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BEST MANAGEMENT PRACTICES AS ALTERNATIVE FOR FLOOD AND URBAN STORMWATER CONTROL IN A CHANGING CLIMATE

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ABSTRACT: Global climate models regarding the predicted scenarios of Greenhouse Gases (GHG) emissions, forecast a general increase in intensity and frequency of extreme rainfalls. Advanced studies in regional and local scales attest this intensification with greater spatial and temporal precision. The increase in rainfall associated with urban growth and more impervious surfaces, will lead to unprecedented impacts on drainage infrastructures, with high risks of flooding. Facing the need of adaptation to this future scenario, cities have the opportunity to perform an infrastructural transition when adopting stormwater Best Management Practices (BMP) as sustainable, resilient and landscape friendly solutions. This paper presents a qualitative and quantitative comparison between BMP techniques and usual detention reservoirs as runoff control strategies. Regarding a case study urban watershed in the Greater São Paulo - SP - Brazil, where two reservoirs with a total volume of 19.200m^3 were built, porous sidewalks and bioretention elements have been located in the contribution area within this basin. The retention volume of these proposed techniques considering their average porosity corresponds to 42% of the reservoirs capacity. It is then confirmed the stormwater BMP viability and suitability as alternatives to adapting cities to climate change, but their efficiency relies on a design that takes into account the specific local environment.

Key Words: climate change; extreme rainfall; urban drainage; best management practices

1. INTRODUCTION

Design, engineering and construction have been under a global urgency to develop new languages and new tools so that we can live without exhausting nature. These innovative solutions are at landscape scale and involve a comprehensive approach of how it works aiming to reach balance between design and the natural system structure that support us (Dramstad et al., 1996, p. 13). We must then apply creativity to the artificial systems so they can meet the challenges of urban infrastructure and perform closer to the natural processes, especially those related to drainage and water quality (Cormier & Pellegrino, 2006).

The eminent climate change related to greenhouse gas (GHG) emissions reinforce this urgent challenge of adapting cities to greener infrastructures since the largest share of the world population lives in urban areas. The predicted scenarios of environmental impacts on urban infrastructure, such as the general increase in the intensity and frequency of extreme rainfall events, demand more sustainable technologies that mitigate the problem and set more resilient urban areas. In this context, considering the increased demand and burden on drainage infrastructure and flood control, stormwater Best Management Practices (BMP) must be examined as a technical possibility. When compared to conventional solutions, such as detention reservoirs, BMP emerge as an alternative to the evident drawbacks in the so-called *piscinões*[1], that even with effective results in flood control, have presented problems in maintenance and operation.

2. MORE INTENSE RAINS, LARGER IMPACTS ON URBAN DRAINAGE

Increases on intensity and frequency of extreme events[2] across the globe are an eminent consequence of a changing climate. Reinforced by simulations and climate models projections, extreme precipitation should increase worldwide for the future climate, as a result of global warming attributed to the rise in emissions and concentrations of greenhouse gases - GHG (Mailhot & Duchesne, 2010). Distinct scientific research has investigated this subject field and became reference to projections at regional scales in order to establish policies to mitigate emissions and provide resiliency to the effects of climate changes (cf. IPCC, 2007). Studies conducted to specific locations, in turn, have confirmed recent variations in the pattern of more intense rainfall, ratifying that the increase in extreme precipitation is already a reality in some places or regions.

The greater intensity and frequency of rainfall will certainly have impacts on urban drainage. Currently, the design of drainage infrastructure in cities is based upon statistical analyzes of intensity-duration-frequency of rainfall events that have already occurred. This infrastructure is dimensioned to support specific flows, considering return periods of events with greater magnitude like 100 years rainfalls (Denault et al., 2006). Traditionally, the statistical parameters of hydrological variables for this design are considered constant over time, without large fluctuations, and, therefore, are stationary. However, with the contribution of climate change on the acknowledged patterns of rainfall intensity and frequency, this stationary model applied to dimension and design drainage infrastructures is no longer accurate. In addition, if it prevails as the only method in use, overloads in urban drainage systems or floods, to be worse, are very likely to increase (Mailhot & Duchesne, 2010; Denault et al., op cit.; Guo, 2006).

Despite uncertainties regarding the magnitude and regional variations of climate change, some cities and regions have evaluated the possible impacts of more intense rainfall in its urban drainage systems. Even with an inaccurate quantification of the expected enhance in precipitation events, one of the pioneer studies in this field simulated the implications on drainage infrastructure assigning different percentages for the intensification of rains: 10, 20 and 30% (cf. Niemczynowicz, 1989, p. 655-657). Although in different scenarios, this research along with similar studies, have reached some common ground as to the impacts of more intense and frequent rainfall on urban drainage:

- greater impervious areas in cities, associated with urban growth, should increase the risks of flooding and environmental impacts on rivers and streams, which are the final destinations of runoff;

- the costs of adapting drainage infrastructure to more intense and frequent rains are high if it is made the choice to expand this network expansion thorough conventional techniques. Separate sewer systems, which provide detachment between sewage and drainage conveyance, are suggested as a more sustainable solution to mitigate the impacts caused by heavier rainfall, but they are also more expensive (Faram et al., 2010, p 108.);

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[1] This Portuguese term, which can be literally translated as *big pools*, refers to detention reservoirs, and has gained both popular and technical acceptance when mentioning these stormwater control facilities.

[2] Classifying precipitation depends on intensity patterns of regional or local rainfall. The works reviewed in this article consider the relation of intensity-duration-frequency relationship to define extreme rainfall events (eg.: Mailhot & Duchesne, 2010, p 202.).

- the use of larger diameter pipes to withstand greater runoff may reduce the flow rate during dry periods and thus cause problems of sediment accumulation;

- if the intensity and frequency of heavy rains continue to increase, the expansion in drainage systems may require new interventions in the future, meaning more expenses and reworks;

In addition to the expected impacts, the analyzed studies, corroborated by other researches (Faram et al., 2010; Mailhot & Duchesne, 2010; Scholz & Yang, 2010; Waters et al., 2003), recognize the importance of a long term urban planning to be started from now on, as a key strategy to avoid further problems regarding drainage in a not too distant future. They also suggest that, when considering the high investments needed to adapt conventional systems to the predicted scenarios, alternative and more naturalized approaches, such as techniques of stormwater retention and infiltration can be employed as a complementary solution to mitigate the problem and lower adaptation costs.

3. STORMWATER BEST MANAGEMENT PRACTICES AS A STRATEGY TO MITIGATE IMPACTS ON DRAINAGE INFRASTRUCTURE

Figure 1: 12th Green Street. Portland, OR (USA).

Of all soil uses that result in impacts on watersheds and surface water, imperviousness, associated with urbanization, is by far the most significant (Riley, 1998, p. 132), causing disturbances on all chain of ecological processes. According to Science Magazine (Cohen, 2003), in 2030, the urban population will grow from 75 % to 83 % in developed countries and 40% to 56% in developing countries, indicating that the impervious surfaces will also be expanded, and with them the environmental impacts. Consequently, runoff should be enhanced and, with increased rainfall expected, the drainage infrastructure in cities will be under an unprecedented demand. In this context, Best Management Practices (BMP) as alternatives of Low Impact Development (LID) or compensatory stormwater conveyance techniques[3] may mitigate the problem and ensure greater longevity to drainage systems besides improving the quality of water that reaches urban streams and rivers (City of Portland, 2009).

Since 1970, according to Nascimento & Baptista (2009), BMP have been applied as an alternative to address the issues of runoff quantity and quality. Since 1987, when the U.S. Congress included diffuse pollution control measures to the Clean Water Act[4], BMP have become indispensable tools for drainage (Ha & Stenstrom , 2008) being extensively used by the U.S. in the 1990s (Roesner, 2001) and subsequently gaining supporters worldwide (Ha & Stenstrom, op cit.). Currently, U.S. cities like Portland (OR), in the northwest America, have a whole technical and legal apparatus to ensure these stormwater management techniques are mandatory (cf. City of Portland, op cit.). In the design and landscaping of

[3] These techniques are said to be compensatory since they aim to mitigate the impacts of urbanization on the hydrological cycle (Nascimento & Baptista, 2009).

[4] The CWA, approved in 1972, is the U.S. federal law that deals with water pollution control, setting goals to eliminate discharges with high concentrations of toxic substances and ensure the necessary standards for human appropriation of surface water, through sports and recreation.

open areas, either public or private, these solutions reduce runoff, increase infiltration and remove diffuse pollutants before they reach water resources (Dietz, 2007).

Based upon bioretention principles, which seek to mimic pre-urban hydrologic conditions through the use of more naturalized retention, infiltration and evapotranspiration techniques (DeBusk, 2011), BMP make use of various typologies, recommend in stormwater management manuals (eg.: City of Portland, 2009). Some of them are:

- rain gardens: topographic depressions that receive stomrwater runoff. Their soil is treated with organic compounds and other inputs, such as gravel, which increase its porosity and acts like a sponge while bacteria and microorganisms remove diffuse pollutants brought by runoff. The addition of plants increases evaporation and deletion of nutrients (Figure 1);

- stormwater garden plots: are basically rain gardens that have been compressed into small urban spaces. This type of bioretention facility has usually a limited infiltration capacity, counting on evaporation, evapotranspiration and overflow as a contribution to stormwater management;

- bioswales: similar to rain gardens , but generally refer to linear depressions filled with vegetation soil and other filter elements , cleaning processing of rainwater at the same time as they increase their flow time , for driving this rain gardens;

- stormwater ponds: act as retention basins that receive runoff by natural or artificial drainage. Part of the captured stormwater remains trapped between precipitation events. Thus, these types end up featuring landscaped as a wetland constructed , but it is not designed to receive effluent from domestic or industrial sewage.

The efficiency of these bioretention elements to decrease runoff volume and some of its main problematic constituents - according to Roesner (2001), suspended solids , nutrients (N and P), heavy metals (Cu, Pb and Zn) and fecal bacteria (E. coli) - has been proven by researches and field studies. DeBusk et al. (2011) has found that bioswales associated with parking, reduce runoff from impervious areas in 97 to 99% and decrease the mass of sediments, total nitrogen and total phosphorus by 99%. Weiss et al. (2007) has investigated many bioretention models and measured reductions of 85% in suspended solids and of 72 % in total phosphorus in rain gardens. Dietz (2007) demonstrated reductions in the concentrations of metals (Cu, Pb and Zn) above 90% by testing both laboratory and field prototypes. This author (op. cit., p. 360-361) also emphasizes that the LID stormwater management techniques and practices are relatively new and are still evolving, but have shown great potential to mitigate the problems of urban development on water bodies. However, Dietz notes that the efficiency of bioretention elements can be compromised by inadequate aspects of design and implementation, such as the use of clay substrates that may avoid infiltration or settlement in very sloped terrain or over soils with shallow depth to bedrocks.

4. CASE STUDY: DETENTION RESERVOIRS IN 'GOOD SHEPHERD' NEIGHBORHOOD - SANTO ANDRÉ CITY - SP

4.1 Climate change and the increase in extreme rainfalls in São Paulo

Climate simulation models for South America, considering the scenarios for GHG emissions (cf. IPCC, 2007) have detected possible changes in climate as a consequence of global warming, which includes significant increase in extreme precipitation. Grimm (2011) stresses the difference in results among the models used for simulations and the inter-annual climate fluctuations caused by El Niño as possible indicators of scientific uncertainty. However, in the southeastern portion of South America, where the state of São Paulo is located, the coincidence among simulations reinforce the possibility higher intensity and frequency of heavy rains, especially in summer, which is also observed in the study of Marengo et al. (2009).

Projections by the National Institute for Space Research (INPE) in regard to the Metropolitan Area of São Paulo (MASP), which already suffers from floods every summer, indicate a likely increase in the number of days with heavy storms until the end of the century (Noble et al., 2009). Preliminary studies also by INPE suggest that, between 2070 and 2100, a regional average rise in the temperature of 2 to 3° C could double the number of days with heavy rainfall (over 10 mm) in Greater São Paulo.

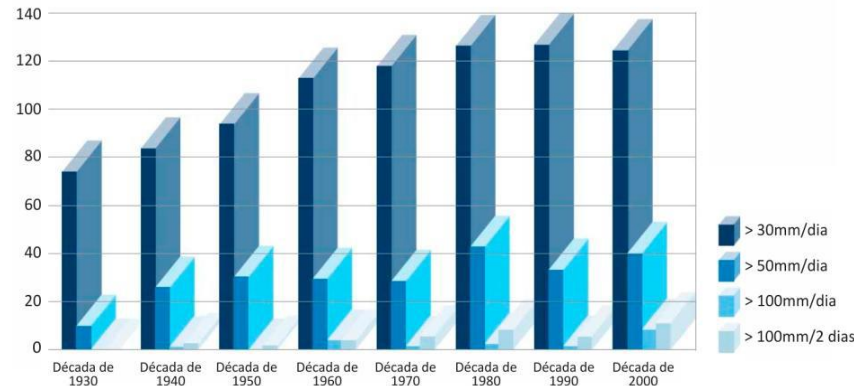

Figure 2: Extreme rainfall in MASP. INPE, 2000.

In addition to the future scenarios, the rainfall pattern for southeastern South America examined by Re & Barros (2009), in the period of 1959-2002, has shown an increasing trend in annual precipitation and in the frequency of the heavier storm events, from 50 to 150mm, in recent decades. A specific study for the State of São Paulo (Ambrizzi & Dufek, 2008), with income data from 1950 to 1999, has identified a significant increase in both extreme precipitation and the number of days with rainfall above 20mm or in the maximum rainfall in 5-day periods. INPE, in analyzing the precipitation of MASP from 1933 to 2009 also found an increase in the number of heavy precipitation events (Figure 2), above 30mm/day, which has the potential to cause flooding or severe flooding (Noble et al. 2009). There is thus a consensus as to the increase in the frequency pattern of heavier storms in São Paulo and its metropolitan area.

Marengo et al. (op. cit.), however, states that it is impossible to assign, with certainty, the occurrence of extreme events to anthropogenic climate change, due to the probabilistic nature of them. The authors emphasize that there is always a chance that these events are the result of natural climate variability. IPCC reports (cf. Cubasch et al, 2001; Meehl et al, 2007 & IPCC , 2007), in turn , employ expressions such as probably, most likely and extremely likely to qualify projections of climate changes and their relation with the increase in GHG emissions. Even with uncertainty, these reports emphasize the importance of taking a preventive positioning on possible climate change, which must include the following strategies: use of models to understand regional and local scenarios for future climate trends; mitigation of GHG emissions, and adaptation to the environmental impacts expected.

4.2 Stormwater control techniques under current use in the Greater São Paulo

Given the current context of urban sprawl and heavy rains in the MASP, which tends to worsen, conventional solutions have still imposed themselves as a dominant model. Traditional drainage based upon fast stormwater conveyance and detention have acquired technical respectability and proven efficiency in critical situations, through satisfactory hydraulic performance and results that could be foreseen and precisely calculated. Public administration and infrastructure builders then make their choice for drainage systems that carry runoff on quickly to major rivers without prior treatment, which

Figure 3: Detention reservoir in São Paulo.

overloads the infrastructure itself and the damages surface water quality.

As for rain control, the use of detention reservoirs, popularly known as *piscinões*, has proved to be a very effective solution to prevent floods in urban watersheds in the Greater São Paulo (Figure 3). Since providing reduction of flooding areas in rain events, they minimize eventual material losses for the population, traffic problems and many other issues related to the inability of streams to give vent to the volume of water that needs to be drained. In regard to the critical situation of São Paulo´s metropolitan area, 134 detention reservoirs are to be constructed in the urban area of the Tietê[5] watershed until 2020 in an attempt to simulate the hydraulic role of floodplains. However, when considering the hydrological cycle and natural processes, not to mention social and urban impacts, this strategy has proven to be ineffective. The issue is solved in regard to hydraulics, but, when considering the waves of floods, pollution throughout the watershed is drained to the reservoirs, which hold not only the surplus water, but also waste and sediments. Many drawbacks then become usual for the operation and maintenance of these facilities, such as problems of obstruction in pumps and drain grills, unpleasant smell and landscape, which have led to a rejection of this type of infrastructure by the population and by their surrounding neighborhoods.

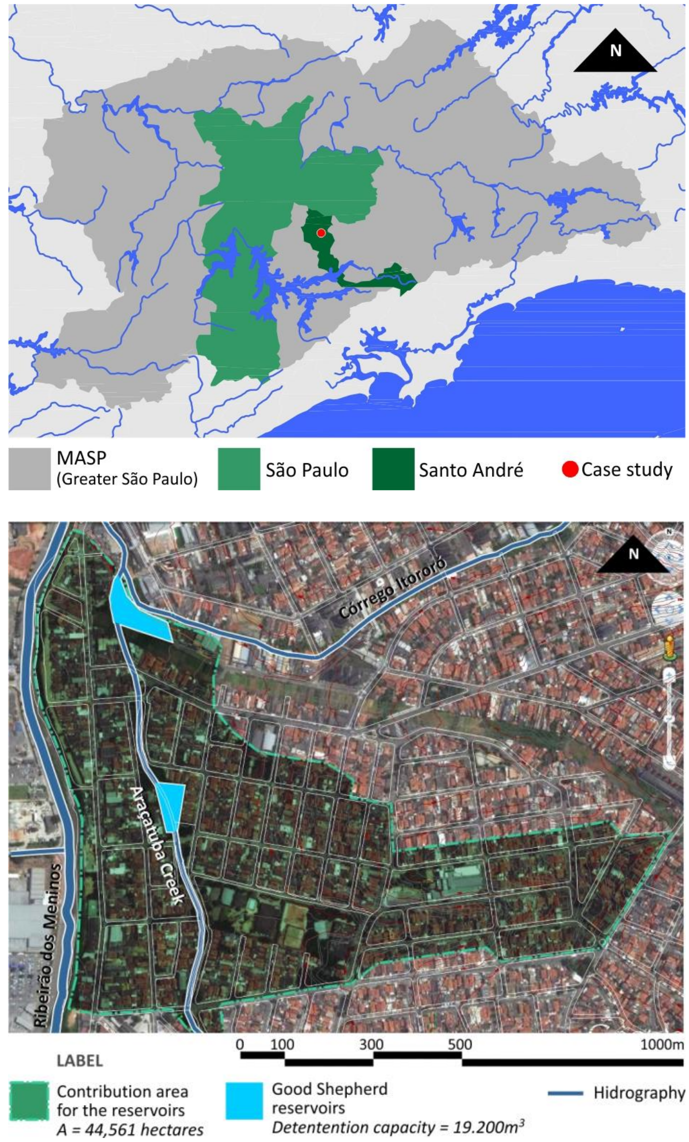

Figure 4: Location and detail of the case study area.

Another relevant issue contributes to the environmental impact caused by the reservoirs under operation in São Paulo: illegal connections and maintenance problems in the collecting structure that lead to sewage leakages in stormwater networks. Usually from unknown sources, this contamination by domestic sewage is very difficult to correct. The result, according to the report *Water Quality Study in Urban Flood Reservoirs* (PHD, 2008) is that virtually all stormwater detention facilities in the MASP present problems of water quality and of total volume capacity reduction due to siltation.

[5] Nationally known for covering in its 1.010 km extension almost all the state of São Paulo, from east to west, the Tietê River marks the urban geography of the country's largest city, São Paulo. Unlike other rivers, Tietê flows toward the country and not into the ocean.

4.3 Case study

The neighborhood watershed elected as a case study is located in the city of Santo André, which is part of the MASP (Figure 08). In this basin, with an contribution area of approximately 45 hectares, two reservoirs were built in 1991 in the neighborhood of Good Shepherd. With total storage volume of 19.200m^3 , these reservoirs, settled along the *Araçatuba Creek*, have the function of holding the excess of the watershed flow, that, besides avoiding local flooding, prevents the overflow from a larger stream, *Ribeirão dos Meninos*, from which *Araçatuba* is a tributary (Figure 4).

Sized for a return period of just two years, it was found that the reservoirs have worked very well for the purpose of flooding prevention, and the locals no longer have their homes threatened. However, there were several complaints of the neighborhood due to the presence of mosquitoes, unpleasant smell and look. Furthermore, water quality analyzes from the reservoirs conducted by the Department of Hydraulic and Environmental Engineering at the Polytechnic School of USP (cf. PHD, 2008), revealed the presence of pollutants such as heavy metals, and indicators of environmental degradation such as high concentrations of coliforms. These analyzes, carried out in dry and wet periods also proved that the pollution of reservoirs and streams worsens in the rainfall season, when superficial diffuse pollutants accumulate in larger concentrations in the detention facilities.

4.4 Analysis of the retention capacity of stormwater BMP

In order to measure the possible retention volume through the use of stormwater BMP techniques, bioretention elements and porous pavements were carefully distributed in one of the local streets within the contribution area of the detention reservoirs in the Good Shepherd neighborhood (Figure 5). Based upon principles of traffic calming, narrower streets with subtle winding paths have been proposed, not only to reduce the vehicle speed, but also to create retention voids for rainwater storage in subsurface gravel beds underneath rain gardens, bioswales, standardized porous sidewalks and permeable tracks in the property accesses. It was chosen not to implement permeable pavements on the streets due to the high discharges of diffuse pollutants on these surfaces (Debusk et al., 2011).

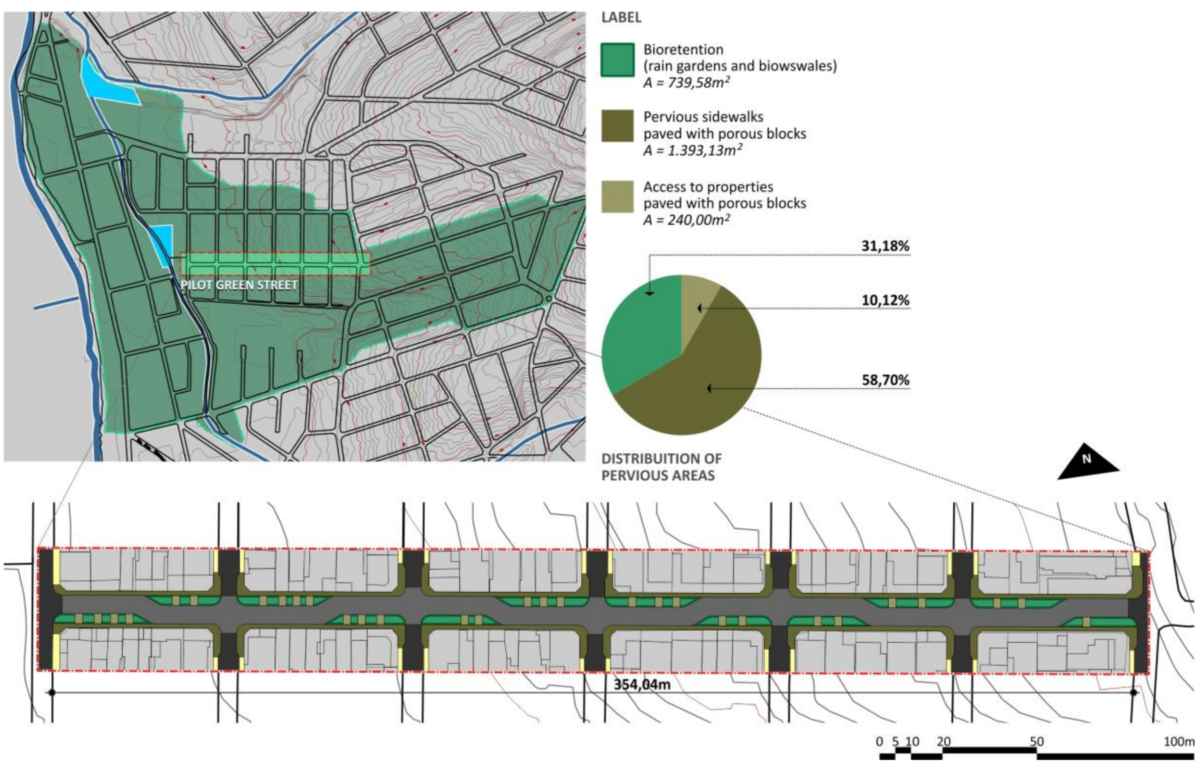

Figure 5: Pilot green street in the case study area.

For this pilot street, the total areas of each bioretention element, such as gardening or permeable paving, were added up in order to define their respective percentage of surface coverage for other local streets within the catchment basin of the reservoirs. Through traffic calming and high performance landscaping, a network of green streets can be structured and integrated to a proposed waterfront along *Ribeirão dos Meninos*. The streets chosen to receive this specific landscape treatment were identified by observing the topography and are slightly sloped towards the *Araçatuba Creek* (Figure 6). The neighborhood is then able to reach landscape and urban improvements by retrofitting public areas right next to their doorsteps. Ordinarily limited to transportation, usual streets become greener and bring a healthier and more sustainable environment by remodeling existing public open spaces rather than creating new ones, which would demand more expensive interventions. At the same time, runoff can be reduced and initially treated by a grid of bioretention elements.

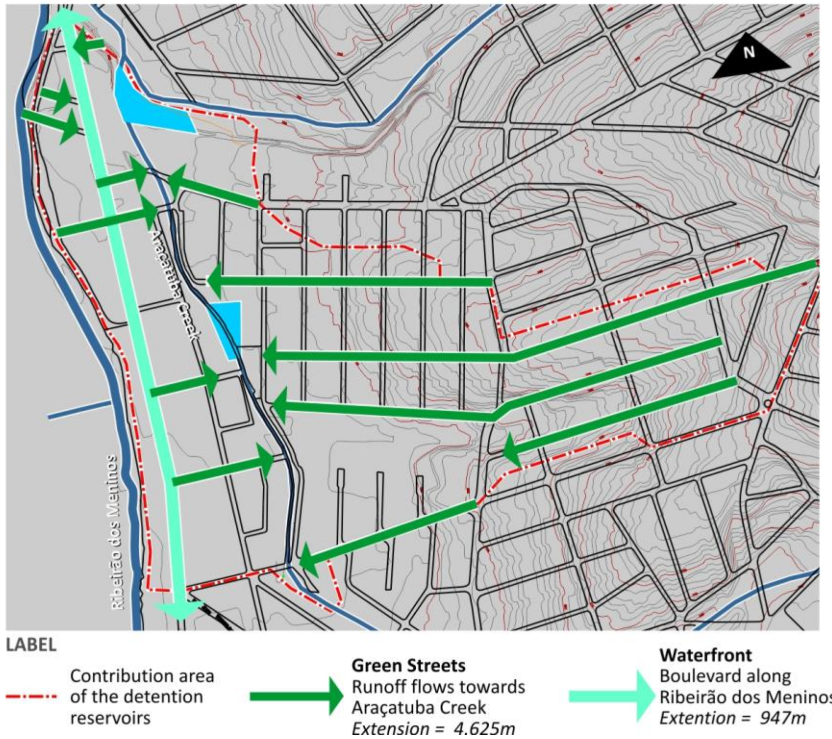

Figure 6: Network of green streets and waterfront.

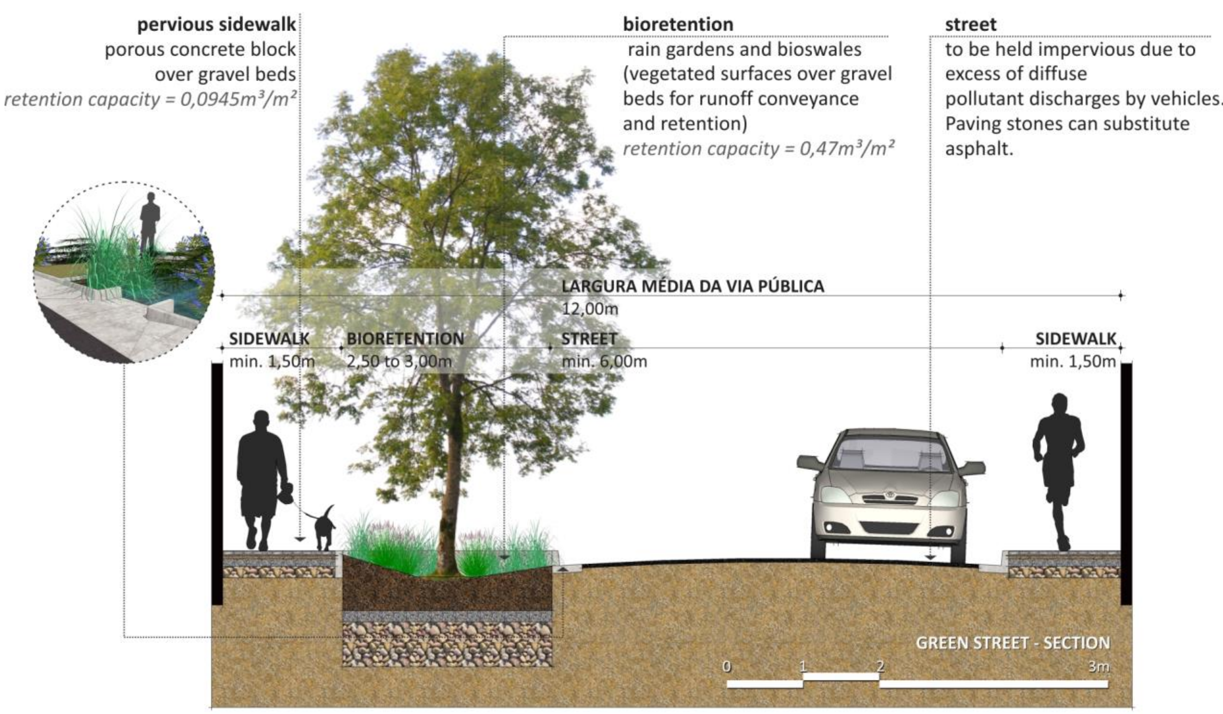

Figure 7: Green street - section.

Figure 8: Green street - detail.

Considering the construction details of these elements (Figures 7 and 8), the retention capacity (storage in m³/area in m²) of each has been calculated from the porosity of the materials used (cf. Virgilis, 2009; Pinto, 2011) (Tables 1 and 2). Regardless the natural ground infiltration and evapotranspiration by the vegetation cover, a total volume of runoff retention is possibly held by stormwater BMP techniques, which corresponds to approximately 42% of the detention volume in the reservoirs (Table 3).

parameters for calculating porosity	gravel	bedrock
apparent specific gravity (g/cm³) • γ_d	2,169	1,491
real density of grains (g/cm³) • G_s	2,643	2,704
real density of water at 25° C • γ_w	1,00	1,00
porosity (*n*)	**0,18**	**0,45**

$$n = \frac{\gamma_d}{G_s \cdot \gamma_w}$$

Table 1: Calculating the porosity of the materials used.

	h BGS	h B3	n_m	volume de retenção/m²
bioretention	15cm	60cm	0,396	0,296+0,174 = **0,47m³**
porous pavements	15cm	15cm	0,315	**0,0945m³**
porous accesses	15cm	15cm	0,315	**0,0945m³**

retention volume from gravel layers + runoff volume accumulated over bioretention elements (58% of a 30cm layer)

$$n_m = \frac{(h_1 \times n_1) + (h_2 \times n_2) + \dots + (h_n \times n_n)}{h_1 + h_2 + \dots + h_n}$$

Table 2: Calculating the volume of retention/m² of bioretention elements and pervious pavements.

5.572m linear extention of the streets **37.342,50m²** pervious areas	**area 31,18% bioretention** 11.643,39m²	**area 58,70% sidewalks** 21.920,04m²	**area 10,12% accesses** 3.779,06m²
retention volume **7.900,63m³**	**volume 69,26% bioretention** 5.472,07m³	**volume 26,21% sidewalks** 2.071,44m³	**volume 4,53% accesses** 357,12m³

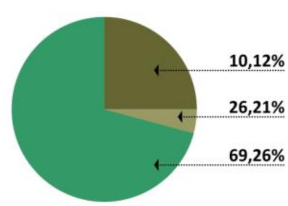

Table 3: Calculating the total storage volume by BMP in the contribution area.

5. CONCLUSIONS

Climate change implies several challenges specially to the built environment. Since the urban infrastructure for drainage and flooding control has already reached its limit or is very close it, the predicted intensification of extreme rainfall events will soon create a greater and unprecedented demand for stormwater management. The need to adapt cities to this scenario is imminent and calls for more sustainable solutions, which will provide us with urban resiliency, a key role for the uncertain future. From the results obtained from the case study, considering the permeable pavements and bioretention, one can conclude that:

- stormwater BMP are technically viable alternatives to increase the stock of retention volume in urban areas, specially when regarding the trend of increased intensity and frequency in extreme precipitation;

- these solutions can be used to complement or replace conventional drainage and stormwater control structures. In both situations, comparative costs and feasibility of the technical possibilities must be taken into account in order to choose the best available technology;

- employment of stormwater BMP in new development areas is less expensive and involves less impacts than in retrofitting consolidated areas, considering that in the former situation there will be no demolition costs or construction wastes. In both cases, though, bioretention and porous pavements can ensure greater longevity for drainage infrastructure and avoid future investments with the implementation of detention reservoirs, which have expected drawbacks in maintenance and operation. BMP are therefore an important tool among public policies that strategically aim adaptation of the urban environment to the challenges of climate change;

- BMP techniques are relatively new solutions when compared to conventional technologies of drainage and stormwater control. Therefore they are still in evolution process, yet presentin inaccuracies regarding the intended results and lack of information about costs, maintenance, operation and Life Cycle Analysis (LCA);

- since they are more naturalized and more suited to pre-urban water cycle, such solutions have less impact on the built environment, however, their technical efficiency depends on local conditions, which may also limit their use, such as shallow groundwater, superficial bedrocks, collapsible soil and very sloping areas.

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