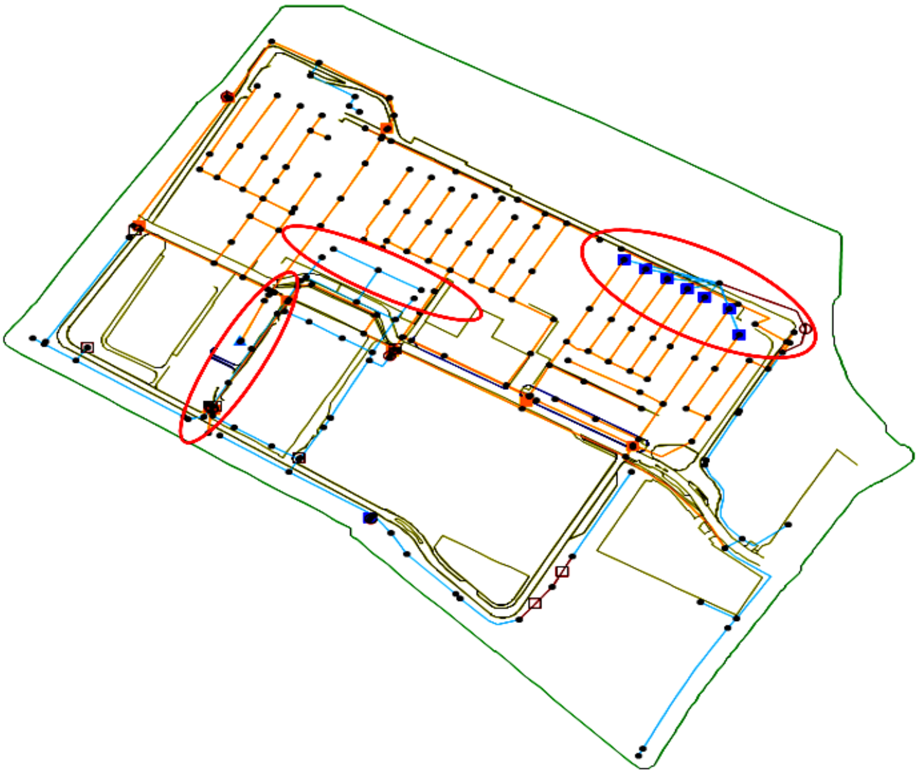


Fig. 11. Locations where solutions need to be applied

In the case of the proposed scenario, solutions have been offered to improve the drainage system in order to reduce the volume of rain water which need to be taken over by the sewerage system. These can have significant effects in reducing the flood plain extent in the area we have analyzed if will be implemented.

## 5. Conclusions

This paper includes documentation and studies with the respect to the use of the GIS technology for the assessment and simulation of the run-off in risk cases for a study area in the city of Westerlo. This new field of study which opens and creates new perspectives for the development and assertion of the specialists in urban flood models, has outstanding implications in the analysis and decision-making process for planning the works related to the maintenance, repair and replacement of the storm network system, and implicitly substantial cost savings.

The hydrological modeling was performed using the InfoWorks ICM calculation software. This program allowed to model the hydrological and hydraulic processes in the studied area in a single integrated catchment model. The integrated model can be considered as an aid tool in flood risk management and can be used at a high level to evaluate potential flood mitigation options.

In conclusion, the paper addresses a recently topic, addressing problems related to the assessment of flood zones, the elaboration of a flood hazard analysis and the proposal of a scenario for improving the sewerage system in order to reduce the flood risk. The more the models resulting from the flood modeling 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.

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