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VEGETATION AND DIFFUSE PERMEABILITY AS A SOLUTION TO URBAN DRAINAGE IN THE CITY OF BELO HORIZONTE

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Abstract: The recurrent episodes of floods and inundations and the analysis of the history of legislation and drainage projects in the city of Belo Horizonte allow us to visualize the limits of public action in relation to the theme. They reveal the urgency of rethinking what has been practiced and what can still be done to increase the infiltration capacity and water retention in the soil. Minimizing floods and their impacts has been one of the main objects of public concern, but in addition to this, allowing the waters to penetrate the soil is of fundamental importance for the maintenance of the hydrological cycle and the water table levels. Alternatives to the drainage issue have been sought on public ground from the construction of detention basins and the implementation of rain gardens on sidewalks. The present case study, in turn, intends to evaluate the possibilities and effectiveness of extending microdrainage strategies, with solutions contained within the internal limits of the lot. To this end, we evaluate not only the rates, but the permeability capacity of soils, emphasizing characteristics that define their storage capacity, such as composition, occupation and, not least, the presence and size of vegetation. It is concluded that such characteristics can serve as a basis for formulating policies to encourage the expansion and maintenance of permeable and vegetated soil within the lot, such as the IPTU Verde and the granting of Non-Onerous Grant.
Keywords: Drainage. Vegetation. Infiltration.

INTRODUCTION

Floods and inundations have accompanied the development of Belo Horizonte since the beginning of the urbanization process, due to the solutions presented to the urban drainage and sanitary sewage system. On one hand, hygienist techniques treated rivers as the final destination of rain and wastewater for almost a century. On the other hand, the prioritization of automobiles found in valley bottoms, with low slopes, the ideal space for the implementation of expressways. Both postures contributed to the implementation of the sanitary avenues, which culminated in the canalization and buffering of urban rivers, taking them out of the scene and hiding their state of degradation.

The concerns about environmental management emerge in Belo Horizonte from the 70’s on, given the international repercussion of environmentalism and the alarming situation resulting from a rapid and unplanned urban expansion, with a growing soil sealing, occupation of valley bottoms and environmental degradation. But the road was long until there was a paradigm shift in the management of urban drainage, with the replacement of channeling by the search for the maintenance of waterways in natural beds and their reinsertion in the landscape and the daily lives of the population.

This aspect still remains today more as a desire than a practical reality, the exceptions being implemented from the institution of the Drenurbs program in 2010. The program in question was created to act in a considerable extension of the territory, covering 51% of the total area of the municipality, with interventions focused on the streams that present flood risks and a high degree of environmental deterioration; and has as one of its premises the maintenance of waterways in their natural state. However, in addition to budgetary difficulties that have considerably reduced the program’s ability to act, the projects executed show some disparity between each other, sometimes comprising changes of a comprehensive and intersectoral nature, with the construction of linear parks, which transformed the valley bottoms into areas for leisure and social use - which happened in the streams 1º de Maio and Baleares, for example

- and other times focusing on the performance of the waterways in their natural state; and sometimes focusing on the construction of detention basins without any relationship with the surroundings - as happened in the streams Engenho Nogueira and Bonsucesso, where, in the latter case, there was the implementation of a new arterial road, contrary to the principles propagated by Drenurbs (Araújo et. al, 2015).

Figure 1 - Córregos Baleares and 1º de Maio detention basins, undertaken by the Drenurbs program.

Source: PBH-SUDECAP (2011). Adapted by the author.

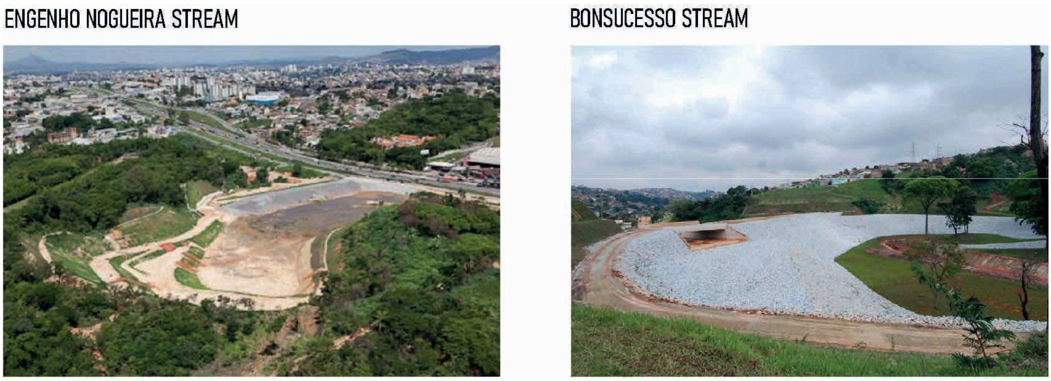

Figure 2 - Detention basins of the Engenho Nogueira and Bonsucesso streams, undertaken by the Drenurbs program. Drenurbs.

Source: PBH-SUDECAP (2011). Adapted by the author.

Not only drainage projects, but also urban legislation and its construction parameters have only recently incorporated alternative solutions to surface runoff of rainwater and the promotion of land occupation with less environmental impact. The key turning point occurred in 1996, when the city government began to define a fee for controlling the permeability of the intra-lot soil, through Law 7166. With the institution of the Permeability Rate - TP, part of the ownership was transferred to the owner. responsibility for the management of precipitated water under its lot, with the aim of unburdening the public rainwater drainage system and mitigating the impacts caused by soil sealing.

The law represented an advance in relation to urban drainage management and a prognosis for the alarming situation of floods and inundations, but its definition was already accompanied by a compensatory strategy that was not very interesting. It was allowed the complete sealing of the lots (except those located in protection zones - ZPAM and

ZPs) if the percentage of the uncovered and vegetated area was maintained, even if on a waterproofed slab, combined with a catchment box. The strategy aimed to delay the release of rainwater into the public drainage system, but prevented it from infiltrating the soil. Thus, the destination of the waters collected by the collection box continued to be the pipes that flowed into the rivers (often channeled), making it impossible to recharge the aquifers, so important for the maintenance of the hydrological cycle of water and flood control.

The city expanded and was built this way until 2020, when the new and current legislation came into effect, No. 11.181, which proposed structural changes in the definition of the Permeability Rate. From then on, it is mandatory that the permeability rate is met in natural and vegetated land, allowing the infiltration of water into the soil. The collection box is also mandatory for all lots, as a complementary device to the TP, so that together they result in a flow rate of the built-up land equivalent to its primitive flow rate, in other words, to that which the land had when it was 100% permeable. Thus, the catchment box must support the excess water that the impermeable land is not able to retain, releasing this excess little by little to the public drainage network and relieving the public stormwater galleries.

But the city suffers, today, the consequences of the practices stipulated by previous legislation. As a result of the non-mandatory maintenance of soil permeability/vegetability until 2020, urban expansion has resulted in a scenario where approximately 63% of the municipality is completely waterproofed (PMS, 2016/2019). As a result, we are witnessing recurrent episodes of flooding in already consolidated occupation areas, which have high levels of waterproofing. To mitigate such problems, the city hall has been building detention basins in floodplains, as part of the strategy for the Drenurbs program. But would this be the most efficient flood containment strategy in built environments?

It starts from the assumption that sectoral strategies, such as detention basins, are not capable of solving drainage problems, they are only mitigating strategies. It works with the hypothesis that diffuse solutions, which increase soil permeability and reduce the speed and volume of water concentration in the valley bottoms, can reverse the situation of floods and inundations that are so recurrent in the municipality of Belo Horizonte.

GOAL

This article aims to evaluate the infiltration and retention capacity of water in the soil and to show how the presence of vegetation increases the water storage capacity in urban areas and, therefore, guarantees the maintenance of permeable and diffusely vegetated lots. across the territory is able to minimize floods and their consequences.

METHODOLOGY

In order to measure the infiltration and retention capacity of rainwater in the different possible scenarios, a territorial cut was chosen that consists of the junction of 3 elementary hydrographic basins of Belo Horizonte, the basins of Córregos Cachoeirinha, Engenho Nogueira, Suzana and, finally, it was Also included is the southern portion of the Ribeirão Pampulha basin. The choice of the area for analysis was based on the unfavorable characteristics of the environment for drainage, in view of the high rates of land occupation and the channeling of 84.5% of the existing water channels in the area of analysis. Such characteristics resulted in high risks of flooding in the valley bottoms, with 7 critical points arranged in the region. According to data provided by SUDECAP (2001), the region already had, in 1996.

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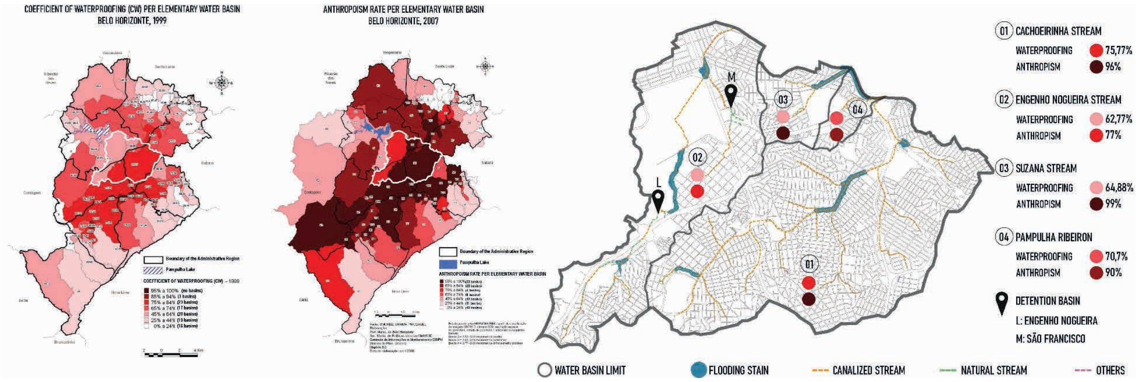


Figure 3 - Summary of the drainage conditions of the analyzed elementary watersheds.

Source: PBH - SMPU (2008). Adapted by the author.

Due to recurrent episodes of flooding, the Municipality of Belo Horizonte built two detention basins in the region to contain the floods, the Engenho Nogueira Basin, which has a maximum retention volume of 130,000 m^3, which cost 28.4 million reais (Brazilian currency); and the São Francisco Basin, which has 66,000 m^3 of capacity, with estimated investments of 20.8 million reais (SUDECAP, 2011).

In order to establish a comparison between the infiltration capacity of water into the soil, with the maximum retention volume of the built basins, the SCS (Soil Conservation Service) method was adopted for calculating the accumulated infiltration over a rainfall event, which considers the characteristics of the soil and occupation of the basin defined through the CN (Curve Number). The equations were demonstrated by COLLISCHONN, W. and DORNELLES, F. (2013) in the book Hydrology for Engineering and Environmental Sciences.

$$P = Ia + F + Q$$

$$\frac{Q}{P - Ia} = \frac{F}{S}$$

$$Ia = 0{,}2 \,.\, S$$

$$Q = \frac{(P - Ia)^2}{(P - Ia + S)} \quad \text{, when } P > Ia \text{ and } Q = 0 \text{ when} P \leq 0$$

$$Q = \frac{(P - 0{,}2 \,.\, S)^2}{(P + 0{,}8 \,.\, S)} \quad \text{, when } P > Ia \text{ and } Q = 0 \text{ when } P \leq 0$$

$$S = \frac{(25400)}{CN} - 254$$

P = Precipitation occurring over the course of a rainfall event (mm)
Q = Effective rainfall, or runoff, over the course of the event (mm)
F = Cumulative infiltration over the rainfall event (mm)
Ia = Initial losses (mm)
S = Maximum accumulated potential infiltration

Figure 4 - Formulas used by the SCS Method for macro drainage projects.

Source: Collischonn, W., Dornelles, F. (2015). Adapted by the author.

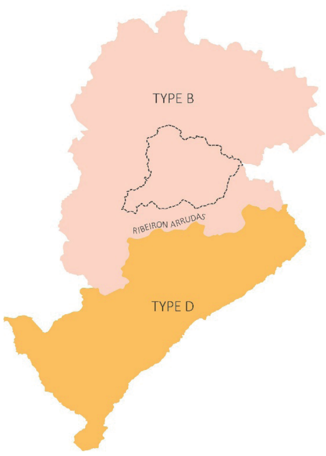
The Curve Number, in turn, is associated with three variables: the hydrological group to which the soil belongs, its cover and moisture conditions (McCuen, 1998). The SCS, from the United States Department of Agriculture, classified soils into 4 different hydrological groups: A, B, C and D, according to their texture characteristics and hydraulic conductivity. Type A soils have the highest permeability capacity and, therefore, generate the lowest volumes of surface runoff; and they decrease in order of permeability, until reaching classification D, which consists of soils with low permeability and high potential for runoff generation. Ramos (2008) applied the SCS classification to the territory of Belo Horizonte, which resulted in the subdivision of the municipality into two categories: B (in which the study area is fully inserted) and D.

SCS TYPE	CHARACTERISTICS
A	Soils with low runoff potential and high infiltration rate, deep and erodible
B	Soils less permeable and shallower than type A and with higher runoff generation potential
C	Soils with higher runoff potential than type B soils. They are moderately deep soils, with low permeability and resistance to erosion
D	Shallow, low infiltration capacity soils, with high potential for runoff generation and erodibility

Figure 5 - Types of soil considered in the SCS method, for the determination of CN values.

Source: Collischonn, W., Dornelles, F. (2015), apud Hawkins et al. (2009).

Tucci (1993) translated the NC values for Brazilian urban watersheds. Of all the categories in subgroup B, 3 were selected to equate the simulations of infiltration capacity of water in the soil: 1) "earth", to simulate non-vegetated permeable soil (exposed), 2) "grass", for soils with grassy vegetation and 3) "forest", for soils with arboreal vegetation.



GROUND COVER	A	B	C	D
Cultivated areas: without soil conservation	72	81	88	91
with soil conservation	62	71	78	81
Pastures or land in poor condition	68	79	86	89
Common land in good condition	39	61	74	80
Prado in good condition	30	58	71	78
Woods: poor coverage	45	66	77	83
Forests: coverage good	25	**55**	70	77
Open spaces, lawns, parks, golf courses: good conditions				
with grass in more than 75% of the area	39	**61**	74	80
with grass 50 to 75% of the area	49	69	79	84
Commercial and Office Zones	89	92	94	95
Industrial zones	81	88	91	93
Residential areas:				
lots (m^2) — average waterproof (%)				
< 500 — 65	77	85	90	92
1000 — 38	61	75	83	87
1300 — 30	57	72	81	86
2000 — 25	54	70	80	85
4000 — 20	51	68	79	84
Parking lots, rooftops, overpasses, etc.	98	98	98	98
Paved streets and roads with storm water drainage	98	98	98	98
Parallelepipeds	76	85	89	91
Ground	72	**82**	87	89

Figure 6 - CN values for different vegetation cover conditions.

Source: Collischonn, W., Dornelles, F. (2015), apud Tucci (1996). Adapted by the author.

To prepare the calculation, the permeability rate of current legislation (No. 11,181) was applied to the lots, so that the infiltration capacity could be compared based on the same permeable area, but with different treatments. The area of the lots was calculated based on the "lote CTM" shapefile base – that is, lots according to the Municipal Land Registry, the basis for the collection of IPTU –, available on the BHMap website. Road areas, ZEIS and the cemetery were disregarded, due to the low infiltration capacity of these environments, due to their high waterproofing rates.

The monthly rainfall index used was measured by Station No. 83587 and made available by the National Institute of

Meteorology (INMET), referring to the month of January 2021. To simplify the calculations and to simulate a critical rainfall event, the volume was considered of monthly rainfall as a single event. Having the variables: precipitation, CN and infiltration area, the SCS method was applied and the soil infiltration volumes were generated in the 3 analyzed scenarios.

It must be noted, however, that in the scenario where the soil contains tree vegetation, the water infiltration capacity of the soil is not sufficient to supply the total volume of water retained by the vegetation. In addition to the water infiltrated into the soil, part of the precipitated volume will also be captured by the tree roots for use in their evapotranspiration processes, further increasing the water retention capacity. In this process, the infiltrated water is drained by the roots of the plants and conducted to the leaves, due to the potential difference established by the stomata, which transpire, returning water to the atmosphere. This process takes place during the day, while at night the stomata of the leaves close, which reverses the potential difference, leading water back to the soil (HAYCOCK, et al, 1997).

For the simulation of vegetation capture, the scheme by Ray R. Weil and N. Brady (2017) was used, which stipulates, for the vegetated soil, an infiltration between 40 and 95% of the total volume precipitated under the area. Of this total, 30 to 65% would be equivalent to the water captured by the plants and used in the evapotranspiration process. Therefore, two scenarios were calculated, the one with the lowest contribution (where 40% of the precipitated volume is infiltrated and, of this, 30% is retained by the plants) and the one with the highest contribution (where 95% of the precipitated volume is infiltrated and, of this total, 65% is retained by plants and used in evapotranspiration).

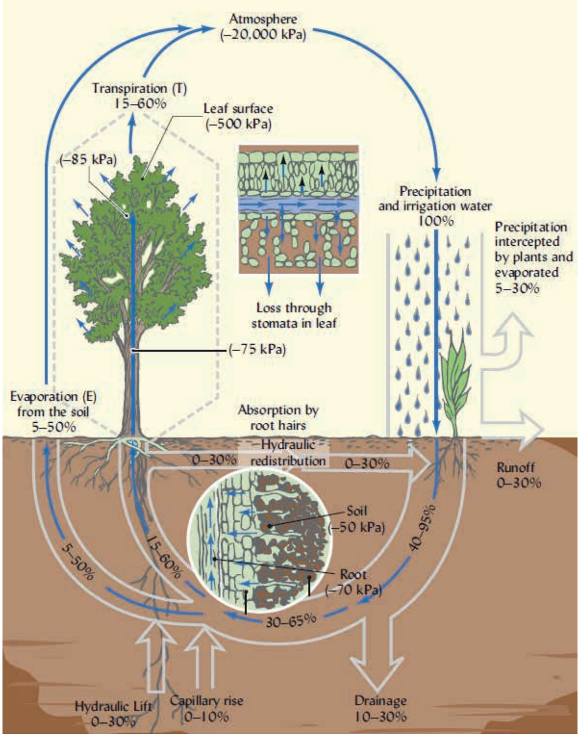


Figure 7 - Soil-plant-atmosphere continuum

Source: Weil R., Brady N. (2017).

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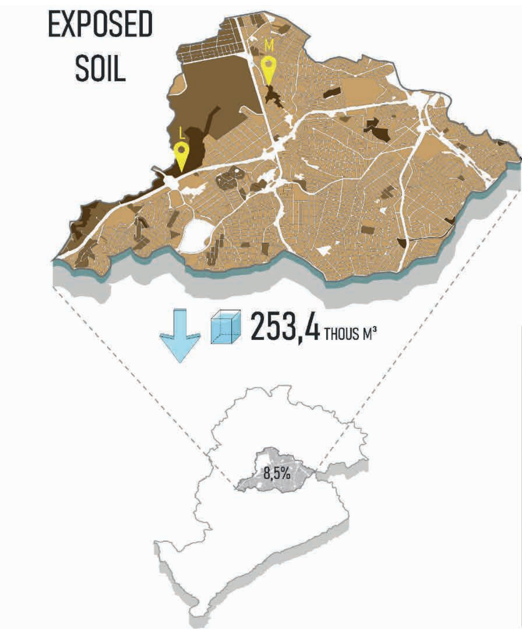
RESULTS AND CONCLUSION

Based on the methods mentioned above, it was concluded that if all lots in the analysis area (except ZEIS and Cemitério da Paz) fulfilled the required minimum permeability rate, but kept the soil exposed (without any vegetation) the potential infiltration volume, in a critical rainfall event, of 309.9mm, would be 253.4 thousand m³, as shown in figure 8. For the event in question, the total rainfall volume in the study area would be 8.8 million m³, therefore, the exposed soil would be able to capture approximately 3% of the event's rainfall.



INFILTRATION IN THE STUDY AREA IN A HIGH INTENSITY EVENT

RAINFALL INDEX JANUARY 2021	309,9 mm
PRECIPITATION IN THE STUDY AREA	8,8 milion m³

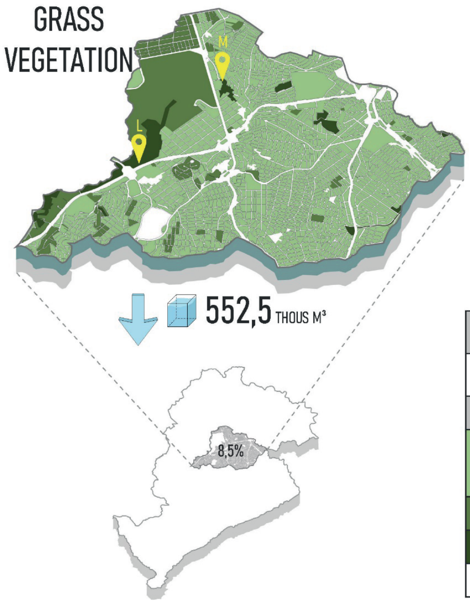
DETENTION BASIN	CAPACITY
L: ENGENHO NOGUEIRA	130 thousand m³
M: SÃO FRANCISCO	66 thousand m³

Q = EFFECTIVE RAIN (mm)	F = ACCUMULATED INFILTRATION (mm)	S = MAXIMUM ACCUMULA-TED INFILTRATION (mm)	Ia = INITIAL LOSSES (mm)
175	102,4	55,75	11,15
PERMEABILITY RATE (%)	**Total AREA lots(m²)**	**permeable AREA (m²)**	**infiltrated VOLUME (m³)**
10 to lots ≤ 360m²	4,29 milion	429,18 thous	20,1 thous
20 to lots ≥ 360m²	11,22 milion	2,24 milion	105,4 thous
30	5,18 milion	1,55 milion	73 thous
95	1,22 milion	1,16 milion	54,8 thous
Not accounted areas			TOTAL = 253,4 thous

Figure 8 - Infiltration capacity in the study area in a high intensity event for exposed soils.

Source: Prepared by the author.

In the second scenario, where compliance with the permeable area stipulated by Law 11,181 with grassy vegetation was considered, the infiltration capacity increased to 552.5 thousand m³, which corresponds to 6.3% of the total precipitation of the event.



INFILTRATION IN THE STUDY AREA IN A HIGH INTENSITY EVENT

RAINFALL INDEX JANUARY 2021	309,9 mm
PRECIPITATION IN THE STUDY AREA	8,8 milion m^3

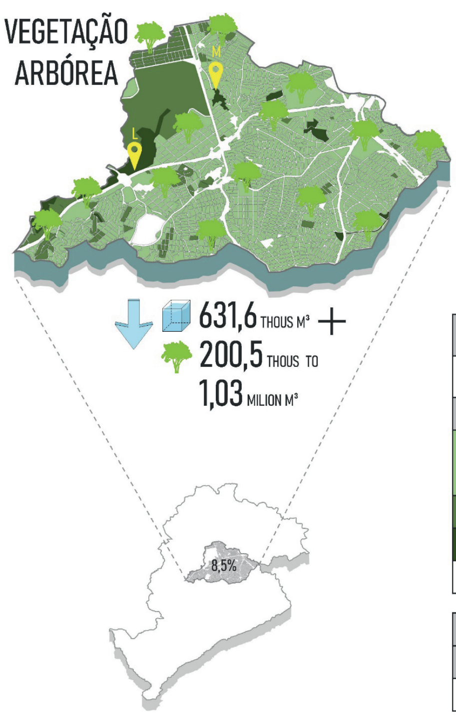
DETENTION BASIN	CAPACITY
L: ENGENHO NOGUEIRA	130 thousand m³
M: SÃO FRANCISCO	66 thousand m^3

Q = EFFECTIVE RAIN (mm)	F = ACCUMULATED INFILTRATION (mm)	S = MAXIMUM ACCUMULATED INFILTRATION (mm)	Ia = INITIAL LOSSES (mm)
175	102,4	162,4	32,48
PERMEABILITY RATE (%)	Total AREA lots(m²)	permeable AREA (m²)	infiltrated VOLUME (m³)
10 to lots ≤ 360m²	4,29 milion	429,18 thous	43, 9 thous
20 to lots ≥ 360m²	11,22 milion	2,24 milion	229,8 thous
30	5,18 milion	1,55 milion	159,2 thous
95	1,22 milion	1,16 milion	119,4 thous
Not accounted areas			TOTAL = 552,5 thous

Figure 9 - Infiltration capacity in the study area in a high intensity event for vegetated soils.

Source: Prepared by the author.

In the third and last scenario, with the presence of tree vegetation, the soil infiltration volume increased to 631.6 thousand m³. Added to this, the retention carried out by the plants to carry out evapotranspiration could vary between 200.5 thousand m³ to 1.03 million m³, according to the percentages shown by Weil R. and Brady N. (2017) in figure 7, the which would result, in the best scenario, in a capture of 1.66 million m³, which corresponds to 19% of the total precipitation of the event.



INFILTRATION IN THE STUDY AREA IN A HIGH INTENSITY EVENT

RAINFALL INDEX JANUARY 2021	309,9 mm
PRECIPITATION IN THE STUDY AREA	8,8 milion m^3

DETENTION BASIN	CAPACITY
L: ENGENHO NOGUEIRA	130 thousand m³
M: SÃO FRANCISCO	66 thousand m^3

Q = EFFECTIVE RAIN (mm)	F = ACCUMULATED INFILTRATION (mm)	S = MAXIMUM ACCUMULATED INFILTRATION (mm)	Ia = INITIAL LOSSES (mm)
175	102,4	162,4	32,48
PERMEABILITY RATE (%)	Total AREA lots(m²)	permeable AREA (m²)	infiltrated VOLUME (m³)
10 to lots ≤ 360m²	4,29 milion	429,18 thous	50,2 thous
20 to lots ≥ 360m²	11,22 milion	2,24 milion	262,8 thous
30	5,18 milion	1,55 milion	182 thous
95	1,22 milion	1,16 milion	136,5 thous
Not accounted areas			TOTAL = 631,6 thous

ARBOREAL VEGETATION			
Total permeable AREA of the lots (m²)	PRECIPITED VOLUME IN PERMEABLE AREA (m³)	40% infiltration 35% retention	95% infiltration 65% retention
5,39 milion	1,67 milion	200,5 thous m³	1,03 milion m³

Figure 10 - Infiltration capacity in the study area in a high-intensity event in soil with arboreal vegetation.

Source: Prepared by the author.

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Comparing, therefore, the worst scenario (exposed soil) with the best one (tree vegetation with high retention capacity), a difference of 1.4 million m^3 is obtained, a figure 7 times greater than the maximum volume captured by the two watersheds. existing detention in the analysis area (which is 196 thousand m^3). Therefore, maintaining the permeable and vegetated soil is more effective, in terms of rainwater storage capacity, than the detention basins.

Certainly, the permeability rate stipulated by Legislation 11,181 is not in fact complied with in its entirety, in view of the high rates of anthropism in the hydrographic basins studied in 2007 (Figure 3), when it was still allowed to overcome the TP from pickup box. That is, not even the worst simulated scenario is actually practiced, which allows us to understand the implementation of detention basins to mitigate the effects of intense waterproofing.

However, continuing to invest in the construction of detention devices will not solve the cause of flooding, which is the impermeability of the soil. The accumulation of water manifests itself in the valley bottoms (where the detention basins are located), but the intensity of the accumulation downstream is due to the waterproofing that starts upstream. Thus, ensuring soil permeability throughout the basin is of fundamental importance for flood containment. As demonstrated, the vegetation significantly assists in the process of infiltration / retention of rainwater, minimizing both its flow velocity and the volume of concentration in the valley bottoms. Therefore, the practice of diffuse vegetation proves to be an efficient solution strategy for recurrent floods.

So far, the investment stipulated in the construction of the detention basins in the analyzed area totals 49.2 million reais. What would be the scope and effectiveness of applying a similar amount in alternative drainage projects, which aim to implement and maintain diffuse vegetated permeability in urban lots? It is possible to think of strategies such as the green IPTU, which consists of exemption, or discounts on the Urban Land and Property Tax (IPTU) through the adoption of socio-environmental practices, or even the granting of a non-onerous grant to promote diffuse vegetative permeability.

The advanced level of consolidation of the territory proves to be an obstacle to the application of diffuse, non-conventional drainage projects, but the urban environment is dynamic and is constantly changing. Therefore, we need to offer attractions capable of generating the desired transformations.

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