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URBAN RUNOFF SOURCE CONTROL MEASURES IN SÃO PAULO: TECHNICAL AND LEGAL ASPECTS

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ABSTRACT: New urban developments may cause serious inconvenience on urban drainage systems when their hydrologic impacts are not properly mitigated. Many cities around the world tried to minimize the effects of urbanization by implementing source control measures encouraged by regulations, laws or ordinances. In many cases, the introduction of this type of solution has led to adverse outcomes, not only because of the choice of the device, but also due to regulations control standards. This study evaluated four different urbanization scenarios in order to analyze São Paulo´s ordinance efficacy on controlling hydrologic impacts of new developments. Among these scenarios, the installation of micro reservoir and rain gardens were evaluated. Results showed that it would possible to attenuate peak flows from source-controlled areas by 20%, and by 11% and 9% considering the contribution from the whole development the basin, respectively. When the location of the micro reservoir was changed, it was possible to double the attenuation efficacy. The use of rain gardens showed worse results for peak flow attenuation. However, these devices can reduce by 64% the number of runoff events from controlled areas, which are strongly linked to water quality. It was concluded that the existing law (municipal law 41.814/02 and state law 12.526/07) only partially meets its goal for flood control. The law presents a good opportunity to increase the effectiveness of urban drainage systems and its contents should be revised in order to allow non point source pollution control and urban river degradation.

Key Words: storm water regulation; source control, urban drainage planning and management.

1. INTRODUCTION

The new housing and commercial developments under construction in the São Paulo Paulo Metropolitan Region (RMSP) have been generating an increase in soil impermeabilization. New impermeable surfaces, and their consequent impacts on the magnitude of flows, are responsible for increasing flood occurrence and the fast obsolescence of urban drainage systems.

In many cities around the world, these effects of urbanization were balanced with the introduction of source control measures, which are encouraged from different kinds of regulations.

According to (Petrucci, 2011), most of these regulations are based on two different technical approaches:

- Adoption of a maximum specific flow rate;
- Respect to pre-development flow rates.

City	Volume Equation (m^3)	Volume/Area (mm)	(Volume/Area) /Rain (TR 10 d=1hr)
São Paulo e Rio de Janeiro	V=0,15.Ai.IP.t	9	15-16%
Guarulhos	V=0,006.Ai-0,4	5	10%
Belo Horizonte	V=0,03.Ai	30	63%
Porto Alegre	V=4,25.(Ai/At).A	44	86%

Table 1 –Brazilian regulation examples

In Brazil, many cities already developed different provisions, based on detention volume. The Brazilian regulations already predict the volume to be available for storm water control according to the impermeable surface. Table 1 shows different Brazilian regulations. It can be noted that the volume that must be available is very different between each regulation, while the rainfalls have the same magnitude.

However, there are few consistent results relating the use of source control and their effects on the watershed scale, what causes difficulties on the development of politics to accomplish this objective (Petrucci, 2011). Therefore, many solutions were adopted in the local scale, with the implicit idea that this measures, if effective locally, would propagate its benefits to the whole basin (Faulkner, 1999). In many cases, the introduction of this kind of solution can lead to adverse effects, not only because of the control structures, but also due to the standards adopted in the regulations. The main hydrologic aspects related to these problems are:

Flow Estimation Methods – Hydrologic analysis for many of these regulations are based on the adoption of the Rational Method. According to Cawley e Cunnane (2003), this method is reliable for basins areas between 5 and 100 ha, when there is no flow data. Source control techniques needs results for areas from 0.01 to 2.0 ha.

Strecker (2001) states that these methods were developed to obtain conservatives flood flows for channel design. They do not take into account that the runoff does not derive only from the amount of rain, but also how it moves in time and space, the degree of antecedent soil saturation and the type of vegetation in the basin. In the end, real conveyed flows are smaller than calculated with this method.

Return Periods and Rain Duration – The return periods typically used in laws and ordinances varies from 2 to 100 years. The return periods used represent only a small fraction of the annual precipitation, near 3%, resulting in a lack of management of the other 97 % (rainfall with return periods smaller than two years); these events are related to water quality due to diffuse pollution (Guo and Urbonas 1996). Mays (2001) emphasized that for an integrated and sustainable storm water management, events of high and low frequencies must be included.

The effects of urbanization are less significant for greater return periods because these events are likely to occur during the wet seasons when the soil is partially saturated. The construction of source control structure for such rare events can be inefficient from the hydrological point of view, and uneconomical (Faulkner, 1999).

Fennessey et al. (2001) noted that in many urbanized watersheds even with the use of storm water regulation there has been an increase in the number of cases of flooding for frequent rains. One of the author's conclusions is that most of the regulations ignores the events of low recurrence times (up to 5 years), for which the effects of urbanization are “propagated” downstream. One way to reverse the inconveniences related to this aspect is to develop rules to provide control for the entire spectrum of events (Wulliman and Urbonas, 2007).

Structure localization – The interaction between discharges from urbanized areas (controlled areas) and those from non-occupied areas (uncontrolled) may result in concomitant peaks in localized points of the basin. Furthermore, the different parts of the basin have a different behavior, i.e. some areas more contribute strongly for the peak than others do.

In parallel, various design concepts based on the preservation of local hydrology have been employed. Among them, we can mention the Low Impact Development (LID) and Sustainable Urban Drainage Systems (SUDS), which employ, reservation and infiltration measures, along with urban planning.

2. OBJECTIVES

To analyze the impact of these control measures, hydrologic simulations were performed for a small watershed in the RMSP considering micro reservoir or infiltration devices, according to the local law. The watershed in question is located in São Caetano do Sul, where an industrial area was turned into a new commercial and residential area.

3. MATERIALS AND METHODS

Based on the assumptions above, four different scenarios were evaluated, so it was possible to make quantitative comparisons between runoff generated in the basin and transferred downstream, using micro reservoir and infiltration measures, based on the "lei das piscininhas" in São Paulo (municipal law 41.814/02, which subsequently formed the basis for the state law 12.526/07). Thus, the following scenarios were assessed:

- Pre-development scenario (1);
- Developed scenario(2);
- Developed with micro reservoir (3);
- Developed with bio retention (4).

The scenarios were evaluated utilizing the Storm Water Management Model (SWMM) from EPA (Environmental Protection Agency). According to Elliot and Trowsdale (2005) SWWM is one of the more suited models for the simulation of SUDS and LID structures.

The Soil Conservation Service (SCS) hydrological model was selected to perform simulations used according to the Alto Tietê Drainage Master Plan recommendations (Kutner, 1999). IDF curves for São Paulo (Martinez e Magni, 1999) were used for discrete events, while the continuous simulations were performed with a 12 years observed rainfall series in the São José station, far 200 meters from the watershed. The watershed is presented in the Figure 1 and 2.

The chosen watershed is part of low Ribeirão dos Meninos basin, at São Caetano do Sul city. New housing and commercial buildings are now occupying an old pottery industry located in the area, this area has 0.32 km².

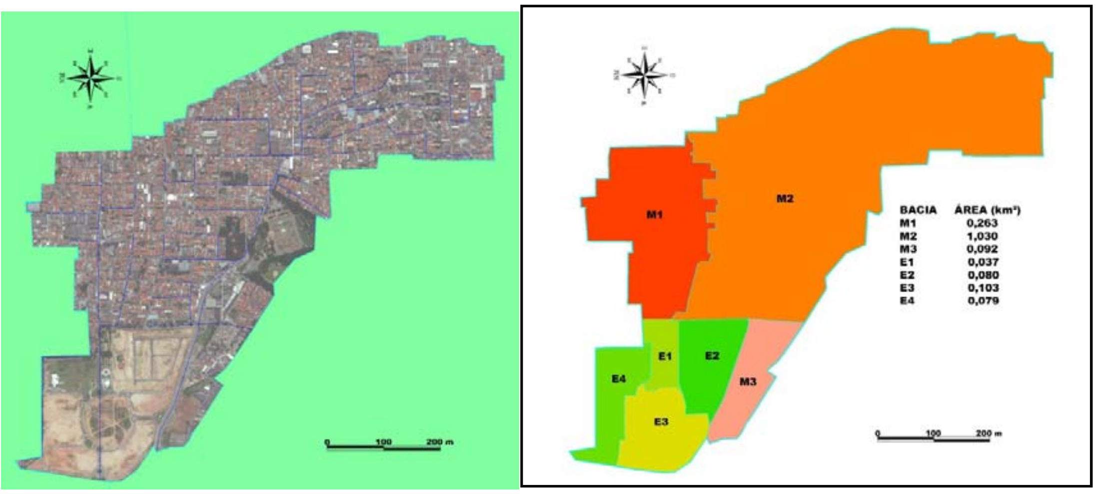

Figure 1 and 2 – Case Study basin and Areas

This new neighborhood is comprised between two different watersheds. One part is located inside a 0,55 Km² basin (consisting of E1, E3, E4 and M1 sub-basins) that drains directly to the Ribeirão dos Meninos, and another inside a 1,0 km² (consisting of E2, M2 and M3 sub-basins), that drains parallel to the first one, join it at the discharge point in Ribeirão dos Meninos. Figure 3 shows a scheme of the simulated basin.

The analysis was performed on four different levels. First, it was individually assessed the effectiveness of the devices attenuating peak flow on the private constructed areas of basins E1, E2, E3 e E4 that, by law, must receive micro-reservoirs.

Then, the efficacy for the entire development, consisting of public (roads, sidewalk and squares) and private (constructed or not) areas was assessed. This analysis was referred to as "Development" as is the joint analysis of basins E1, E2, E3 and E4.

The third level is represented by the impact of using control devices when considering the watershed where the new development is being built, consisting of basins E1, E2, E3, E4 and M1, which is the upstream basin. This watershed was named “Basin 1”. Finally, it was evaluated the efficacy considering the watershed as a whole, called “Basin 2”.

According to the law, the total volume that should be available, when considering the impervious area of each allotment, is 1688 m³. The discharge devices were designed to maximize the effectiveness for a 10-year rainfall with a 1-hour duration, as considered in the law.

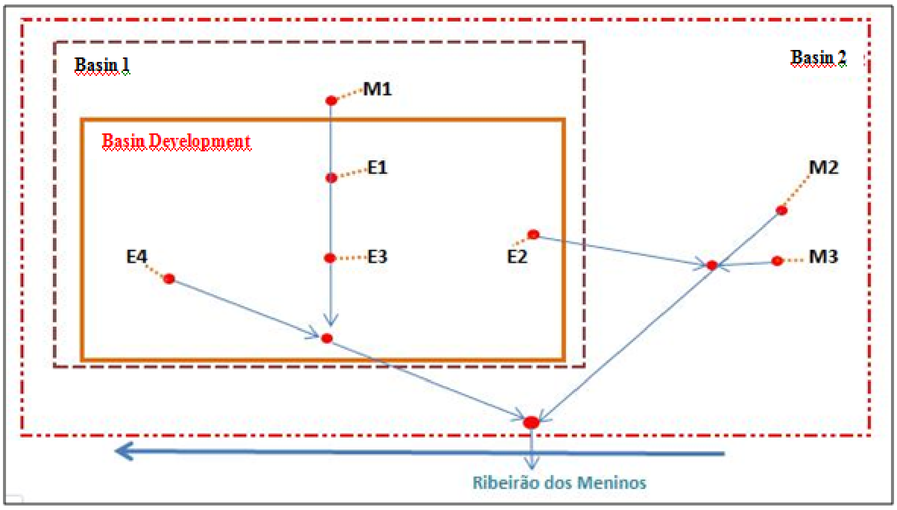

Figure 3: Simulation Scheme.

4. RESULTS

4.1 Micro-reservoir

For the impervious controlled areas, the efficacy for the peak flow abatement were around 18-20% , a 10-year rainfall. Figure 4 shows the result for the RT's of 2, 5 and 10, for an impervious areas controlled by micro-reservoir in the E2 basin. Table 2 shows the results and effectiveness for these areas.

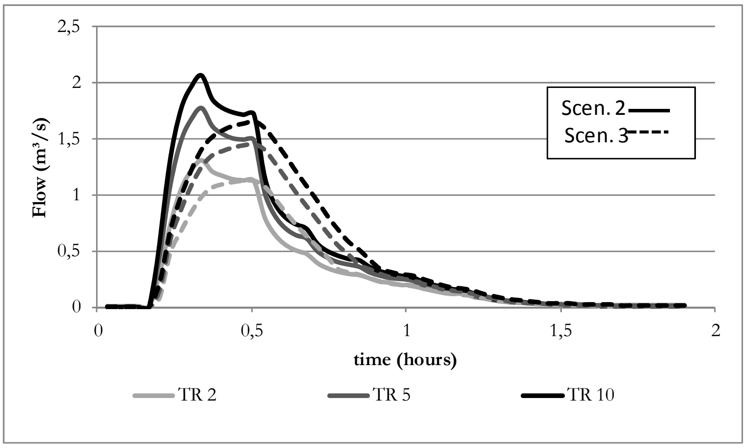

Figure 4: Results for E2 controlled areas.

Results for Basin E2			
Return Period (years)	Scenario 2 (m^3/s)	Scenario 3 (m^3/s)	Efficacy (%)
2	1,31	1,12	14,5%
5	1,77	1,45	18,1%
10	2,07	1,66	19,8%

Table 2: Results and Efficacy for E2 micro-reservoir controlled areas

When considering the outflow of basin “Development”, i.e., considering also the contribution of permeable and impermeable public areas (road system, squares and parks), the efficacy is around 11.4%. Figure 5 shows the results for the RT's of 2, 5 and 10. Furthermore, the use of micro reservoir as stated in the law has not reached the flows that were conveyed to Ribeirão dos Meninos prior to the development.

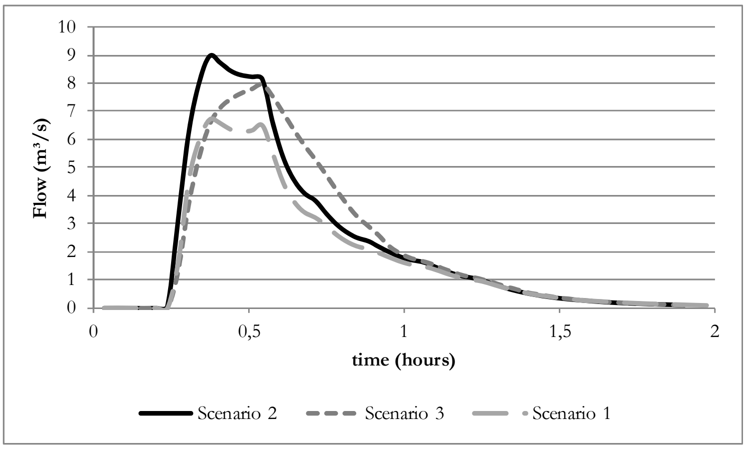

Figure 5: Results for Basin Development (RT 10 years)

For the Basin 1, the efficacy in reducing peak flow was only 9.4%, while for the Basin 2, the result showed a slight worsening of 0.4%, or there was a slight increase in the flow discharged into Ribeirão dos Meninos when compared with the situation without micro-reservation. Figure 6 shows the result for Basin 1. Although the use of micro-reservation was able to reduce part of the peak, they are not able to prevent a worsening of the situation, when comparing with Scenario 1.

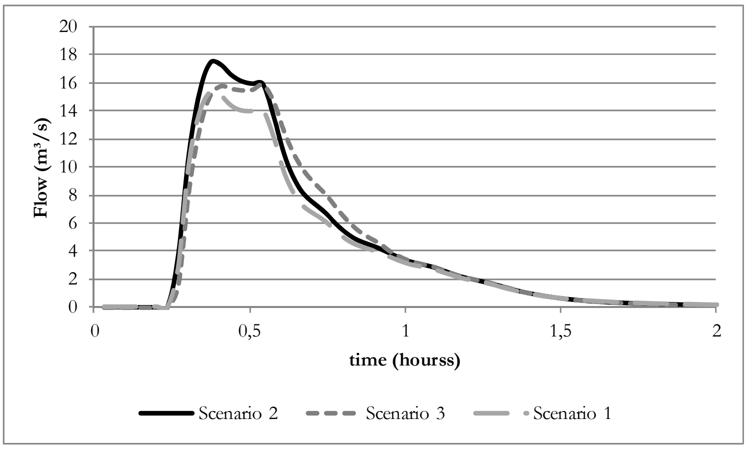

Figure 6: Results for Basin 1.

The results for the micro reservoir are quite limited, even for an impervious controlled area and the "Development" basin, which has an area greater than 60% under control of micro reservation. These results reflect the small volume required by the law.

Moreover, the location of the detention can lead to smaller effectiveness on peak flow abatement. For comparison, a simulation was performed by allocating the same volume at the point of best efficacy, in this case sub-basin E2, but controlling the public and private areas. The result was an increase in the effectiveness of the abatement from 11.4% to 21.6%, for Development basin. For Basin 1, it showed an improvement of 9.4% to 10.7%, while for the Basin 2 from -0.4% to 2%. Figure 7 shows this result at the outflow of Development basin.

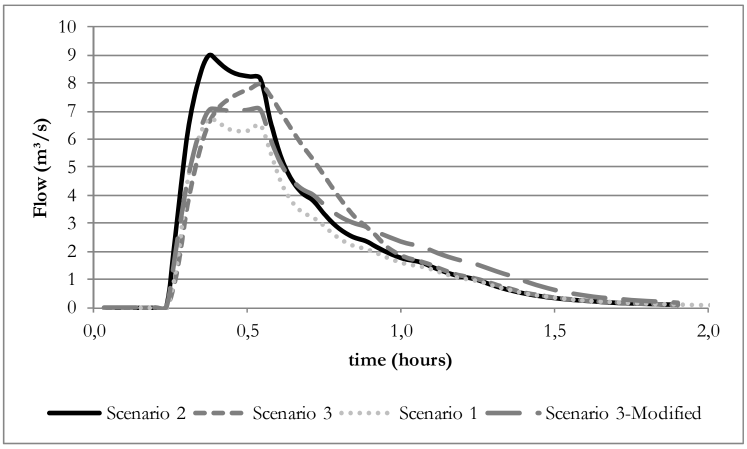

Figure7: Results for basin Development with control of public and private areas.

4.2 Bio retention/Rain Garden

A vegetated shallow bed that promotes physical and biological processes like infiltration, retention, adsorption, assimilation and evaporation forms this type of device. Thus, it is necessary to direct runoff through the garden. These devices have longer retention time, around 24 hours, which leads to a poorer performance for more severe events when compared to micro-reservoir with the same volume.

The efficacy of the areas directly connected to these devices on reducing peak flows was around 2.8 % for the 10 years rainfall. For Basin 1 the result was 8.4 %

The impact of these systems is better observed when we analyze the results for continuous simulation. It is possible to observe that the benefit of this technique for high frequency events with recurrence times of less than 2 years. With the use of these devices, it is possible to achieve a reduction of 62.5 % in the number of days with runoff. Figures 8 and 9 present the results for the number of days with runoff and infiltration volume. A 40% reduction in runoff volume can also be observed. According to Emerson et al. (2005), Booth e Jackson (1997) e Hunt e Tillinghast (2011) wwith fewer days with runoff, it would result in less erosion problems and less pollutants carried to the water body.

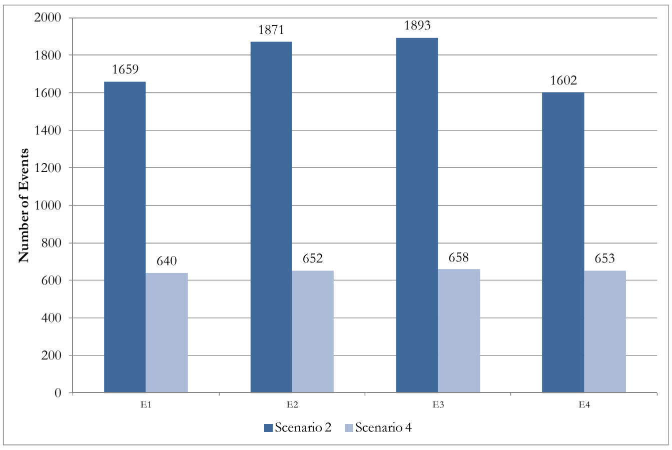

Figure 8: Results for days with runoff events.

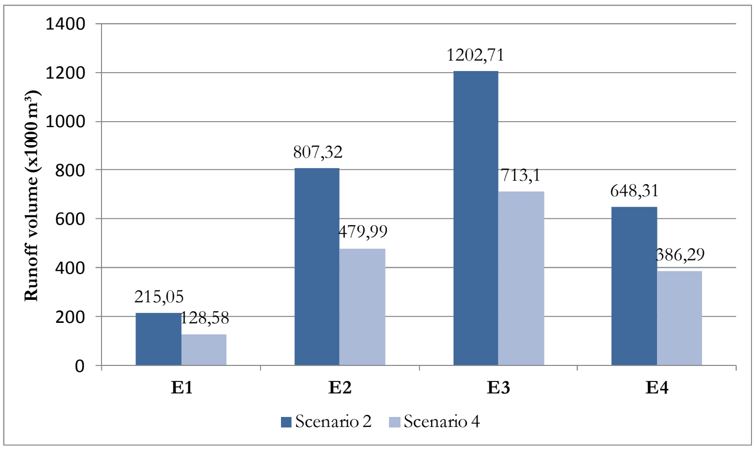

Figure 9: Results for runoff volume.

Although a remarkable improvement can be achieved with the use of these devices, according to Urbonas (2009), for the city of São Paulo, the minimum volume required to quality control would be 20 mm; this is the volume that covers the 80th percentile of rain events.

In this way, the law is incompatible with the quantity control, as partially incompatible with quality control, which should encourage a technical review in order to achieve these goals.

5. CONCLUSIONS

It can be concluded that the "law of piscininhas" used today in the city and state of São Paulo should be revised to fully achieve its objectives of flood and water quality control. Although the use of micro reservoirs enables a reduction in peak flows for controlled areas, the results do not diffuse throughout the basin due to the following factors:

- The reservation volume required is very small, equivalent to 15% of the 10 year rain, which does not allow a substantial peak flow attenuation;
- Almost no lag between hydrographs is observed as only part of the developed areas receive detention devices, in this case, only private and impervious areas. As a consequence, some of the impacts from urbanization on basins' hydrology is fully transferred to downstream;
- The volume of reservation, although is important to ensure the peak flow attenuation by storing locally, is not the only responsible for the effectiveness of the system. The introduction of reservoirs in a basin, can remotely influence the composition between peaks from various sub-basins due to delay generated in these structures. This point becomes clear in the analysis of the modified Scenario 3.

On the other hand, the "law of piscininhas" presents a great opportunity to control diffuse pollution and the correctly manage runoff from very frequent storms (RT less than 2 years), which represent 97% of total rainfall. If the law is revised, infiltration devices could be used with inherent gains that would complement the ongoing efforts for flood control in the RMSP.

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