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Research Article

Permeable paving alternatives for expansion areas of Sub-basin St. Mary Magdalene

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Abstract

Jackets and floors of structures that have the ability to drain the water and send it, by infiltration to the lower layers of the soil, have relevance to ease the flooding caused mainly by the increase in number of dwellings, and the growth of waterproof coatings, and consequent deficiency in urban drainage. This study evaluated the effectiveness of permeable pavements in reducing runoff, by comparing the experimental simulations flow generated in various kinds of floor. The comparative analysis between the permeable pavements and conventional allowed a study to better occupation of the sub-basin St. Mary Magdalene in the city of São Carlos, SP. From the feasibility study of permeable pavements, the flow calculation, four scenarios were developed with four types of permeable pavements, simulating the use of these new materials in urban expansions possible according to the Master Plan of the city. With the results obtained in the simulations of the current situation and the other four scenarios, permeable materials have a flow less than conventional materials and show that streets and sidewalks rather contribute to runoff and should be used primarily for stage areas urban expansion, due to the ease of deployment and its benefits to the environment. Despite the cost analysis proves unfavorable to the implementation of permeable pavements, it is concluded that the environmental benefits and in improving the quality of life are unmatched, and led to a degree of extreme importance in the cost calculation benefíciopara a later occupation sub-basin under study.

Keywords: urban drainage, runoff, permeable pavements; St. Mary Magdalene.

INTRODUCTION

One of the main impacts that the development of an urban area causes the hydrological processes is related to the increase in impervious surfaces. In Brazil, cities grew up without proper planning of land use. The population explosion and the lack of government policies have led to an improper occupation of floodplains and changes in river regimes, due to the removal of vegetation cover and the large soil sealing throughout the basin area. The latter decreases the infiltration capacity, resulting in increased runoff. Thus, the peak of the floods is increased and the time of arrival of water to the rivers is reduced. This increase in runoff, combined with the occupation of the banks of rivers and streams, aggravates the problem of urban flooding (Polastre and Santos, 2006).

A new bill the State Legislative Assembly of the Holy Spirit shows that, on the issue of floods, traditional sanitary concepts of construction works aimed at getting rid of water as quickly as possible (such as gutters, gutters, sluice gates and straightening of the river channel) only transfer the problem of full downstream, as accelerate the flow of water.

In addition, such interventions involve high costs, and environmental problems (due to solid waste) and the interconnection of storm water pipes to the sewage systems, commonly done in Brazil. Because of this widely used system, the money spent occurs twice. First when inadequate urban drainage projects are developed; and the second, when it is necessary to invest more money to restore areas flooded due to bad projects.

In recent years, they have been applied and developed worldwide, especially in developed countries, new concepts of management of rainwater in urban areas. Known as "best management practices" (BMPs or), aim the damping of the floods from the source of the problem and improving water quality from runoff. These operations are based on micro accumulation reservoirs, chemical and biological filters and increased permeability areas. They are arranged in combined mode in the basin in order to approximate the behavior of urban rainwater to pre-urbanization flows, while still getting secondary use these waters. Thus, one of the principles of this reasoning is to treat storm water waters where they fall, preventing its displacement and subsequent increase in their volume, speed and pollution (Polastre and Santos, 2006).

In Brazil, several studies have been conducted to evaluate the efficiency and applicability of these structures to damp the floods. In developed countries, more advanced in this respect, we can see the concern for water quality and various practical applications in order to reuse it (Polastre and Santos, 2006).

In the process of managing storm water, municipal role is fundamental, with the creation of laws and preventive measures, as well as the enforcement of these standards. There are measures that are available to any resident of the city, such as porous pavements, gutters that dump rainwater in gardens, permeable covers, etc. He is emphatic that the key to the management of floods is to recover the infiltration capacity of the soil.

It is in this context that the present work, the permeable concrete and other permeable paving alternatives will be analyzed and contextualized, so that through the creation of scenarios, the best coverage in the areas of urban expansion of the Sub-basin of the Santa Maria Magdalene is proposed.

OBJECTIVES

General purpose

Identify the permeable pavements options for better implementation in the study basin Santa Maria Leme, which is in the process of urbanization, as a possible preventive measure and defense against critical hydrological future events, and thus offer subsidies to planning activities and urban local expansion.

Specific goals

- Identification of permeable paving options available on the market;
- Creation of current and future scenarios of occupation, for comparative effects of stormwater runoff;
- Analysis and future scenario proposition better suited to environmental improvement.

Context

Sub-basin St. Mary Magdalene

The study area is the sub-basin St. Mary Magdalene or also known as Santa Marai Leme, located in São Carlos - this is between coordinates 197000-209000 E e7553000 to 7,568,000 N (Pedro and Lorandi, 2004).

The region of São Carlos has the Altitude Tropical climate, or has dry winters and rainy summers (SEE, 1992). The temperature of this region varies near 21°C and the precipitation is between 1100 mm and 1500 mm per year (Oda, 1995).

The original vegetation consisted predominantly of Cerrado and semi-deciduous seasonal forest, but now what lies are remnants of these ecosystems, due to pressure from agricultural activities, mining and forestry (Espíndola et al., 2000).

The Sub-basin Stream St. Mary Magdalene has the lowest percentage of urban settlement within the river basin Monjolinho, the main use of the rural activity. Nevertheless, the degradation was observed by the removal of riparian vegetation, including the head region. Associated with this degradation, the observed damage refer to the risk of contamination of surface and groundwater by the absence of vegetation. Also has the risk of formation of erosion due to steep slopes in the valley and the presence of sandy material, the release of rainwater with high speed in the watercourse (Pons, 2006).

The sub-basin has an area of 11.43 km² and a perimeter of 15.32 km, with its main river is the Stream St. Mary Magdalene, 2nd order (Figure 1) and with an approximate length of 4.7 km . Suas springs are located upstream of the Washington Luis highway in a predominantly rural area with pastures and agriculture, whereas 16% urban occupation.

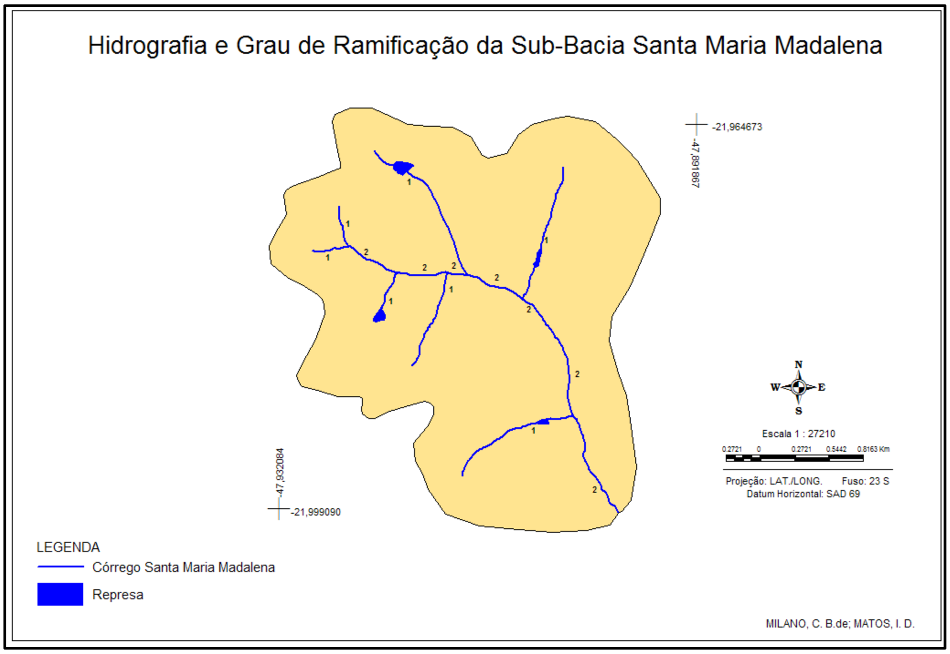

Figure 1. Hydrography and degree of branching sub-basin
Source: MILANO, C.B. in; MATOS, 2011

CHARACTERIZATION FLUVIOMETRIC

Compactness factor (Kc)

It is the relationship between the perimeters of the bowl and of a circle of area equal to the basin.
P = 15.36 km
A = 11.86 km²

Where P is the perimeter of the basin and A, basin area.
$Kc \times D = 0.28 / \sqrt{A} = 0.28 \times 15.36 / 3.44 = 1.25$
With the value of compactness factor 1.25, the Basin has a medium risk propensity to flood.

Form Factor (KF)

It is the ratio of the average width of the basin (L) and the axial length of the watercourse (L). The length "L" is measured following the stroke d 'longer water farthest from the head to the mouth of the basin. The average width is obtained by dividing the area of the basin by the length of the basin. L = 4.710 km
Kf = A / L2 = 0.53

The basin has an average form factor so the basin has an average risk of flooding.

Drainage Density (Dd)

The drainage density is expressed by the total length of all watercourses (segments) of a bowl and its total area. The higher the density, the greater the flow and the volume flow.

Size of the segments = 4.710 + 1.687 + 0.3665 + 0.4162 + 1.019 + 1.4 + 1.351 = 10.9497 = ΣliDd = Σli / A = 0.9232 km / km2

With the data obtained, it is concluded that the drain bowl has a low density.

Extension average Superficial flow (l)

This parameter indicates the average distance that rain water would have to flow over the land of the basin (straight) from the point where precipitation occurred to the course d 'nearest water. It gives an idea of the average distance from the runoff.
l = A / = 0.27 km 4Σli

Sinuosity of the water body (Sin)

Ratio between the length of the main stream (L) and the length of a talvegue (Lt). This is a factor of the flow rate controller.

= Sin U / I = 1.082 (not very sinuous, i.e., shows a flow rate not so low).

Average Slope Basin (Dm)

Dm = ΣDiAi / A where Di is the average slope between two curves levels, Ai is the area between two curves levels in m^2 and A is the area of the Basin in m^2. To obtain the result, it was calculated, first, the ratio of the difference between altitudes (between contour) and the distance between the contour lines. For this polygons were made (according to the distance of the contours and elevations).
Dm = (50.62 x 5.145) + (100 x 1.661) + (25.84 x 4.614) + (1.25 x 0.1801) + (1.27 x 0.2661) / 11.86

Elevation (altitude) average Basin (H)

Table 1. Data for obtaining the average elevation of the basin

Cotas	Ponto Médio	Área	Área Acumulada	% da área Acumulada	Ponto médio x área
890 - 880	885	0,1819	0,1819	1,53	160,9815
870 - 860	865	4,615	4,7969	40,43	3991,975
860 - 840	850	5,141	9,9379	83,77	4369,85
840 - 820	830	1,66	11,5979	97,76	1377,8
820 - 810	815	0,2652	11,8631	100	216,138
Somatória		11,863		10116,7445	

H = Σ ha / A, where h is the average elevation between two consecutive contour lines and is the area between the contour lines.

M H = 852.79

Use and Occupation

With a total area of approximately 11km², use and soil occupation sub-basin St. Mary Magdalene (Figure 2) are composed of urban areas (33% of the total basin area), grasslands (25%), rural facilities (0.6%), agriculture (14%), bare soil (5%), riparian vegetation (14%), native forest (3%), cerrado vegetation (2.4%) and road network (3%) (swift; CARVALHO, 2011). The sub-basin has a population of 8,478 inhabitants, the population density of 7.8 inhabitants / ha (Giuntoli, 2008).

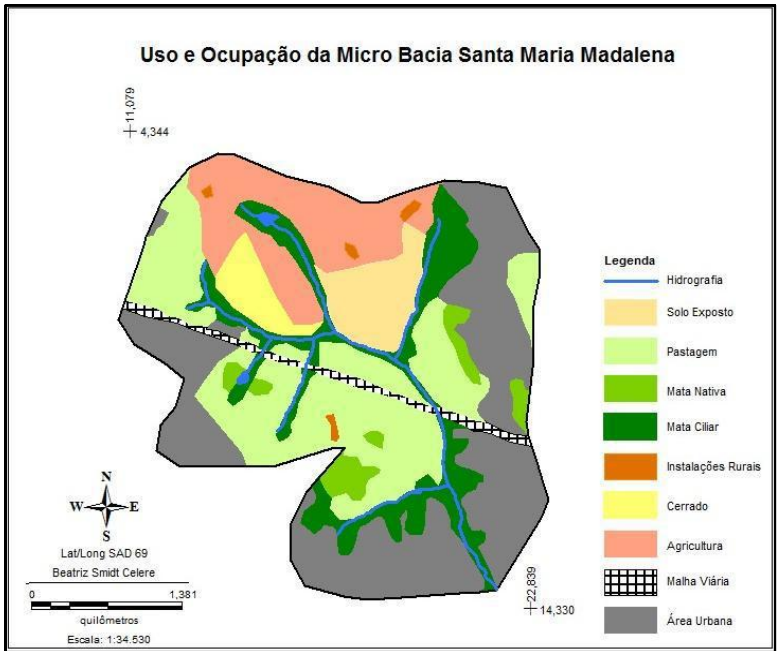

Figure 2. Use and occupancy of the soil sub-basin St. Mary Magdalene
Source: swift; Carvalho, 2011

Rural areas of the study have an urban sprawl planning, according to the Master Plan 2005 in São Carlos, these areas are inserted in the areas of: induced occupation, occupation and regulation conditioned and controlled occupation. Already in the Master Plan 2011 some areas already have installment guidelines, showing a clear trend waterproofing site under study.

REASONS

The continuous development of cities tends to increase the impervious areas and to decrease the permeability of the soil. As a result, less rain water will seep underground, leaving more water to drain through the streets and avenues, from the storm sewer not meet the new demands. This leads to the occurrence of flooding that can be ameliorated or eliminated through the use of floor structures with having the ability to absorb waters abundant. The higher the permeability of the subgrade soil and the storage capacity of the floor structure, more rainwater can penetrate the subsurface and therefore less water will flow over the surface reducing the risk of flooding that generate large losses. As it is impossible to prevent the growth of cities, we must find solutions to a better quality of life for people with the use of new technologies such as the permeable pavements (Sales, 2008).

The extensive waterproofing of urban land due to rapid growth of cities has contributed to the generation of urban flood events that recur and worsen each year if crediting to this responsibility for 50% of all victims of natural disasters in world, between 1966 and 1990 (Chocat, 1997).

The National Water Agency (ANA) in conjunction with the Civil Defense is mobilizing investment in developing the Induction Program for Water Management in Urban Environment and Flood Control. According to ANA, the occurrence of floods in urban areas in Brazil has intensified and become more frequent every year and one of the factors that contribute to this deterioration is the increasing soil sealing, resulting from rapid urbanization, resulting in the occurrence of peaks increasingly difficult to flow control by traditional structural interventions (Ana, 2006).

With regard to urban drainage, the impact of urbanization is transferred downstream, ie, those producing the impact is not generally the same as that suffers the consequences. Therefore, for a better solution of the problem, it is necessary, in principle, interference of public action through regulation and planning, is an important instrument called the Master Plan for Urban Drainage (Tucci, 2002).

Thanks to the operating principle, which allows storage, infiltration and the delayed flow is clearly stated that the floors that have the ability to drain the water through the structure represent an appropriate means to meet the requirements of a management system of water. In this same focus, the nature protection organizations consider the floors that drain rainwater a good management tool with regard to the problem of water seeping surface (Sales, 2008).

The main advantage of using this type of structure for urban pavements, undoubtedly is focused on reducing flooding and flooding as mentioned above. But beyond this, the use of this system has other advantages, which will be presented throughout this work (Sales, 2008).

Following this line, the case study occurs in the sub-basin St. Mary Magdalene, which is increasingly becoming urbanized, also motivated to be a growth industry. In view of urban expansion in the north vector is noticeable the imminent occupation of the basin, which makes up one of the empty ones in the direction of urban growth vector. According to the Master Plan, the map of guidelines for urban expansion expresses the number of requests for projects in the region.

Among the devices that seek to restore the original conditions soil flow of retention is the permeable paving, it is an infiltration device where the runoff is diverted through a permeable surface into a reservoir rocks through which percolates through the soil and may undergo evaporation or reach the water table (Urbonas and Stahre, 1993).

Research has been conducted in several countries, in order to master the technique of permeable paving, to assess their behavior, their efficiency and durability, and in Brazil, this device is still little known and little used (Acioli, 2005).

In this context, this paper aims to contribute to the unprecedented implementation of a permeable paving in Brazil, and assessing the feasibility of their use in specific climate and soil conditions of the sub-baciado Santa Maria Helm in the city of São Carlos, São Paulo . As a contribution to preparing current and future scenarios that compare the flow of rain water.

FOUNDATION THEORY

Permeable pavements

The traditional drainage system based on the rapid clearance of excess rainwater, contributes to an increase in the drained volume and peak flow and a reduction in the flow time causing full hydrograms are most critical, with increasing thereby the frequency and severity of flooding (Acioli, 2005).

Among the main impacts of urbanization, are mentioned (Ciria, 1996):

• Increase in the volume of runoff;
• Increased frequency of floods, as well as its intensity;
• Soil moisture reduction, which leads to a reduction of the water table;
• Decreased base flow of rivers;
• Reduction of potential storage, and transport capacity of river valleys;
• pollutant load increase due to network or rainwater runoff.

One of the steps for the modernization of the urban drainage system is the adoption of control in the generation of runoff source. Suderhsa (2002) divides the drainage alternative techniques into two groups, which follow two basic principles:

• Infiltration of water in the soil, where possible, to reduce runoff downstream (infiltration devices).
• The temporary storage of rainwater, to control runoff and limiting downstream pollution.

According Azzout et al. (1994), among the advantages of these types of drainage techniques, are:

• The maintenance of the pre-urbanization of the local conditions with respect to runoff;
• Lower costs than traditional solution, or, for an equivalent cost, techniques offer superior protection against the risk of flooding;
• Possibility of aesthetic integration to the environment, reaching contribute to the development of the site. Forexample, in the case of the use pavimentospermeáveis.

Despite these advantages, alternative urban drainage techniques are still widely used, especially in developing countries. Azzout et al. (1994) and Epa (1999) show the use braking factors, some disadvantages:

• relatively new techniques are, where they do not exactly know their behavior over time, and are not entirely dominated design techniques, implementation and maintenance;
• They are complex devices that can change in a significant way the ordination of a site;
• The design, implementation, maintenance and operation depend on the environment in which the devices, the physical, social and institutional point of view are included.
• Little expertise of engineers and contractors with respect to technology;
• There is a risk of aquifer contamination, depending on soil conditions and the susceptibility of the aquifer;
• The porous pavement and has a tendency to become clogged if improperly installed or maintained.

Araújo et al. (2000) used a rainfall simulator to compare the runoff values generated by six different surfaces used in paving. These were:

(i) compacted soil;
(Ii) conventional concrete;
(Iii) cobblestone pavement and sand together;

(Iv) pavement with concrete blocks and sand together;
(V) hollow concrete blocks, filled with sand;
(Vi) porous concrete. It used a rain simulator 1m² modules each surface (see Figure 3), and came to the values runoff coefficients shown in Figure 4, where the simulated rain has five years. Among the studied surfaces, porous concrete and hollow blocks have runoff coefficient values of the order of only 5%.

Figure 3. 1m² modules used in the simulation of surface runoff (Araujo et al., 2000)

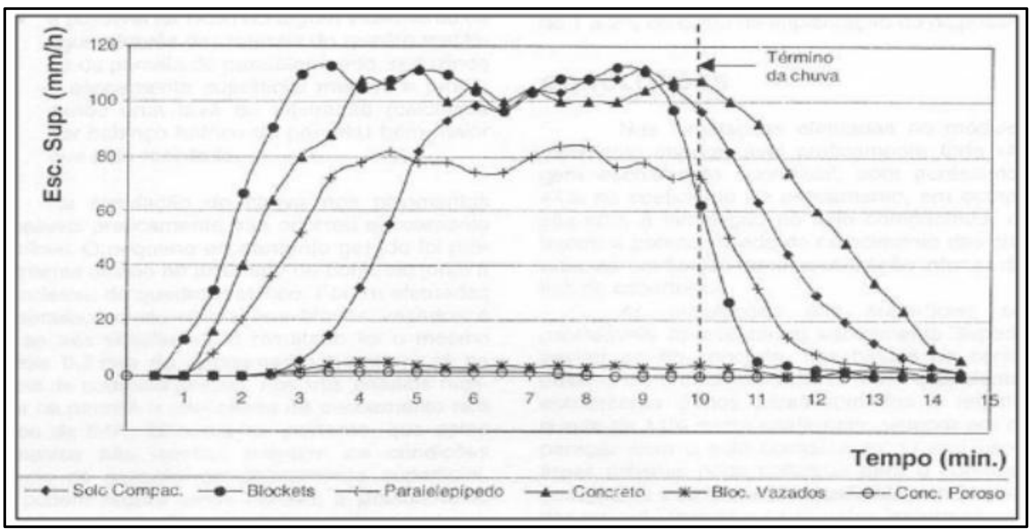

Figure 4. Runoff observed in the different surfaces tested for rain with return time of five years (Araujo et al., 2000)

The permeable paving is one which has significantly higher porosity and permeability in order to influence the hydrology and causing some positive effect on the environment (Virgiliis, 2009).

In Brazil, permeable paving is one of control techniques at the source of the flow proposed by the majority of Master Plans of the cities (Tucci, 2000). However, its implementation comes up against the lack of knowledge of professionals and contractors, which tends to be decreased with continued study.

The permeable pavements can also be known as a reservoir structures. According to Rimbaud et al. (2002) and Acioli (2005), the description refers to functions performed by the porous matrix of which they consist:

• mechanical function, associated with the term structure, which allows it to support the loads imposed by vehicle traffic.

• Hydraulic function, associated with the term reservoir which ensures the porosity of the material, temporarily retain water followed by draining and if possible infiltration into the soil subgrade

Components of porous pavements

Any porous pavements as conventional basically consist of the same components. Table 1 defines some types of components used in paving. A few floors have everything listed, instead, each deck must have a specific combination atendas your needs (Virgiliis 2009).

Table 2. Terminology often applied to porous surfaces

Terminologia aplicada a Pavimentos Porosos	
Terminologia	**Definição**
Camada de base	Camada colocada abaixo da superfície de revestimento para aumentar a espessura do pavimento. Pode ser chamada de base.
Camada	Espaço ocupado entre dois tipos de materiais na estrutura do pavimento.
Camada filtrante	Qualquer camada entre outras ou entre o pavimento e o subleito que detenha a migração de partículas para os vazios da camada subjacente.
Geomembrana	Tecido impermeável geralmente plástico ou Polietileno de Alta Densidade (PEAD) utilizada em sistemas impermeabilizantes.
Geotextil	Manta não tecida de filamentos de polipropileno que possibilita a livre passagem das águas de infiltração para o meio drenante.
Pavimento	Qualquer tratamento ou cobertura na superfície que suporte qualquer tipo de tráfego.
Sobrecamada	Camada aplicada sobre qualquer tipo de pavimento preexistente.
Estrutura do pavimento	Combinação de camadas de materiais colocadas sobre o subleito que possibilitam o suporte mecânico do pavimento.
Reservatório	Qualquer parte do pavimento com capacidade de estocagem e condutividade de água. Pode ser sobreposto ou combinado com outras camadas do pavimento.
Sub-base	Camada colocada abaixo da Base a fim de aumentar a espessura do pavimento.
Subleito	Solo natural ou reforçado abaixo da estrutura do pavimento, responsável pela absorção em ultima instancia dos carregamentos.
Revestimento	Camada do pavimento que recebe diretamente a carga de tráfego.

Source: Virgiliis (2009)

Materials used in Permeable Pavements

Ferguson, 2005 generically classified permeable flooring materials families:
• Aggregates
• Grasses
• Plastic geocells
• Porous Concrete
• Hollow blocks
• Concrete blocks interlocked
• Concrete porous asphalt / concrete permeable

Brief history of deployment in other countries

Traditionally, paving seek give the coating maximum tightness possible. This measure aims to provide the soil protection against increased humidity, which would decrease their carrying capacity, as well as prevent the rapid degradation of the coating, which crack when subjected to pressures due to water (Acioli, 2005).

With the growth of the road network around the world, along with the growth of cities, soil sealing made to increase the frequency and intensity of intra-urban flooding events. This led him to seek alternative techniques for drainage give back to the soil infiltration capacity of previous urbanization (Acioli, 2005).

The pavement with porous structure was first used in France in the years 1945-1950, but without much success, because the quality of bitumen at the time did not support the connections of the structure, due to excess empty. It was used again only twenty years later, in the late 1970s when some countries such as France, the United States, Japan and Sweden, returned to be interested in porous pavement (Azzout et al., 1994). The main reasons that led to the use of permeable pavements were:

• The increase in impervious surfaces, due to the rapid population growth of the postwar overloaded the existing drainage systems, leading to frequent urban flooding.

• The drain water prevents the formation of puddles on the floor, which increases the safety and comfort for driving during rain events.

• The reduced noise emission level compared with the conventional floors, which helps reduce noise pollution in cities.

In the United States, several states have created laws changing the goals and methods of urban drainage, imposing the maximum temporary storage or infiltration of runoff water. In some cases, the stored water was conducted for various uses, such as irrigation (Azzout et al., 1994).

In France, the "Ministère de l'Equipement" launched in 1978 a research program to explore new solutions to reduce flooding. Among these surveys, permeable paving, also called pavement with reservoir structure, stood out as one of the most interesting solutions, thanks to its ease of integration into the environment of cities. Since then, permeable paving became the subject of research and trials, so that was reached mastery of technique and its advantages. The permeable paving then passed through an important industrial development started in 1987 and is now widely used in roads, sidewalks, squares, etc. (Azzout et al., 1994).

In Japan, permeable paving is integrated with programs that include all infiltration techniques. Such techniques are used primarily in blocks of big cities, in places available and can be flooded, such as sports facilities of universities, school yards, etc. One can cite as an example the city of Yokohama, which peaked at 4.4 million in 1994, and so, since 1982, has studied the flow control techniques at source, among them permeable paving (Watanabe, 1995).

More recently, other countries have adopted the control at source of runoff as a goal for problem solving in urban drainage. Among them, Australia, since 1996, has researched the techniques of control at source through the UWRC (Urban Water Resources Centre), which has incorporated the techniques to various urban allotments projects, industrial land and parking lots. (UWRC 2004)

5.3. Negative aspects related to soil impermeability

The soil sealing process causes it to lose its natural ability to infiltration. Where before the water percolavam naturally in the soil, they are installed waterproof elements, such as basalt tiles, asphaltic concrete or Portland concrete. This increases the volume of runoff and promotes rapid transportation of water to the lower areas, favoring the occurrence of floods.

As advances the soil sealing process, it is noted that the impacts on the hydrological cycle of the affected regions will worsen. One consequence is the reduction in the level of the water table, it ceases to be replenished by rain. Lerner (1990), speaks in a loss of 10 to 50% in water supply networks in large urban centers. This volume, seeping of urban networks, together with the precipitation ends recharging aquifers that receive discharges between 100-300 mm / year. Another is to change the movement of the water flow in the basin.

These changes led to an increase in the hydrograph. Where previously rainwater percolavam naturally in the soil, it now does not occur, so that these remain lower in some places, causing many disorders, as illustrated in Figure 5.

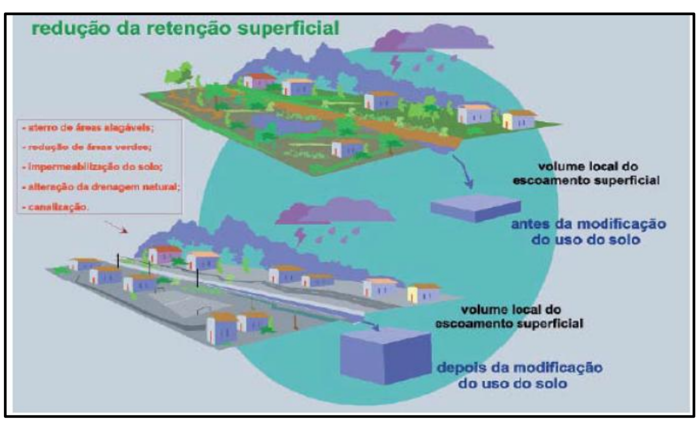

Figure 5. Comparison between hydrograph before and after the process of urbanization. Source: Polastre and Santos, 2006

With the removal of vegetation and the change to the environment, and the loss of infiltration capacity of the soil, there is also a significant reduction in evapotranspiration. Explains Tucci (2007), with the absence of vegetation, which retains water inside the sealed surfaces end up not performing this important function. Consequently, the heat balance is affected. In large cities, where there are many roofs, asphalt and similar buildings, heat retention occurs, and, in warmer weather, this phenomenon is slowed down by evaporation. When the soil is dry, such compensation does not occur.

Another important point associated with the issue of lack of management of rainwater, increasing runoff, involves loading of solid waste. Neves (2006) points out that, together with uncontrolled urbanization of large cities and soil waterproofing concrete and asphalt, there is a tendency to increase the generation of solid waste, which are often stored in the streets, waiting for collection, and they are loaded by the floods, blocking the pipes and increase the drainage problems. In addition to the drainage problems, the loading of solid waste causes a deterioration of water quality, which can threaten the water supply systems. Table 3 below presents a summary of the study on the question of rainwater in big cities, taking into account the main types of urban land use.

Table 2. Relations between sources, changes and consequences of rainwater in large cities.

Fontes	Alterações	Principais consequências
Ocupação, residencial/comercial	Desmatamento, impermeabilização, condutos e canais, depósitos, etc.	Inundações urbanas; erosão do solo e material solido, contaminação da qualidade da água superficial, contaminação de aquíferos e alteração da biodiversidade.
Infra-estrutura urbana: ruas, parques, passeios, comunicação, etc.	Desmatamento, impermeabilização dos espaços, condutos e canais.	Inundações urbanas, erosão do solo e material solido, contaminação da qualidade da água superficial.
Serviços; comercio, transporte, água e esgoto, postos de gasolina	Emissão de gases, vazamentos, depósitos de produtos químicos e usos de produtos nos serviços, efluentes de esgoto.	Contaminação de aquíferos, da qualidade da água superficial devido à poluição aérea e dos esgotos, alteração na biodiversidade.
Ocupação e produção industrial.	Efluentes industrias, emissão de gases, impermeabilização e condutos.	Inundações, contaminação superficial e subterrânea, alteração da biodiversidade com componentes químicos.

Source: Tucci, (2007)

Types of Floors Permeable

The porous pavements are also known as shell structures. Raimbaultet al. (2002) state that this description refers to functions performed by the porous matrix of which they consist:

• mechanical function, associated with the term structure, which allows it to support the loads imposed by traffic vehicles;

• Hydraulic function (associated with the term reservoir) which provides for the porosity of the material, temporarily withhold the waters, followed by drainage, and if possible, by infiltration of the subgrade soil.

Azzoutet al. (1994) featuring four types of porous pavements. According to them, the floor may have drainage or waterproof coating and still have the infiltration function or just storage.

Permeable concrete

To Polastre and Santos (2006), permeable concrete must have a high rate of interconnected voids, with little or no sand portion in its composition to allow percolation of large amounts of rainwater. When the material is suitably dimensioned to their degree of permeability is sufficient to allow the passage of all the precipitate flow in the majority of rain events, practically nullifying runoff and reducing peak floods. Due to the high porosity of the permeable concrete as shown in Figure 6, it may allow passage of a quantity of water that reaches 5.080 mm / h per 0.09 m², which translates to 11.4 to 19 L / min (Huffman, 2005).

Figure 6. illustrative permeability of concrete
Source: Ecodevelopment, 2009

For the production of permeable concrete it is very important to form interconnected voids, as shown in Figure 7, indeed essential to ensure the permeability of rainwater. For this reason, most of the mixtures do not use fine aggregate (sand), and concrete made with only water, cement and coarse aggregate covered with a fairly thick layer of cement and water. In some cases they use small amounts of sand to increase the volume of the covering layer, without increasing the cost. With this strategy usually get a material with a voids between 15-25%, and percolation capacity of around 200L / min, a lower porosity may compromise their hydraulic properties (Montes and Haselbach, 2006). However, due to its high porosity, the strength of the concrete can be more reduced compared to conventional concrete. So its use is often limited to light traffic areas or little intense, as sidewalks, parking lots, low traffic streets, etc. (Polastre and Santos, 2006).

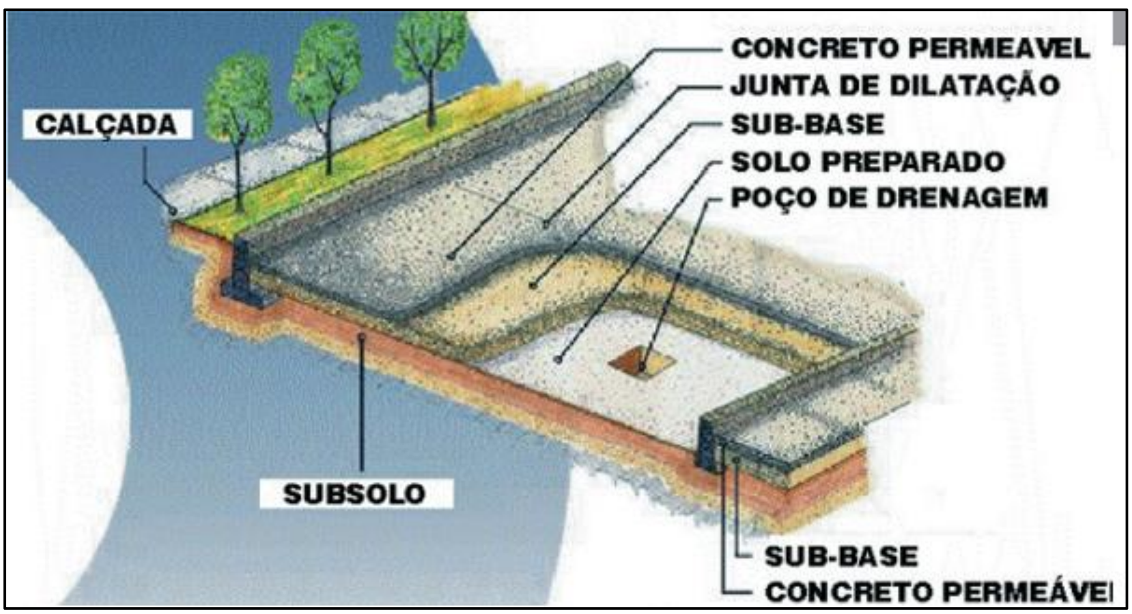

Figure 7. Illustration of the implementation of permeable concrete
Source: Civil Pet UFJF, 2011

The main applications of the material stand out: sidewalks; parking lots; low-traffic streets; parks and squares; residential courtyards; tennis courts; golf courses; hydraulic structures; Greenhouse plants etc.

Research of the Institute of Hydraulic Research (IPH) of UFRGS, reported by Araujo et al. (1990) evaluated the effectiveness of permeable pavements in reducing runoff. It was noticed in testing that impervious surfaces typically used in urban paving with asphalt use, concrete slabs and stones, eventually generating a runoff 44% higher than other surfaces such as compacted soil. Already in the semi-permeable areas, made up of permeable pavements and cobbled bloquetos was recorded a level of flow below the impervious areas, but still 11-22% higher than in compacted soils. When used permeable concrete virtually no runoff occurred. This demonstrates that this new technology can actually help mitigate floods, reversing, at least in part, the problematic framework associated with high soil sealing.

Regarding the economic advantages of permeable concrete production it is that it has low density (incorporating many empty) and can be performed on site, using local materials, avoiding high transport costs. In addition, it should be noted that pervious concrete can be manufactured using low-tech and labor-intensive unskilled, to even receive adequate basic training. Ie to opt for permeable concrete there is the possibility of helping local economies to use hand labor and local materials (Polastre and Santos, 2006).

The permeable concrete also has economic benefits include: a reduction of spending on big pools, pump, drain pipe and other urban drainage systems; stormwater retention areas (tanks) can be reduced or eliminated, making better use of the floor area of the ground; is adaptable to different regions, using local materials for aggregates and other components; the choice of this concrete is good for local economies, requiring companies close to transport and application, as well as hand possible use of labor and local materials; decreases maintenance costs, since it is effective with little or no maintenance for a period between 20 and 40; lower cost during the life cycle when compared to other alternatives, such as asphalt.

Although the initial cost of application is somewhat higher than the asphalt, pervious concrete is more economical, as has durability and superior resistance, requiring fewer repairs; There is little waste, since it is done directly on site according to the project's needs, and may be recycled; permeable concrete is strongly recommended for the low cost of the life cycle, or the cost to build, maintain, dismantle and recycle is low.

An important aspect favors the use of permeable concrete, from the point of view of sustainability, is that EPA (US Environmental ProtectionAgency) classified the same as an appropriate management practices (Best Practice Management - BMP). Thus, their use can help a project earn LEED certification (US Green BuildingCouncilLeadership in Energy and Environmental Desing) (Holtz, 2011).

LEED for evaluation purposes, the sustainability of permeable concrete comes from three basic characteristics:

- Assists in reducing the earth warming by allowing the exchange of heat between the underground and the surface;
- It is a recyclable material that could be recycled after their life cycle;
- Can be made with local materials.

This type of pavement and allows better water infiltration into the soil and aquifers, it also reduces runoff and peak floods. Its lighter color absorbs less solar radiation and its sparse structure stores less heat, assisting in the reduction of heating in urban areas, it also facilitates the survival of trees located on paved areas, by allowing the arrival of air and water to the plant roots.

In Brazil, the permeable concrete it is an innovation applied in pilot projects around the country. In 2006, in Belo Horizonte (MG), began construction of the Technology Park Belo Horizonte (BH-Tec), operating near the Pampulha campus of UFMG. According to the works coordinator, Eduardo Roscoe, the project was designed to run in an environmentally sound way and have unprecedented nature in Latin America. The paving space is permeable concrete. A vezque reduces flood risk and feeds the headwaters of the park. In June 2006, the Secretariat for Coordination of Subprefectures of São Paulo, in partnership with organizations and companies, reported that he was testing new technologies through pilot projects that are recovering degraded areas of the city. In this project, CASACOR would have the role to test the living pavement, using, among other innovations, the permeable concrete, because it allows for feedback from the water table. (Polastre and Santos, 2006).

Permeable asphalt

Porous asphalt pavement, porous concrete are manufactured similarly to the conventional pavements, the basic difference is that the fines are removed from the mixture.

Porous pavements developed by the Polytechnic School (Poli) of USP can absorb easily and quickly rainwater and can help reduce the impacts of floods. According to professor and research coordinator José Rodolfo Scarati Martins, "the pavements act as if they were sand and allow the water from reaching rivers and streams with half the speed."

A research experiment containing both types of pavement - one made with concrete slabs and the other with common asphalt mixed with additives - has developed into one of the parking lots Poli and managed to retain almost 100% of rainwater for the months of January and February in 2010. The differential of porous pavements developed by Poly compared to existing due to the fact of possessing a 35cm stones base, which is responsible for retaining water for a few hours and decrease the likelihood of flooding on site.

The difference between the two types of flooring on the surface (Figure 8), one is made with concrete and the other with common asphalt. "Even with minor differences between them, both retains large percentage of water compared to conventional asphalt and work very effectively," says the researcher.

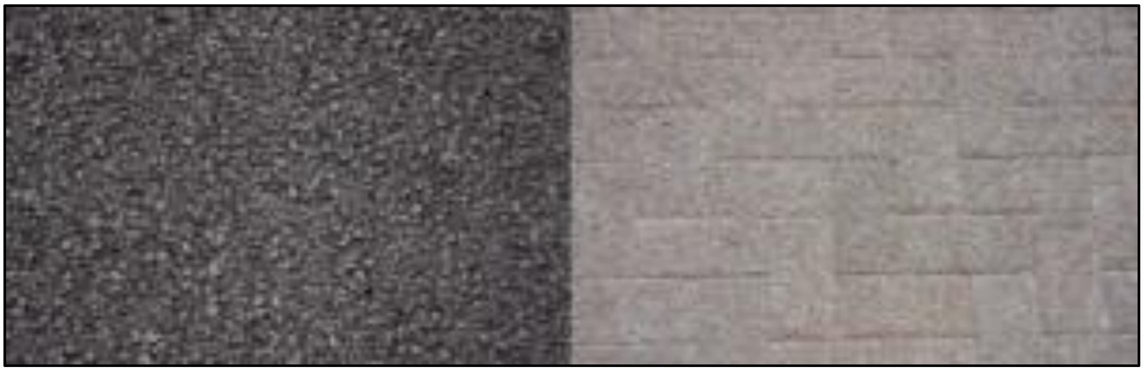

Figure 8. The porous asphalt (left) and the porous concrete (right) can retain nearly 100% of water
Source: Mark Santas, www.usp.com.br

Porous asphalt is developed in a mixture of Poly common asphalt concrete and various additives that allow spaces to be kept as pores on the surface. In this way, water from rainfall is absorbed by the pores and end up being held for a few hours, among the rocks that form the basis.

According to Martin, the porous pavement cost 20% more than conventional asphalt, but with its large-scale deployment that price decrease. "The value we have is related to the experiment. When we think of the use of porous asphalt in big cities like São Paulo the cost drops too, it would be produced in much larger quantities and thus cheapen the production and maintenance ".

Hollow blocks

Concrete block units designed with cells or openings that can be filled with aggregate or gramináceos. They are deployed side by side resulting in a surface similar to a grid or symmetrical design in straight or diagonal angle. How pavement are not relatively inexpensive. Many types are durable and have considerable life. Most are able to support heavy loads well (Virgiliis, 2009).

There are many companies that manufacture this type of coating material, so its cost is high compared to other materials including compared to interlocking concrete blocks.

To acquire good compressive strength are performed in concrete at least 25 MPa (ABNT 97880/87 and 9781/87 ABNT). They must work solidly united and confined to concrete edges. In terms of porosity and hydraulic conductivity are excellent (Virgiliis, 2009).

Figure 9. Concrete blocks precast hollow. Virgiliis 2009 Source

Concrete interlocking blocks

This type of coating allows many traffic types. Massive concrete blocks, aligned side by side are the most common. They are generally seated on the sand layer which gives the assembly porosity and permeability.

Many blocks have good durability and resistance allowing longer service life and consequent economy from the aspect benefit cost. Some blocks can withstand heavy traffic, however they are relatively expensive when compared to other floors. The longitudinal deformation as well as the deformations at the base and subgrade are sensitive. When settlers should be confined to rigid edges that prevent parts are free of tension and may come off. Generally they are limited at their ends to gutters or concrete beams (Virgiliis, 2009).

Figure 10. Concrete blocks interlocked sitting on sand cradle
Source: Virgiliis, 2009.

MATERIALS, METHODS AND RESULTS

Methodology

The methodology of work in question consists of a literature review on the topic from the theoretical basis, a critical analysis of permeable paving methods and the final analysis, with the creation of future scenarios and assess the current situation and subsequent sub-basin using the techniques proposed.

Table 3. Description of shares / proposed activities

Objetivos específicos	Resultados Esperados Qualitativos	Resultados Esperados Quantitativos	Atividades/ações
Identificar opções de pavimentos permeáveis disponíveis no mercado	Encontrar pavimentos de boa qualidade ambiental.	Reduzir consideravelmente o índice de escoamento superficial no local de estudo.	Implementação do pavimento mais qualificado em todas as novas áreas expandidas
Criação de cenários atuais e futuros de ocupação, para efeito comparativo do escoamento de águas pluviais.	Melhoria do escoamento superficial da área.	Implementar em 100% das calçadas, estacionamentos e áreas públicas de lazer e saúde, pavimentos permeáveis.	Criação de cenários atuais e futuros de ocupação.
Eleição de cenário futuro mais condizente a melhora ambiental	Criar o cenário futuro ambientalmente ideal.		

Source: Authors

Viability study

The feasibility study to determine whether the permeable paving is the alternative control in the most appropriate source for the implantation site conditions; and if so, help in choosing the type of flooring to be used for the occupation of basin, aiming to reduce runoff and scenario building that show the established conditions.

Using georeferenced data through the Geographic Information System (MapInfo) studies were designed to examine the feasibility of expanding sidewalks on streets and sidewalks for materials with higher permeability index, aimed at measuring the difference between the different flow peaks.

To predict the amount of total area would be expanded to urban areas, was followed by the Master Plan of San Carlos sorting basin area into three zones. The areas still undeveloped are classified as shown in Figure below: Zone 2 - Occupation Guests and Zone 4 - Regulation and Occupation Subsidiary.

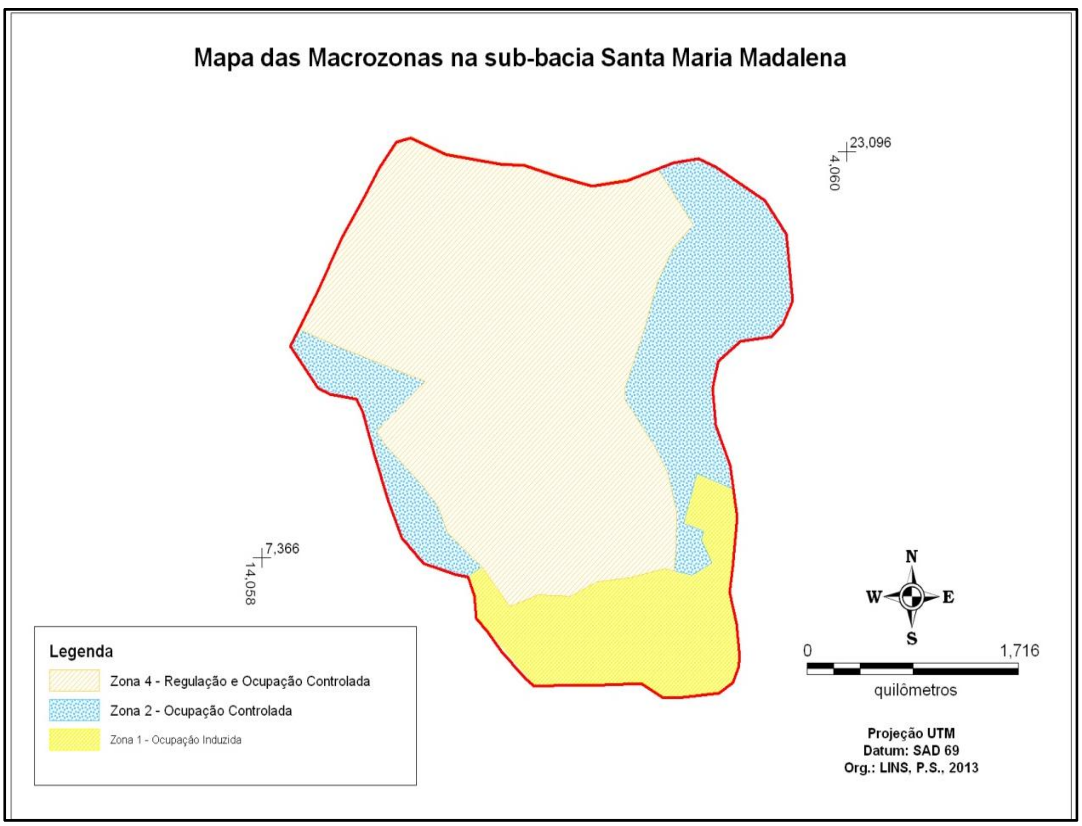

Figure 11. Map of macro-areas in Sub-basin St. Mary Magdalene
Source: Authors

Below the tables 4 and 5 show the percentages that each zone must follow.
Table 3. Coefficients of MacrozonaUrbana.Legenda: CO - occupation / CAB coefficient - basic floor area coefficient / CAM - maximum utilization coefficient / CA - coefficient of utilization / CP - permeability coefficient. Source: (LAW 13,691 / 05), Plan 2005, São Carlos, SP.

Table 4. Ocupacao Condicionada

Zona 2 – Ocupação Condicionada
CO = 70%
CAB = 1,4 **CAM** = 3 nos eixos da zona 2* **CA** = 1,4 para **uso estritamente residencial unifamiliar**
CP = 15%

Table 5. Coefficients of Use Functional Rural Macrozone

Zona 4 – Regulação e Ocupação Controlada
CO = 30% para **chácaras** de recreio **CO** = 70% para **demais** parcelamentos
CA = 0,3 para **chácaras** de recreio **CA** = 1 para **demais** parcelamentos **CA** = 1,4 para **EHIS**
CP = 40% para **chácaras** de recreio **CP** = 20% para **demais** parcelamentos
obs.: Chácaras de Recreio serão admitidas somente na **Zona 4A**, com **lotes mínimos de 1.500m²**

Source: (LAW 13,691 / 05), Plan 2005, São Carlos, SP

The study was based on rational method based on the estimated maximum flow drain an area subject to a maximum intensity of rainfall, with a definite concentration. Also considers the type of use and the slope relief to estimate the runoff coefficient (runoff).

Rational method:
• Q = CIA / 360
Q = maximum discharge flow in $m^3.s^{-1}$;
C = runoff coefficient;
I = mean maximum intensity of precipitation in mm.h-1;
A = contribution of basin area in ha.

For the simulation of the data mean maximum intensity of precipitation, we used data from the Integrated Center for Agrometeorology Information (Ciiagro, 2011). From this source, we were obtained from monthly rainfall data for a period

of 10 years, corresponding to the years 2003 to 2013. The mean maximum intensity of precipitation was obtained by considering the values of the rainiest months (November-March) each year, within the range of 10 years.
As for the estimated area reliably, it was performed using MapInfo software, measurement of existing streets and sidewalks in order to quantify future areas within the urban area. After performing the calculations, we have come up with an estimate of 0.969136 square kilometers of area streets and sidewalks 0.4527168 area of square kilometers.
Based on data use and occupation of the Sub-basin was made the analysis of your current situation, taking into account conventional paving materials (asphalt and concrete) and also the creation of four scenarios:

Scenario 1. Current urbanized area, as possible areas that may be urbanized according to the Master Plan, using conventional paving material (asphalt and concrete)

Usos	Área (km²)	Área (ha)	C	I (mm/h)	Qpico (m³/s)	Qpico total (m³/s)
Área Urbana	3,325025	332,5025	0,9	0,289295	0,240478277	0,109119575
Vegetação	2,456885	245,6885	0,4		0,078973838	
Pastagem	2,85558	285,558	0,4		0,091789446	
Agricultura	2,53441	253,441	0,6		0,12219869	
Malha Viária	0,1681	16,81	0,9		0,012157622	

Scenario 2. Current urbanized area, as possible areas that may be urbanized according to the Master Plan, using permeable materials (streets - porous asphalt / Walks - hollow concrete block)

Usos	Área (km²)	Área (ha)	C	I (mm/h)	Qpico (m³/s)	Qpico total (m³/s)
Área Urbana	7,5421	754,21	0,9	0,289295	0,545472955	0,66755223
Vegetação	2,456885	245,6885	0,4		0,078973838	
Área Permeável	1,341015	134,1015	0,4		0,043105437	

Scenario 3. Current urbanized area, as possible areas that may be urbanized according to the Master Plan, using permeable materials (streets - porous asphalt / Walks - bloquetos)

Usos	Área (km²)	Área (ha)	C	I (mm/h)	Qpico (m³/s)	Qpico total (m³/s)
Área Urbana	6,1202472	612,02472	0,9	0,289295	0,442639228	0,569703885
Vegetação	2,456885	245,6885	0,4		0,078973838	
Área Permeável	1,341015	134,1015	0,4		0,043105437	
Ruas	0,969136	96,9136	0,05		0,003893975	
Calçadas	0,4527168	45,27168	0,03		0,001091406	

Scenario 4. Current urbanized area, as possible areas that may be urbanized according to the Master Plan, using permeable materials (streets - porous asphalt / Walks - porous concrete)

Usos	Área (km²)	Área (ha)	C	I (mm/h)	Qpico (m³/s)	Qpico total (m³/s)
Área Urbana	6,1202472	612,02472	0,9	0,289295	0,442639228	0,596989032
Vegetação	2,456885	245,6885	0,4		0,078973838	
Área Permeável	1,341015	134,1015	0,4		0,043105437	
Ruas	0,969136	96,9136	0,05		0,003893975	
Calçadas	0,4527168	45,27168	0,78		0,028376553	

Scenario 4. Comparison between the current situation and other situations
One can observe a comparison diagram of the different types of situations in

Usos	Área (km²)	Área (ha)	C	I (mm/h)	Qpico (m³/s)	Qpico total (m³/s)
Área Urbana	6,1202472	612,02472	0,9	0,289295	0,442639228	0,56879438
Vegetação	2,456885	245,6885	0,4		0,078973838	
Área Permeável	1,341015	134,1015	0,4		0,043105437	
Ruas	0,969136	96,9136	0,05		0,003893975	
Calçadas	0,4527168	45,27168	0,005		0,000181901	

Table 6. Comparison of different types of scenarios

Situação	Descrição	C	Qpico (l/s)	Diferença (l/s)
Situação Atual	Área urbana atual com lotes impermeabilizados Ruas e calçadas com materiais convencionais (asfalto e concreto) Áreas de agricultura, pastagem e vegetação.	0,9 0,4 0,6	109,12	
Situação 1 (ruas e calçadas com material convencional)	Área urbana atual + futura com lotes impermeabilizados Ruas e calçadas com materiais convencionais (asfalto e concreto) Áreas de vegetação	0,9 0,4	667,55	558,43 (+611,75%)
Situação 2 (ruas-asfalto poroso/calçadas- bloco de concreto vazado)	Área urbana com lotes impermeabilizados ruas e calçadas com materiais permeáveis (ruas-asfalto poroso/ calçadas - bloco de concreto vazado) Áreas de vegetação	0,9 0,05 0,03 0,4	569,70	97,85 (-14, 66%)
Situação 3 (ruas-asfalto poroso/calçadas-bloquetes)	Área urbana com lotes impermeabilizadosRuas e calçadas com materiais permeáveis (ruas-asfalto poroso/ calçadas - bloquetes) Áreas de vegetação	0,9 0,05 0,78 0,4	596,99	70,56 (-10, 57%)
Situação 4 (ruas-asfalto poroso/calçadas-concreto poroso)	Área urbana com lotes impermeabilizados Ruas e calçadas com materiais permeáveis (ruas-asfalto poroso/ calçadas - concreto poroso) Áreas de vegetação	0,9 0,05 0,4 0,005	568,79	98,76 (-14, 79%)

The current situation of the basin under study indicates a flow peak 109,12 l / s. Based on the Plan of San Carlos, situations 1,2, 3 and 4 show a possible territorial expansion over areas of pasture and agriculture resulting in an increase in peak flow. The situation 1 shows this expansion with the use of waterproof material where the peak flow may reach 667.55 l / s, implying an increase of 558.43 l / s, an increase of 611.75%.

Since situations 2 to 4 show such an expansion by using permeable materials. The situation 2 has the 569.70 peak flow implying a reduction of 97.85 l / s (14.66%) compared the situation 1. Situation 3 has a peak flow of 596.99 l / s implying a reduction of 70.56 l / s (10.57%). The situation 4 has a peak flow of 568.79 l / s implying a reduction of 98.76 l / s (14.79%).

Financial Analysis

In an analysis from an economic point of view, the main difficulty is to quantify in monetary terms some costs and benefits for the system of permeable pavements. For example, the analysis of the costs and environmental benefits of the contribution of permeable pavements for recharging the aquifer requires an assessment of the possible effects of pollution and the benefits of increased sheet level (Acioli, 2005).

One of the biggest issues when it comes to the application of control devices at the source of surface runoff is the comparison with the costs of conventional drainage mechanisms. However, one should reflect on the environmental and human gains that the use of these devices lead to the community. Several times the increase in impervious area of the basin and its consequences come to the point where the control application in runoff becomes only environmentally acceptable solution (Acioli, 2005).

An analysis of the costs involved in the implementation of permeable paving, taking into account was only the values corresponding to the implementation of permeable paving itself, disregarding the values of monitoring devices, installation, maintenance, etc. These values were compared with those corresponding to the implementation of a common floor, in case the conventional asphalt.

The cost obtained for the implementation of each deck can be seen in Table 5. All material components and hand labor were removed from REGISUL (1999). In the hand labor costs included all overhead expenses related charges. (Araujo et al., 2000). The cost of porous asphalt was an estimated 30% higher cost of waterproof concrete, but in large quantities has the possibility of reducing the cost, according to research from the Polytechnic School USP.

The cost obtained for the implementation of each deck can be seen in Table 5 and the amounts were found through contact companies, which are:

- Bandeirantes Group (conventional concrete)
- TecPavi (porous concrete)
- Briquet Floors (bloquete and poured concrete block)

In addition to the permeable pavements deployment costs there is the cost of maintenance entails cleaning the pores of porous pavement (concrete and porous asphalt) with jets of water and sediment and dust extraction machines. These costs have not been estimated due to the lack of companies specializing in the maintenance of this type of device in the country. However, to get an idea of the average cost spent on maintenance in the United States is on the order of 1 to 2% of the device's deployment cost. (Araujo et al., 2000).

Table 7. Implementation of Cost of floors in reais per m²

Tipo de Pavimento	Custo unitário (R$/m²)
Bloco de concreto vazado	28
Bloquetes	23
Asfalto poroso	33,1
Concreto poroso	59,6
Concreto impermeável	22

Table 8. Total cost of deployment scenario for real

Situação	Preço Total para implantação (R$)
Situação 1	31.280,77
Situação 2	44.754,48
Situação 3	42.490,89
Situação 4	59.060,33

Table 8 quota the total price of the implementation of each situation, by calculating the price per square meter of each material multiplied by the area of streets and sidewalks. Analyzing to see that the waterproof asphalt also has a considerably lower cost in relation to other types of flooring, economy occurring between 33 and 88%, but the environmental quality of permeable pavements and their environmental benefits within medium to long term, It should be considered as higher priority before costs.

CONCLUSION

Within the context of a history of urban water proofing, this study aimed to study the feasibility of alternatives that contribute to reducing the runoff in the Sub-basin St. Mary Magdalene which would imply a reduction in peak flow. After defining the objectives, literature searches were conducted in order to select the option that best suited the purpose of this study, which was defined by using more permeable pavements. It analyzed the adequacy of the implementation and of the materials process, verifying their influence on the hydraulic performance of the device.

To compare the efficiency of more permeable materials with materials that are currently used, tests were performed to verify the maximum discharge flow generated in a given area, through rational method. From this, four scenarios were developed to simulate the use of new materials in urban expansions possible according to the master plan, simulating the use of four types of permeable materials.

With the results obtained from simulations of the current situation and four other scenarios, it can be confirmed that in a result to be expected, permeable materials have a drain flow 10 to 15% less than the conventional materials. However, analyzing financial, costs may increase 35-88% compared to conventional asphalt waterproof.

Another important result extracted from this analysis was that the streets and sidewalks rather contribute to runoff and should be used primarily in areas where urban expansion phase due to the ease of deployment and its benefits to the environment. As well as the intensity of runoff from areas of significantly higher lotessão to the streets and side walks.

Thus, there is the need to implement measures to encourage the increase of permeable areas in lots. One of the suggestions is the city hall incentive to green property tax, which already owns the instrument and that could improve the effectiveness of this proposal with a campaign to stimulate the inhabitants of Sub-basin to leave permeable areas on their lots.

Other instruments that do not depend on the municipality, but the population is the use of green roofs, collection and utilization of river water, but also the very permeable pavements in their homes to reduce runoff.

As for alternative materials may be verified numerous advantages of its use, ranging from thermal comfort, ease and economy in the maintenance of floors, better aesthetics, even greater efficiency in lighting. Therefore, of great importance for use in new and growing lots of areas aimed at more sustainable architectural projects.

DeProjetos integration

From the possible future scenario (2023) second Sustainable Urbanization Project created by (Argentine et al., 2013), analyzed the possibility of using permeable pavements on possible new area of sustainable urban growth, showing its benefits compared to conventional pavement.

Table 9. Possible Future Scenario (2023) second Sustainable Urbanization Project

Tipo de Uso	2013	2023	
		Plano Diretor	Urb. Sustentável
Área Verde	2,463	2,376	3,554
Cana-de-açúcar	2,534	2,117	1,407
Urbanização	3,201	4,572	4,572
Pastagem	2,862	2,009	1,509

Source: (Argentin et al., 2013)

With the value of sustainable urban expansion area obtained is calculated by the same methods described above, the peak flow rate value (Qpico) using conventional permeable paving and flooring. In the case of the chosen permeable paving streets was deck to porous asphalt and concrete sidewalks porous due to its efficiency shown in this work.

Table 10. Expansion Area second Sustainable Urbanization Project with the use of conventional paving on streets and sidewalks

Uso	área	C	I	Qpico	Qpico total
area urbana	106,10858	0,9	0,289295	0,076741704	0,0991559
Ruas	21,12378	0,9		0,01527751	
Calçadas	9,86764	0,9		0,007136647	

Table 11. Expansion of area under Sustainable Urbanization Project with the use of permeable paving on streets and sidewalks (streets - porous asphalt / Walks - porous concrete)

Uso	área	C	I	Qpico	Qpico total
area urbana	106,10858	0,9	0,289295	0,076741704	0,0776301
Ruas	21,12378	0,05		0,000848751	
Calçadas	9,86764	0,005		3,9648E-05	

Calculations have shown the efficiency of permeable pavements showing a decrease of 21% of the peak flow in the area. But the cost would increase by 53% from R $ 6,818 to R $ 12,873.

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