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EVALUATION OF ALTERNATIVES FOR REDUCING FLOW PEAKS IN AN URBAN WATERSHED

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ABSTRACT: The lack of planning about the increasing urbanization processes, mainly regarding the irregular occupation of riverbanks and hillsides, the channelization and straightening of river beds and the soil sealing has caused, among others environmental problems, the reduction in rainwater infiltration. The reduction in the infiltration and the increment in the runoff fraction result in increased flows during rainy periods, contributing to flood occurrence. These factors can be potentialized if the disorderly occupation occurs in an urban watershed where critical morphometric parameters are observed, like high values of circularity ratio. This study aims to evaluate the efficiency of alternatives implementation that lead to amortization of flow peaks responsible for flooding thorough different scenarios based on simulation of hydrological processes occurring in an urban watershed. Analyses were performed with the Hydrological Modeling System (HMS) software, developed by the Hydrologic Engineering Center (HEC) of US Army Corps of Engineers (USA) and the ArcGIS software, among others. As a case study, simulations were done in a watershed with great historical problems of flooding events and which comprises the city of Uberaba, located in Minas Gerais State, Brazil. The simulations shown that the implementation of individual measurements, such as, channels cleaning, intervention in agricultural areas and the construction of reservoirs, if taken in isolation, have negligible changes in peak flows. The evaluation of an already constructed reservoir that has a superficial area of 101,640 m² indicated an efficiency of 4% in peak flow reduction. The set of measures to improve infiltration in urban area, through implementation of green roofs, permeable pavements, percolation basins and reforestation, associated with reservoir construction in areas still available in the urban space, showed a satisfactory result, reducing the observed peak flow in 18%, besides the delay in time of concentration. It can be concluded that, in these cases, the combination of structural and non-structural measures should be prioritized in public management, as flood effects are related not only to natural resources degradation, but also, represent a public health problem, having significant impacts in social, economic and environmental areas.

Key Words: Flow peak, HEC-HMS, Urban flood, Urban Watershed

1. INTRODUCTION

The lack of planning about the increasing urbanization processes, mainly regarding the irregular occupation of riverbanks and hillsides, the channelization and straightening of river beds and the soil sealing has caused several environmental problems.

In a flood context, the urbanization tends to reduce infiltration and increment the runoff fraction, increasing peak discharge, decreasing the time taken for the flood discharge to reach its peak, and to magnify the volume of runoff, what can increase the occurrence of extreme events (Campana and Tucci, 2001; Kulkarni *et al.*, 2014). These factors can be potentialized if the disorderly occupation occurs in an urban watershed where critical morphometric parameters, highly correlated to the hydrologic behavior of the watershed, are observed (Aher *et al.*, 2014). Therefore, the increasing flood risk has become a serious problem in many parts of the world (Guhathakurta *et al.*, 2011). In Brazil, many cities of southeastern, where the infrastructure and production systems have been settled on the alluvial plains, suffer the impacts of the flood events (Stevaux *et al.*, 2009). Sometimes, the cost of controlling flood drainage after areas have been urbanized are considered high and most municipal districts do not have sufficient funds to build the necessary protection works (Campana and Tucci, 2001).

Therefore, for minimizing future damage and controlling costs, it is necessary to stimulate the preventive control, accomplished by predicting the impacts from potential urban developments, and planning control measures at an early stage (Campana and Tucci, 2001). Where limited or no discharge data is available, hydrological modeling can be an useful tool to estimate the watershed's hydrological processes to support these decisions (Hunukumbura *et al.*, 2008). This study aims to evaluate the efficiency of the implementation of alternatives that lead to amortization of flow peaks thorough different scenarios based on simulation of hydrological processes occurring in an urban watershed.

2. MATERIALS AND METHODS

2.1 Study area characterization

The study was accomplished in the urban watershed which is localized Uberaba-MG (Figure 1). Uberaba is one of the most important economic city from Triângulo Mineiro region. It is located in the west of Minas Gerais State, Brazil and has a population of 295,998 inhabitants according to the Brazilian Institute of Geography and Statistics (IBGE) cense (IBGE, 2009). There are two climate regimes in the region: a cold and dry winter and a hot and rainy summer. The rainfall regime is characterized by a rainy period from October to April, and by a dry period from May to September (Silva *et al.*, 2003). The average annual precipitation is 1400mm, with December and January as the rainiest months during the year, concentrating 34% of the average annual precipitation (CODAU, s.d., p.18).

The city is inserted in rio Grande and rio Paranaíba watersheds, to which belong the Uberaba River and the Tijuco river, respectively. The stream that runs through the city and is often involved in flood events is the stream of Lajes, a tributary of the Uberaba River. The Lajes stream watershed has a roughly circular format with steep slopes, associated to the following morphometric characterization: form factor = 0,356; circularity ratio = 0,366; compactness constant = 1,640 and drainage density = 0,959. It promotes extremely quick rainfall drainage to the main river, causing nearly simultaneous flow peaks of the sub-watersheds, overloading the main drainage system (Uberaba, 2009).

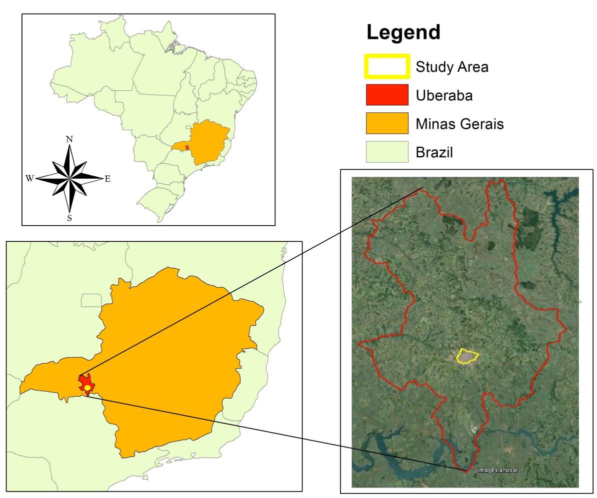


Figure 1: Location of study area.

With the urbanization of Uberaba city, Lajes Stream and its tributaries were channeled in concrete galleries with high slopes (around 1%). These galleries compose the city macro drainage system and above them were built the roads. Flood events in the main avenues and consequently in the central region of the city became more frequently with the increase of impervious areas and the urbanization process.

In order to minimize the frequently flood events in the central area of Uberaba, a reservoir was built at the head of Lajes Stream Watershed. However, the complexity of the factors involved in this problem and the continuity of flood events, even after the reservoir construction, show up the need of a more specific investigation into alternative forms of intervention. These alternative forms of intervention should objective besides the retention of runoff volume, the increasing of rainfall infiltration and also the optimization of flow along the channels.

2.2 Input data

The hydrological processes were simulated in the Hydrological Modeling System (HMS) software, designed by the Hydrologic Engineering Center (HEC) of US Army Corps of Engineers (USA) to simulate the precipitation–runoff processes of dendritic watershed systems (USACE, 2000). A summary of the used methodology is described in Figure 2.

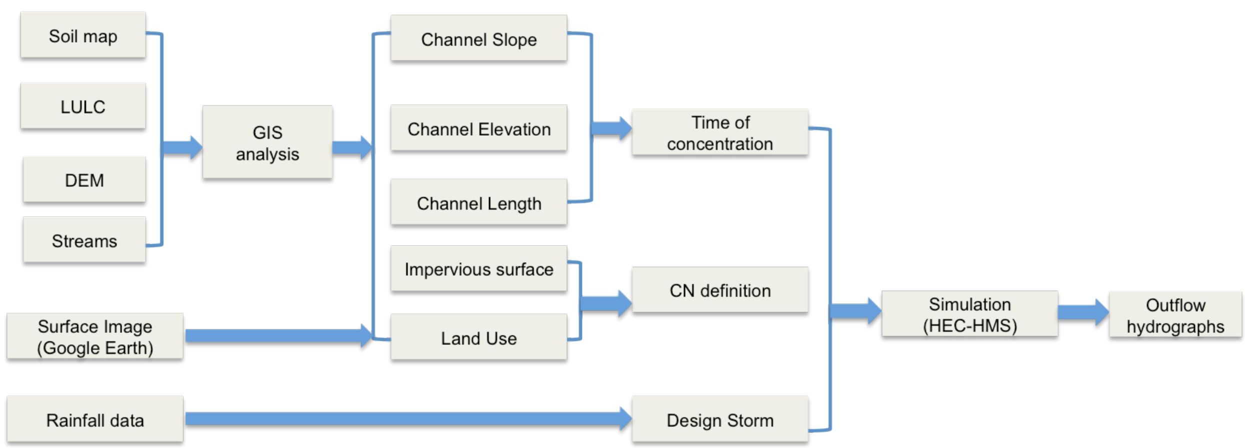
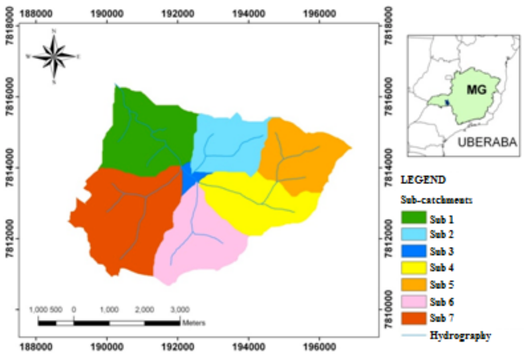


Figure 2: Summary of the method. LULC - Land Use and Land Cover; DEM - Digital Elevation Model; GIS - Geographic Information System

Precipitation data was obtained from the National Water Agency pluviometric station, code 1947016 (-19°46'0''; -47°56'0'), with 32 years of data (1966-1998), through the hydrological system information (HIDROWEB). To estimate the value of precipitation height related to the design rain, the software HEC-SSP (Statistical Software Package) was utilized. The precipitation height resulted from the statistical analysis in the SSP software was 149mm for a rain with 50 years of return period and 160mm for a rain with a return period of 100 years. In the simulation we considered the 100 years rain, as the value of the 50 years was lower than the maximum rainfall registered in the precipitation database (157mm), in order to guarantee greater security to the simulation. The watershed was divided in subwatersheds as show in Figure 3. The land use and land cover within each subwatershed can be observed in Figure 4.



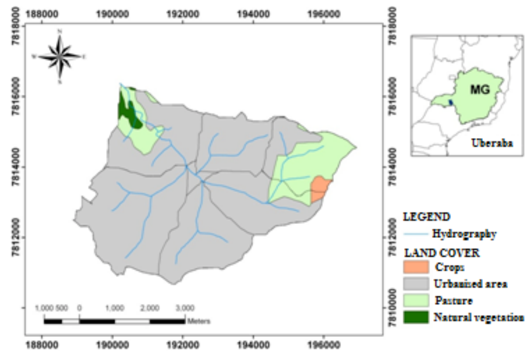


Figure 3: Definition of the subwatersheds.

Figure 4: Land use of the studied watershed.

The storm runoff was estimated with the Curve Number (CN) method, which enables spatially distributed infiltration calculations. In this method, infiltration capacity is quantified in a parameter derived by the Soil Conservation Service (SCS) called the CN (US SCS, 1986). As the input data for the CN determination were used: antecedent soil humidity, soil type and land use category (percentage of each land use). In order to simulate critical flood scenarios, we assumed the largest resulting values, referring to AMC III condition (soil saturated or near saturation). The time of concentration was calculated through Kirpich I and Kirpich II Methods (Kirpich, 1940). To obtain the runoff volume, the direct method of transformation of precipitation in flow, based in the SCS Unit Hydrograph Method was used. Originally design for small agriculture watersheds in United States, this method was chosen as an alternative to simulate the conditions to minimize flood effects. Moreover it is appropriated for the drainage areas of the subwatersheds (areas greater than 2.5km²). As Lajes Stream Watershed covers the urbanized area of the city, it can be stated that the resulted hydrograph will be formed by a single peak, fitting the assumptions of the method. Due to the lack of flow measurement stations in the watershed, the lag time (t_{lag}) used in SCS Unit Hidrograph Method was calculated as 60% of the time of concentration, according to Technical Reference Manual Software HEC-HMS 3.4 instructions (Feldman, 2000). To represent the full propagation condition on channels the Muskingum-Cunge Method was used.

The meteorological method adopted to reproduce the design rainfall was the “Specific Hyetograph”, obtained through the temporal distribution of the precipitation height of a hypothetic 1 day storm. The temporal distribution of the estimated unit value using the method proposed by Huff (1990) was required due to the absence of flow measurements in the watershed. The simulation was performed in scenarios where alternatives have been proposed to minimize flood peaks.

2.2.1 Scenario 1: Reference Scenario

In order to consider the impact of the already existing reservoir, it was included in the simulation through the component “reservoir”. The input parameters were obtained based in the Google Earth images (between July and August, 2011) and based in information disclosed by the city of Uberaba (Uberaba, 2009). The current scenario of the watershed was represented by adding the elements: subwatershed, channel, node/junction and reservoir (Figure 5).

According to the original project, the reservoir has two units in sequence, the first one to store water from a drainage area of 4.15 km² and the second for a drainage area of 0.91 km² (Uberaba, 2009). For the purpose of simulation, we considered one reservoir, equivalent to the sum of the two units (R1). As this reservoir is already constructed, this scenario was taken as reference and for further comparisons.

2.2.2 Scenario 2: Change in land use management (pasture reforestation and adoption of conservation techniques in agricultural area) and intervention in stormwater channels

Scenario 2 comprises the adoption of measures that favor the infiltration of water into the soil through intervention in non-urbanized areas of the city, without changing the land use. We suggested the reforestation of pasture areas and adoption of conservation techniques in areas not yet occupied, like vacant, abandoned or degraded areas.

For the evaluation of the impacts of these measures in the resultant flow, new CN values were entered in the simulation, calculated through the replacement of 50% of the areas of "pastures or land in poor conditions" for "woods or forested areas with good coverage" and 100% of cultivated areas "with no soil conservation" for cultivated areas "with soil conservation". CN values obtained for this scenario are presented in Table 1, as well as the CN values adopted for Scenario 1.

Table 1: CN values for Scenarios 1 and 2.

	Scenario 1	**Scenario 2**
Sub 1	83	73
Sub 2	95	95
Sub 3	95	95
Sub 4	92	92
Sub 5	88	77
Sub 6	95	95
Sub 7	95	95

For the simulation of a possible intervention on channels, were considered two measures: channels clearing and the increase in the cross section of the main drainage channels, from 5 meters of diameter to 7 meters. The modified parameters and Manning coefficient for Scenarios 1 and 2 are presented in Table 2.

Table 2: Parameters for Manning coefficient for Scenarios 1 and 2.

	Scenario 1	**Scenario 2**
Material	Concrete	Concrete
Degree of irregularity	Small	Small
Effect of obstructions	Small	Negligible
Size of vegetation	Low	Low
Interference in the path	Regular	Small
Manning Coefficient	**0.035**	**0.016**

2.2.3 Scenario3: New reservoirs, increase in urban area permeability and previous set of measures

Possible areas for new reservoirs constructions were identified based in city aerial images, through Google Earth program. For this scenario was proposed the construction of two reservoirs along the watershed (R3 and R4), for being strategic locations regarding availability of installation and storage capacity.

These two reservoirs were included in the simulation according to Figure 6. The adopted dimensions are described in Table 3, suggested through area availability.

It was considered as non-conventional measures for increasing the permeability of urban area, the implantation of green roofs, percolation basins and permeable pavements. In Table 4 are presented the percentage for runoff reduction for each adopted measure.

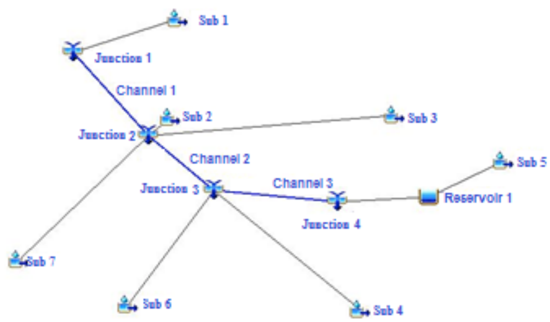


Figure 5: Representation of the current scenario of Lages Stream Watershed in HEC-HMS

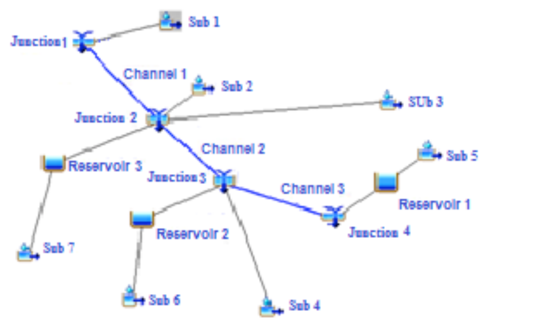


Figure 6: Scenario 3 representation, with the addition of two reservoirs (R3 and R4)

Table 3: Reservoirs dimensions.

Dimensions	**Reservoir 1**	**Reservoir 3**	**Reservoir 4**
Length (m)	462.00	203.00	250.50
Width(w) (m)	220,00	50,81	101.25
Superficial area (m²)	101,640.00	10,314.43	25,363.13
Area of the base (m²)	88,400.00	6,254.4	20,353.12
Slope inclination	45°	45°	45°
Height(m)	5	10	10
Volume (m³)	947,100.00	33,809.65	104,896.88
Dimension of the spillway (width x height)	2x5	2.5x2	4x2
Orifice size (m)	1.0	1.0	1.0

Interventions were proposed in order to reduce 50% of the soil impermeability in the whole watershed. It was considered that 50% of the roofs were replaced for green roofs, 1% of the watershed area as being percolation basins, 35% of the watershed area as reforestation areas and 60% of the pavements as being permeable pavements. In addition to these measures, it was suggested the construction of infiltration lakes with a storage volume of 28.06m³.

Table 4: Runoff reduction percentage for each measure.

Measure	**Runoff reduction**
Permeable pavement	26%*
Green roof	60%**
Percolation Basin	41%***
Reforestation	60%

Source: * HaradandIchikawa, 1994 apud Canholi, 2005 and Pratt et al., 1998 apud Canholi, 2005.** Castro and Goldenfum, 2010. *** Burchale, 2007.

3. RESULTS AND DISCUSSION

It is important to highlight that, due to the absence of flow measurements in the watershed, we could not calibrate the model parameters or validate its performance. However, an independent simulation study reported about 242.1 m^3/s for a return period storm of 25 years in 2 hours (CODAU, s.d.) on Junction 2 (Figure 5). The model parameters based upon the land use scenario were therefore assigned through indications reported by scientific literature. Besides this, a variety of methods can be used to provide information about flood events, since there are poor knowledge of this phenomenon in small urban watersheds (Koutroulis & Tsanis, 2010).

3.1 Scenario 1: Reference Scenario

The results showed the differences in hydrological behavior of the transformations of precipitation into flow according to the predominant type of land use. Table 5 presents the simulated flow peak and its time.

Table 5: Observed peak flow in each hydrologic element of the simulation, and its time.

Hydrologic	Drainage Area	Peak Discharge (m^3/s)	Time of Peak	Volume(mm)
Sub 6	4.16	17.07	09:34	155.82
Sub 4	3.92	16.02	09:30	154.25
Sub 5	3.61	14.32	09:48	146.01
Junction4	3.61	14.32	09:48	146.01
Channel3	3.61	14.03	10:20	143.44
Junction3	11.69	46.96	09:48	151.47
Channel2	11.69	46.96	09:54	151.20
Sub 7	6.56	26.89	09:42	155.69
Sub 2	3.07	12.62	09:16	156.12
Sub 3	0.32	1.31	09:18	156.07
Channel1	21.64	87.61	09:54	153.09
Junction2	21.64	87.62	09:44	153.33
Sub 1	4.93	18.32	10:14	132.01
Junction1	26.57	105.89	09:58	149.18

Subwatersheds 1, 2, 4 and 6 represent totally urbanized environments, 100% occupied by urban area and with 95% of impermeable area. Therefore, it had a minimum infiltration and almost the totality of transformation of precipitation into flow, immediate beginning of flow increase and accentuate peaks. In Sub 5, water infiltration percentage could be considered significant. The flow peak was attenuated regarding the others subwatersheds and occurred a delay on the beginning of the flow curve. Sub 1 presented more appropriated infiltration conditions, since it has the minor urban fraction. Besides maximum flow amortization, the hydrograph presented flow maintenance for a longer period and a delay in the flow peak. The infiltration fraction is also greater than the runoff fraction, representing minimization of the impacts, since it reduces the erosive process and entrainment of particles causing water bodies' siltation.

Warburton *et al.* (2012) also observed that the contribution of streamflow from a specific land use type is not uniformly proportional to the area of that land-use and depends greatly on the location of that land use within the basin. These authors further showed that the streamflow response at the basin outlet is influenced by the spatial distribution of various land uses present in the entire catchment.

The maximum flow peak in the watershed mouth was 105.89m^3/s (Figures 7a and 7b). With the addition of the reservoir already constructed (R1) in the simulation, the peak at the end of the watershed was reduced to 102.3 m^3/s, representing reduction efficiency of 4%, in addition to the notary effect of peak amortization and delay, both desirable effects in flood preventions.

Warburton et al. (2012) observed that water engineered system plays an important role in the watershed's hydrological response. Nevertheless, they concluded that the location of the interferences within a catchment has a role in the response of the streamflow. Uberaba's reservoir (R1) was located upstream, however, we suggest that improved results could be found if the reservoir was better located, in downstream.

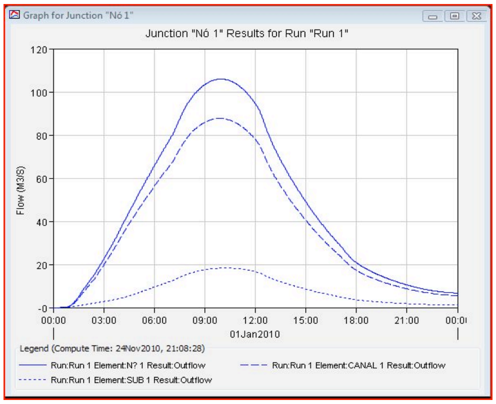


Figure 7a: Simulated hydrograph before R1 inclusion

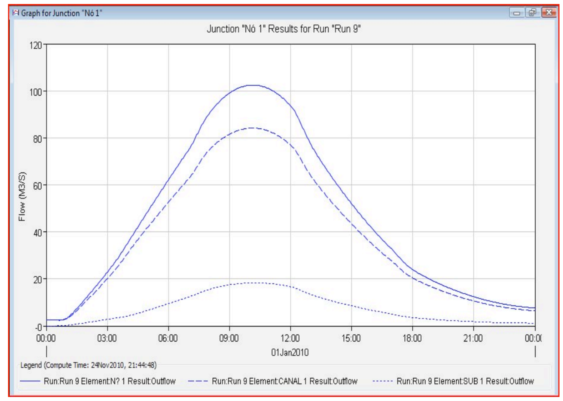


Figure 7b: Simulated hydrograph after R1 inclusion

3.2 Scenario 2

After CN modification based in the land use variation, we can observe a reduction of 2.9% in the final peak flow, resulting in 99.06m^3/s, as shown in Figure 8. The principal impact of this measure was found in Sub 5, which has the greater permeable area and in Sub 1, which has the major pasture area.

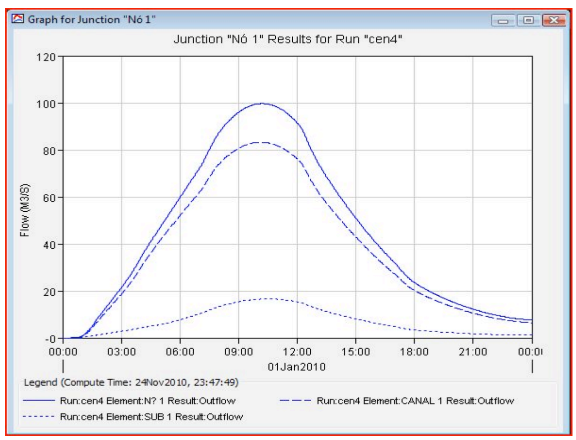


Figure 8: Simulated Hydrograph for land use modifications

According to Fox *et al.* (2012), human intervention by means of augmentation of channel capacity though improved channel management in urban areas can act as a counterbalance to reduce the additional surface runoff generated by expanding urban area or reducing forests. Besides the importance of these practices, our simulation showed non- significant impact on simulated flow peak (data not shown).

The simulations shown that the implementation of such individual measures if taken in isolation, have negligible changes in peak flows.

3.3 Scenario 3

Table 6 presents the impervious reduction percentage caused by the adoption of each non-structural suggested measures.

Table 6: Impervious reduction percentage in Scenario 3

	Measured area	Runoff reduction	Watershed area	Area with the measure	% impervious reduction
Green roof	13.29	60%	26.58	6.65	15.00
Percolation Basin	0.27	41%	26.58	0.01	0.41
Permeable pavement	23.92	26%	26.58	14.35	14.04
Reforestation	9.30	60%	26.58	0.35	21.00
					50.45

Were also evaluated the impacts regarding the construction of two new reservoirs, as dimensions described in Table 3, in association with others measures proposed in Scenario 2.

The simulation of this set of measures resulted in a flow peak reduction of 18%, with a final discharge of 82.9m^3/s (Figures 9a and 9b). Campana and Tucci (2001) simulated the effects of urbanization on floods, considering a scenario of 50% of free space taken as impermeable, concluded that regulation concerning use of free space in building lots can decrease the impact in about 5%. When simulating a past scenario, Sanyal *et al.* (2014) considered the effect of land use and land cover in their study area, it becomes evident that a general increase in the higher runoff producing LULC classes resulted in higher peak discharge and shortened peak time.

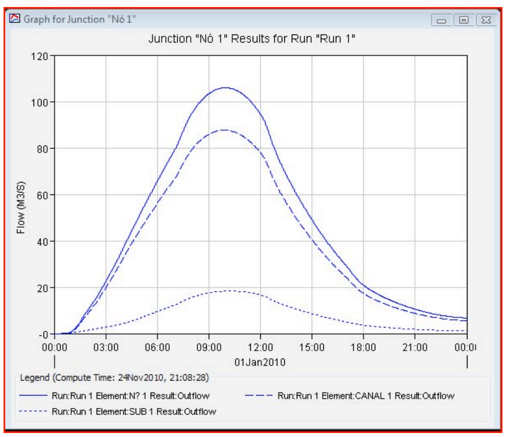


Figure 9a: Simulated hydrograph

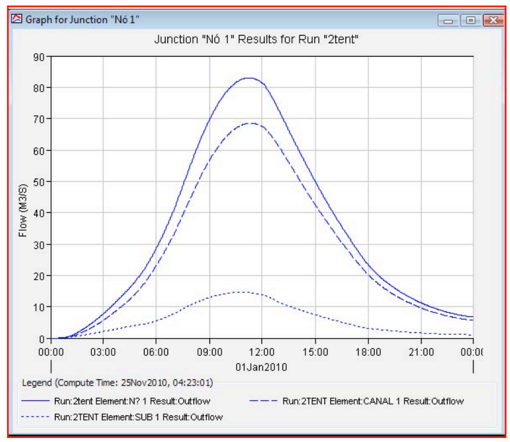


Figure 9b: Simulated hydrograph for set of measures suggested in Scenario 3.

Besides reduction in peak discharge, the implementation of above measures would be able to delay peak time. Pattison Lane (2012) showed the important role played by the timing of extreme rainfall events at different parts of the watershed and the consequent hydrological response.

The studied watershed has its surface almost completely impervious, where is a difficult task to deal with, and so to apply effective contention measures, especially those dependent on changes in landscape. Another relevant factor about the current watershed is the absent of flow measurements, which make impossible to calibrate or validate actual scenario.

4. CONCLUSIONS

Simulations shown that the implementation of individual measures, such as, channels cleaning, intervention in impervious areas and the construction of reservoirs, if taken in isolation, have negligible changes in peak flows. The evaluation of an already constructed reservoir that has a superficial area of 101,640 m² indicated an efficiency of 4% in peak flow reduction. Social and economic issues related to the urban area make effective solutions challenging to implement. However, the set of measures to improve infiltration in urban area, through implementation of green roofs, permeable pavements, percolation basins and reforestation, associated with reservoirs construction in areas still available in the urban space, showed a satisfactory result, reducing the observed peak flow in 18%, besides the delay in time of concentration.

It can be concluded that, in these cases, the combination of structural and non-structural measures should be prioritized in public management, as flood effects are related not only to natural resources degradation, but also represent a public health problem, having significant impacts in social, economic and environmental areas.

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