Assessment of urban drainage system using 1D and 2D simulation at urban basin in Brasília - Brazil

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Highlights

- The 2D model created by using PCSWMM, not widely used in Brazil.
- The drainage systems studied should be modernized using LIDs over the basin.

Introduction

With the expansion and growth of cities worldwide, urban drainage has become a critical problem needing new and creative solutions that can integrate with sustainable ideas. Urban infrastructure modifies the hydrological cycle, leading to an increase of surface runoff volumes and peak flows, amongst other problems (Butler and Davis, 2017). This results in more frequent and more critical floods, which in return will affect negatively the quality of life (health included) for those living nearby. Therefore, some measures have been designed and implemented under different names such as LID, SUDs, BMP's or Green Infrastructures (Fletcher et al, 2014).

In addition to adopting these measures, there is a need for using mathematical modelling capable of representing the studied area and simulating critical events as well as running different scenarios. Without the correct model, one may overlook some problems or sensitive areas as well as sometimes oversizing the actual problem – which although it can help with the flooding, it will do so without being economically sustainable.

The present paper analysis two adjacent areas in Guará, Brazil, one with an existing urban drainage system that has an oversized detention pond at the outlet and an area without any urban drainage system. For the latter a system was designed using SWMM (respecting local and federal laws and recommendations) in which the surface runoff is conducted to the pre-existing detention pond. By using this model, it is shown that the current detention pond can still operate very effectively with this new added area. With the 2D surface water modelling it is shown that there are some sensitive places in the urbanized areas that the 1D modelling was unable to highlight.

Methodology

Study Area

The study area is very close to an existing detention pond located at the Ezechias Heringer park, located in Guará, Federal District – Brazil. This detention pond was originally used as a wastewater treatment pond discontinued in 1993. In 2007 it was redesigned to work as a detention pond. Therefore, its sizing was pre-defined and this is why it is oversized as shown in local studies.

In this study, two urban areas were analysed. One that already have a drainage system working since 2009 and the stormwaters are discharged into the already mentioned detention pond. The other studied area although fully developed, does not have drainage pipe network or LID system implemented.

Drainage System Model

The study was developed using PCSWMM 2D, developed by CHI WATER, that is able to simulate surface runoff regarding the impact of different land urbanization and with the use of a detention ponds. For calculating the infiltration, the Curve Number (CN) method was adopted.

For the whole studied area there is available imaging with less than 10 cm spatial resolution. A land use map was created using supervised classification with QGIS, using a Semi-Automatic Classification Plugin. This evaluated every pixel from the image and classified them into four created classes: Field, Exposed Soil, Urban Areas and Street.

Two rainfall events derived from a local IDF curve were used, as recommended by local regulation. The design rainfall is based on the IDF with a return period of 10 years and 5 minutes time intervals using the alternating blocks method. The duration time recommended for the design rainfall is 24 hours for drainage system and pond evaluation. For drainage network design a critical duration time can be assumed as equal to the catchment concentration time. In this work, Carter method was adopted for concentration time evaluation (Silveira, 2005). Therefore, for each watershed there is a different critical rainfall.

With the available LiDAR data and by using a GIS, a DTM (digital terrain model) was built. With this DTM and the rainfall events, a drainage system design is proposed according to the local legislation in order to evaluate the stormflows generated.

To calculate the wave routing, PCSWMM uses the Saint Venant equations with different possible alternatives. Dynamic wave propagation was adopted. Although 1D modelling with PCSWMM can identify where in the drainage system overloads occur, to analyse the surface water flow paths through the flooded areas, a 2D analysis is needed.

PCSWMM Pro can integrate 1D-2D models. It couples the 1D drainage system with a 2D mesh created using a DTM. As external boundary watershed contour itself was used so that both areas surface floods can interact. The geometry of the mesh chosen was hexagonal – as recommended by CHI WATERS for urban areas. The spatial resolution of this mesh shouldn't be less than 2 meters, but the recommended by CHI WATERS is usually 5 meters (this was the one used). PCSWMM then creates a virtual manhole on the centre of this hexagon and integrates the model by connecting each real existing manhole to the closest virtual one.

Results and discussion

the results of the 1D analysis on PCSWMM for the rainfall events (critical and design rainfalls indicated where are the points where the drainage system used is overloaded and the duration of this occurrence. It is also possible to analyse how the detention pond worked with both watersheds using it. The maximum stormwater flow at the exit of the pond was up to 3% of the entrance value.

In the watershed that already had a drainage system the simulation indicated that there was points of overload (42% of the totality) producing up to 63,618 m^3 of overflow water (for the design rainfall) in this area and a specific manhole was flooded for up to 12.4 hours. For the watershed with the designed stormwater network, no points of overload occurred – as expected considering that the system was designed adequately.

The 2D analysis is important for decision making processes because it shows where there is a need for LIDs or other interventions. It also showed that although the watershed with designed drainage network presented no manhole flooding, the 2D model simulation indicated that the superficial flood created in one watershed goes into the other producing an induced flooding.

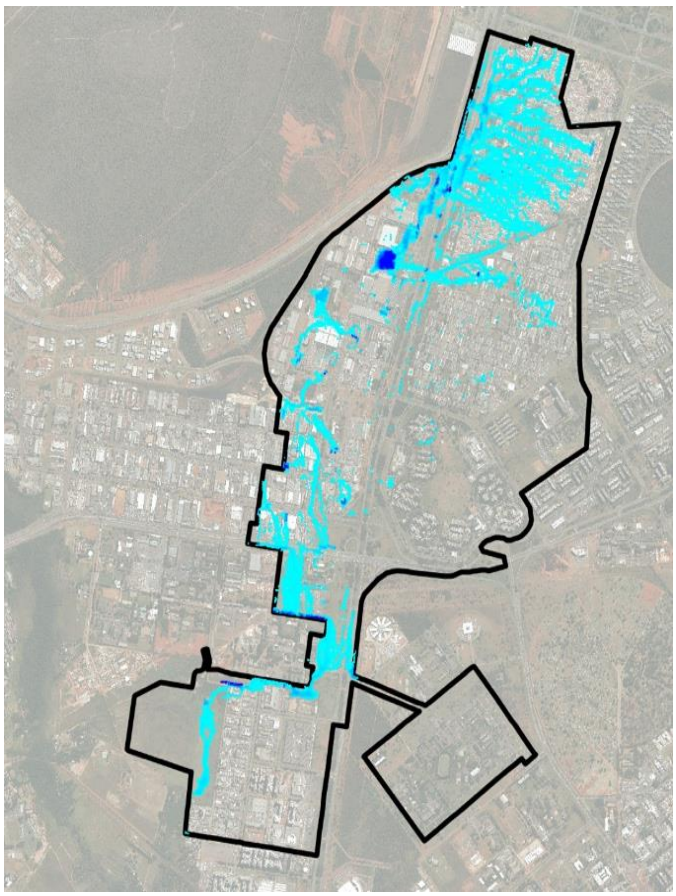

Figure 1. The 2D result using PCSWMM. The boundary is shown with a dark black mark and the flooded area in blue. The darker the blue the worst the flooding is.

Conclusions and future work

Although the drainage system designed for one of the watersheds showed no flooding in the 1D analysis, there is a flood occurrence on the 2D simulation caused by the surface runoff from the upstream watershed. This is important for decision making and urban planning showing that the new system must take into account the whole watershed.

The main results were very significant as it shows where flooding occur, for how long they can persist (up to 12.4 hours) and the total overflow volume (up to 63,618 m^3). The detention pond was able to reduce the stormwater flow peak to 3% of its original value, well below the local legislation limits.

For future work it is recommended to analyse if there are other surrounding areas that can also have their stormwaters sent to this detention pond, as it is still working below it is maximum capacity.

Acknowledgement

We acknowledge CHIWater for PCSWMM licence, NOVACAP, TERRACAP and ADASA for the data.

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