

Scenarios for urban drainage on a Legal Amazon planned city: a case study in Palmas, Brazil

Cenários para drenagem urbana em uma cidade planejada na Amazônia Legal: um estudo de caso em Palmas, Brasil

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ABSTRACT

The significant urbanization of Brazil in the last decades has pushed cities to combine population growth with protection and harmonic living with their natural resources. The city of Palmas, a planned city in the Legal Amazon, is inserted in this context. In this sense, this study sought to analyze the hydrological and hydraulic responses to different scenarios of land use and occupation in one of its watersheds. Scenarios modeled with SWMM software were current, critical and compensatory techniques. The results showed that the conveyance system, including the main stream, are fully capable of conveying the affluent flow, even in the scenarios with greater impermeability of the watershed. The peak flow of the critical scenario is up to 11.12% higher than the current scenario. However, with compensatory techniques, it is possible to have a peak flow up to 25.76% smaller than the critical scenario. Legal Amazon.

Keywords: urban drainage; urban planning; compensatory techniques;

RESUMO

A relevante urbanização do Brasil nas últimas décadas tem pressionado as cidades a aliar o crescimento populacional à proteção e convívio com seus recursos naturais. A cidade de Palmas, uma cidade planejada na Amazônia Legal, se insere nesse contexto. Nesse sentido, este estudo buscou analisar as respostas hidrológicas e hidráulicas para diferentes cenários de uso e ocupação do solo em uma de suas bacias hidrográficas. Os cenários modelados com o auxílio do software SWMM foram o atual, crítico e medidas não convencionais. Os resultados apontaram que os trechos da rede de drenagem, incluindo o curso d'água principal, são plenamente capazes de escoar as vazões, mesmo nos cenários com maior impermeabilidade da bacia. A vazão de pico do cenário crítico é de até 11,12% maior que o cenário atual. No entanto, com medidas não convencionais, pode-se ter uma vazão de pico até 25,76% menor que a do cenário crítico.

Palavras-chave: drenagem urbana; planejamento urbano; técnicas compensatórias; Amazônia Legal.

INTRODUCTION

The context of human settlements has been marked, in recent decades, by an intense migration of people from rural to urban areas. According to estimates by the United Nations (UN), 54.5% of the world population lived in urban settlements, while in Brazil, this figure was 85.9% in 2016. In 1950, the urban population of Brazil and the world represented just 29.6 and 36.2%, respectively (UN, 2014).

Considering these changes, public policy attention has been increasingly focused on the context of cities. Thus, many of the Sustainable Development Goals (SDG), agreed upon by the UN member countries (UN, 2015), deal directly with or have an interface with urban structures and activities.

In this sense, it is important to understand the behavior of urban watersheds and their relationship with land use and occupation. It is a central question because mistaken decisions involving loss of natural capital can be taken

by the lack of information and knowledge regarding the importance of ecosystem services (PAINEL BRASILEIRO DE MUDANÇAS CLIMÁTICAS, 2016). Recognizing this, the National Plan for Adaptation to Climate Change emphasizes relative importance to the production and dissemination of scientific knowledge related to the modeling of climatic and hydrological phenomena (BRASIL, 2016).

Specifically in Brazil, it appears that national policies that deal with the interface city and water resources, even prior to the SDG and the National Plan for Adaptation to Climate Change, were already in line with the current understanding. The National Water Resources Policy, for example, includes among its objectives the necessary preparation against extreme hydrological events, as well as presenting, among its guidelines, the necessary attention to the interface between water resources and land use (BRASIL, 1997).

The city of Palmas presents itself in this context as the last planned capital of Brazil. In its 30 years of existence, it houses approximately 300,000

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inhabitants, with a population growth rate of just over 60% in the last 10 years. Although conceived and implemented at a time when the urban planning and water resources interface were already more present and consolidated, the constant disturbances faced by the population due to the inadequate management of their stormwater are pointed out.

Its climate classification is Köppen's AW, with temperature means just below 17°C. The annual precipitation means flow between 1,700 and 1,900 mm, concentrated through October to April. About the winds, there is a tendency to the west, but it is calm in 70% of the year, according to Prefeitura de Palmas (2017).

Therefore, the objective of this work was to verify whether the occupation guidelines of a recently planned city — reflected mainly on the percentage of impervious areas of the watersheds and areas protected by laws along with the water courses, presumably aligned with the most recent international and national experiences and outcomes — are sufficient to prevent floods on nearby occupations and neighborhoods. Furthermore, it compared hydrological and hydraulic results — expressed by total infiltration, runoff, final storage, flow coefficient, peak flow, peak time, and maximum outfall height — through different occupation scenarios allowed by the city guidelines.

For this purpose, the Suçupara watershed was studied, as it is one of the densest watersheds in the city, and also has drainage problems reported in the Municipal Basic Sanitation Plan (*Plano Municipal de Saneamento Básico – PMSB*) (PREFEITURA DE PALMAS, 2014). A watershed occupation analysis was performed through the visual interpretation of images made available by Google Earth and hydrological and hydraulic studies with the help of the Storm Water Management Model (SWMM), which allowed the construction of three occupation scenarios: current, critical, and compensatory techniques.

URBANIZATION AND STORMWATER DRAINAGE

Stormwater has several ways to reach the watercourse in watersheds that are naturally covered. It can be intercepted at the vegetation itself, stored in the vegetal surface cover of the soil with flow in this same layer or infiltrate and flow in a thin layer below it to finally infiltrate at great depths (BOTELHO, 2011).

The above-mentioned author points out that with the watershed urbanization the possible paths for stormwater are restricted, basically, to the binomial surface runoff and infiltration, with a preponderance of the former. This directly impacts some factors used to measure water behavior in the river basin, especially the increase of the peak flow in the watercourse and the total volume flowed in the watershed, as well as the decrease in peak and lag times.

The cited changes are largely documented in the bibliography, dating back to pioneering studies by Leopold (1968), which compiled results obtained by several US cities. The author has concluded that there is a direct and positive relationship between the impervious area, the area covered by conveyance system, and the peak flow of a watershed, which could reach six times the pre-urbanization flow.

More recently, Jacobson (2011), in his review article on the hydrological impacts of urbanizing watersheds, presented information cataloged in works carried out between the 1960s and 21st century, which corroborate those previously mentioned. Decreased lag time, flood duration, and base flow were observed as well as increased peak flow, bankfull discharge, channel cross-sectional area, return period, drainage density, bank erosion, size of bed material, and rate of bed load discharge.

According to the author, after the 1980s, studies have shown some indirect impacts, mainly pointing out the following: possibility of visualizing two peak flows for the same precipitation, depending on the localization of the urbanized area; possibility of base flow reduction associated with the type of conveyance system; and an impervious limit below which there are no significant changes in hydrological outcomes, varying from 3 to 20%.

It is also important to evaluate Brazilian studies on the subject, of which Tucci (2000) stands out. In his work, the author clearly demonstrates the impacts of watershed urbanization, reflected in an increase of specific flow and volume of surface runoff, when compared to the rural condition. The author observed that in urban watersheds with almost 80% of total impermeable areas, there is an increase close to 26.67 times in the specific flow and 8.58 times in the volume of surface runoff, when compared to a condition of previous rural occupation.

Although it can be pointed out that the studies are always restricted to some watersheds — in the case of Tucci (2000), 12 on South and Southeast regions of Brazil —, what is observed is that the increase of surface runoff and drained volume, varying in magnitude, are always present as consequences of urbanization, whether in the Brazilian context or in other countries. These are the analysis results from the cited publications and from some more recent ones (BASTOS, 2009; MILLER *et al.*, 2014; NIGUSSIE; ALTUNKAYNAK, 2016; ROCHA, 2013).

To manage these impacts, a growing number of compensatory techniques has emerged since the 1980s, as pointed out by Fletcher *et al.* (2015). Their objectives are centered on mitigating the hydrological and hydraulic impacts, focusing on natural levels or local environmental targets. Some of them are the residential reservoirs, green roofs, permeable pavement, infiltration trenches, and infiltration wells. The use of the latter two were particularly studied by Silva (2007), Caputo (2012), and Kusumastuti *et al.* (2014) in situations comparable with the ones simulated for Palmas.

From these elucidations, it is possible to observe that the relationship of the city with its watercourses floods will be closely linked to the urban planning adopted. This planning, in turn, is what induces the territorial occupation of the city and has direct consequences on how the watershed will drain the stormwater. This relationship, specifically in the case of Palmas, is covered in detail in the following topic.

URBAN PLANNING IN PALMAS

The basic plan of Palmas, which represents the technical design and guidelines of the city, with no prior legal status, was developed in the late 1980s and it had guidelines regarding the spatial distribution of the activities. The proposed densities were approximately 30,000 inhabitants per square kilometer in residential areas, as well as a distribution of macro-areas per use, of which 9% of the total urban area is specifically destined for green areas and a reserve of 15% of the total area for green areas in residential macro-areas. In addition, they recommended the creation of linear parks along the streams, which would be made official by subsequent municipal laws (GRUPO QUATRO, 1989).

It is important to note in Figure 1 that the adjacent blocks to the Suçupara stream have their use determined as Green Area. These areas are mainly intended for environmental preservation, and may house low-impact public facilities. They are also sufficient to cover the requirements of the Permanent Preservation Areas, from 30 to 50m adjacent to the edges of the regular stream bed (BRASIL, 2012). Table 1 shows its macro-area land use distribution.



Figure 1 - Land use distribution of Suçuapara Watershed.

Table 1 - Macro-area land distribution.

Land Use	Area (km ²)	Area (% of total watershed)
Residential	5.50	52.11
Commerce / Urban Services	0.69	6.54
Urban Facilities	0.14	1.28
Commerce / Central Services	0.62	5.90
Green Area	1.82	17.28
Public Administration	0.44	4.18
Regional Services	1.34	12.71
TOTAL	10.55	100

Source: elaborated by the authors.

The Suçuapara watershed has an approximately area of 10.55 km², of which 43.24% is impervious. The length of its main stream is 4.10 km (2.36% mean slope) and the average slope of the catchment is 2.24%.

Also, the current municipal master plan, which, in contrast with the basic plan, has a legal status, must be highlighted. The master plan presents important principles, aligned with the national legislation and the scope of this study, such as environment preservation and conservation, the environmental function of property, adaptation, and mitigation of impacts related to climate change, water resources management, and environmental sustainability (PALMAS, 2018).

This reserve of green areas adjacent to the streams, although obligatory to a certain extent by federal legislation, is hardly respected in large metropolitan areas.

Two iconic Brazilian examples can be found in the works of Lucas *et al.* (2015) and Tominaga (2013), referring to Arrudas in Belo Horizonte and Tietê in São Paulo.

After the urbanization context of Palmas, the next topic will address the methodology used to verify its reflexes in the hydrological-hydraulic behavior of the Suçuapara watershed. It should also be noted that it was verified how the watershed would behave in the event that part of its green areas was destined for infiltration wells and trenches.

METHOD

Delimitation and general parameters of the watershed

The watershed delimitation was based on the conveyance system provided in the PMSB. It should be noted that the conveyance system sometimes generates watersheds different from the natural watershed, mainly due to the development of road systems and land parceling, which are limits for the insertion of the conveyance system.

Using the available altimetry for the municipality of Palmas — 1 m inter-spaced level contours, and with the help of geoprocessing tools —, it was possible to raise the necessary parameters for modeling in SWMM, such as area, main river length, main river slope, and the watershed average slope. Figure 2 shows the SWMM conceptual model.

Hidrological and hydraulic model

As previously pointed out, the watershed behavior was analyzed with the aid of SWMM. In this case, an IDF (intensity-duration-frequency) equation was used as input data for Palmas, in addition to the infiltration and propagation models listed below.

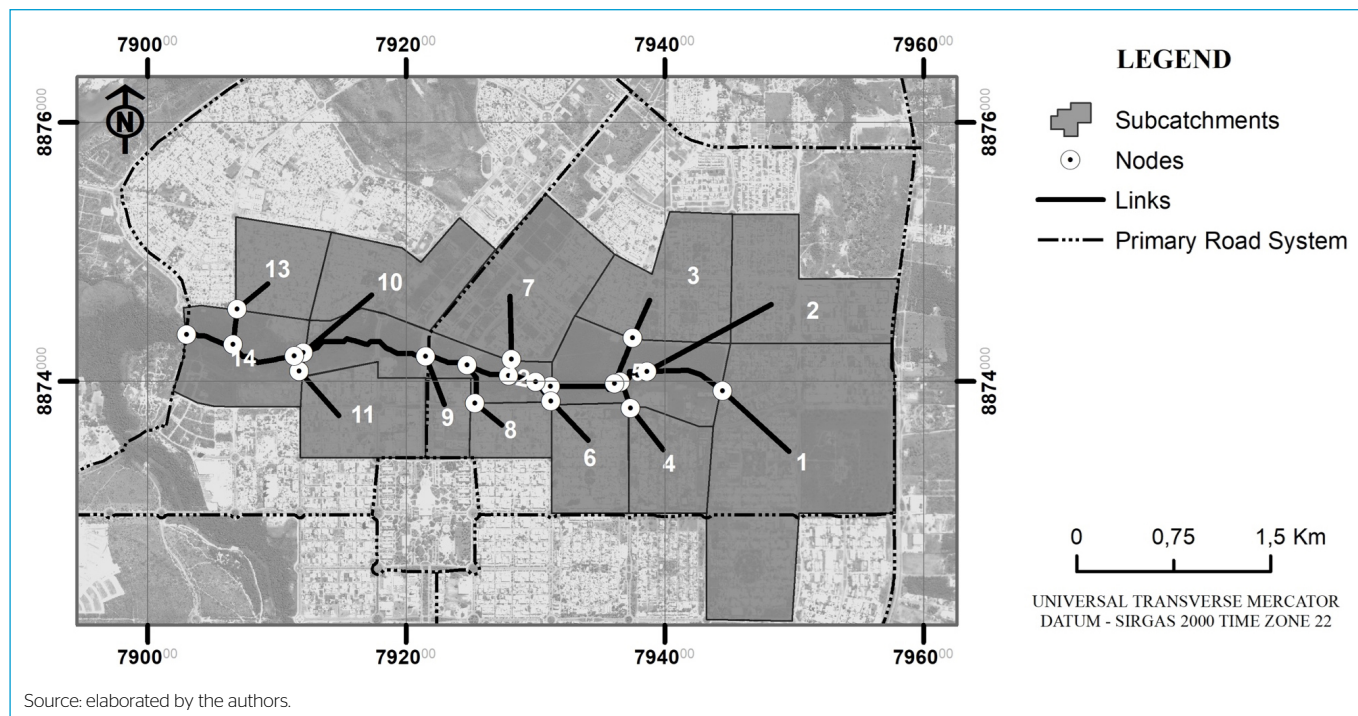


Figure 2 - Storm Water Management Model (SWMM) conceptual model.

The study was based on a rainfall-runoff model, which requires standard precipitation for watershed analysis and its network of conduits intended for stormwater convey. For that, the IDF equation used was that resulting from Andrade (2014), set out below, in Equation 1. The option for this equation was mainly due to its being the most recent scientific work that estimated an IDF equation for Palmas.

$$i = (884.669 * RT^{0.156}) / [(t_d + 9.884)^{0.726}] \quad (1)$$

Where:

i = the intensity of precipitation, in millimeters per hour;

RT = the return period in years;

t_d = the rain duration in minutes.

For the return period, values of 2, 10, 25, 50, and 100 years were used in order to verify the watershed behavior between the storms commonly considered in the urban scenario. The duration of the rainfall was equalized to the watershed time of concentration. The Kirpich formula was used for its calculation, which, in this case, returned an approximate value of 66 minutes.

The Kirpich formula was adopted as recommended by the Prefeitura de Palmas (2014). At the *Plano de Ação Palmas Sustentável*, it was used an average of other formulas, which resulted in a concentration time of 99 minutes (IDOM; COBRAPE, 2014). The 66 minutes value was used in this study as a conservative proposal.

With the IDF equation and time of concentration, it was possible to determine the design hietograms, elaborated by the alternating blocks method based on the arrangement 5-3-1-2-4-6, as recommended by Canholi (2014).

Due to the lack of real infiltration data for the watershed soil, the Soil Conservation Service (SCS) method was chosen. The material used to query the curve number values (CN) was the original work of the current Natural Resources Conservation Service (1986).

The Palmas pedological map classifies the soil of the urban area as a Red-Yellow Latosol. According to the Pedology Technical Manual of the Brazilian Institute of Geography and Statistics (*Instituto Brasileiro de Geografia e Estatística* – IBGE, 2015), these soils are deep and have good drainage. Thus, in this work, the soil was considered as type B for the purpose of selecting CN values.

It is important to note that the CN values used refer to the antecedent moisture condition (AMC III). This option was adopted because, in the rainfall analysis of the Taquaruçu do Porto station, located in Palmas, considering the years with consisted data and the rainy period (October to April), it was found that in approximately 28.57% of the days soil in the region had received above the 53 mm cumulative precipitation for five days.

For the subcatchments discretization of the watershed, the contribution areas of the macrodrainage network were taken into account. For the width of the surface flow, the critical path method was used, which indicates the division of the subcatchment area by the largest path traveled by the water until its arrival in the outfall. Manning roughness values for the surface runoff were chosen for the standard values indicated in the SWMM manual, with 0.011 for impermeable areas — smooth asphalt —, and 0.15 for permeable areas — short grass (ROSSMAN, 2009). The standard values for storage in depressions for pervious and impervious areas were also taken from the manual, assuming the values of 5.08 and 1.27 mm, respectively.

For the impermeable areas without storage percentage, the recommended value of 25% was adopted based on James, Rossman and James (2010) User's Guide

to SWMM5. The definition of propagation type (pervious, impervious, and outlet) was carried out as follows: if the subcatchment contemplates macrodrainage network inserted in the model, the condition adopted was impervious and, if not, pervious. The impervious type of propagation means that water, upon precipitation over the subcatchment, after reaching the storage limit, flows into an impermeable area. In pervious type propagation, it eventually flows into a permeable area.

Regarding the conduits, the main stream as well as some parts of the conveyance system were considered in this study. About the cross section of the main stream, a field survey campaign was carried out with manual tools (measuring tape, stems, and ropes), allowing the depth surveying on an 1 to 2 m of width distance. The definition of the geometric shape of each section was then inserted into the SWMM, seeking to match the actual dimensions observed in the field.

For the conveyance channels, the municipal conveyance network register was consulted. It is important to point out that the complete modeling of the network is impracticable by the numerous subcatchments that would be necessary, so only the sections and manholes that concentrate all the drainage of the subcatchment were inserted. Manning roughness coefficient of the conveyance system was adopted as 0.11 (cement pipe) and 0.03 (natural channels with fairly regular section), both following the recommendations of the Rossman SWMM Manual (2009). The complete discretization of the model is presented at the study by Mendes (2018).

Compensatory techniques modelling in SWMM

The behavior evaluation of the watershed also took into account the possible insertion of compensatory techniques in green areas necessarily reserved by the urban guidelines. The techniques modeled were infiltration wells and infiltration trenches. The selection of these two techniques had as main criterion the possibility of their application directly by the public administration, not depending on residents' adhesion, which reduces the risks for their effective implementation.

For the modeling of these devices, the methodology proposed by Silva (2007) was used. In this methodology, it is necessary to calculate the volume of the structure to be installed and then obtain the corresponding height, by means of Equation 2:

$$\text{Height} = \text{Volume} / [\text{Area} * (\% \text{impervious or } \% \text{pervious})] \quad (2)$$

The equation suggests that the volume that would be captured by the device will be distributed by the area corresponding to its characteristic — impervious or pervious. For the present study, infiltration wells and infiltration trenches were considered pervious. The obtained height value is then added to the storage parameter in the pervious area depressions of the subcatchment under analysis.

To obtain the height, a cross section with an average depth of 1 m was applied to the remaining green areas of the blocks. There was no variation of depth between the devices, as it will depend on the block and the available area. Thus, the option passes through the easiness of structure execution and the area and depth are an option of the possible executor (allowing the avoidance of vegetation, infrastructure, and so on).

This methodology option allows a previous evaluation of the compensatory techniques impacts on the watershed, leaving to the public policy institution the specific area selection and final geometry of the devices if the results are considered relevant. In addition, as these structures are added a more permeable material, the green areas intended for their implantation were reclassified as "Open Spaces — Good" for the CN values, in order to try to simulate the materials permeability gain.

Scenarios

In order to compare the scenarios, the following parameters were used: total infiltration, runoff, final storage, flow coefficient (*i.e.*, ratio between the drained volume and total rainfall), peak flow, peak time and the maximum outfall height, as well as the hydrograph visualization for each precipitation. The scenarios were: current, critical, and compensatory techniques.

In the current scenario, the occupancy parameters derived from the images visual interpretation made available by Google Earth, dated August 2017, were used. For the critical scenario, it was considered that all the basin parcels were occupied, maintaining the permeability rates determined by law, and that all projected roads and sidewalks were executed, which increased its parameter of impervious area percentage and CN values.

For the compensatory techniques scenario, the critical scenario parameters were considered as starting parameters, in order to attempt, through the adoption of these techniques, to provide a hydrographic watershed behavior similar to the current conditions. This scenario also changes by increasing the storage in depressions parameter, reducing CN values of the identified green areas for insertion of the devices, as well as changing the flow propagation in the subcatchments from impervious to pervious.

There is no data available for model calibration. In order to visualize the adherence to reality, the results were compared with two other studies carried out in Palmas, the PMSB and the *Plano de Ação Palmas Sustentável*, both from *Prefeitura de Palmas* (2014; 2015).

RESULTS

After the division of the subcatchments, it was possible to determine their characteristics related to form, derived from the geoprocessing routines, and of land use and occupation, resulting from the visual interpretation of Google Earth images. Table 2 shows the values entered for the subcatchments parameters that did not change through the different scenarios.

Table 2 - Subcatchments parameters.

Subcatchment	Area (km ²)	Width (m)	Slope (%)
1	2410	1,295.86	1.57
2	8.74	546.47	2.35
3	8.61	700.16	1.47
4	4.58	457.72	1.2
5	7.68	537.06	2.96
6	4.93	493.19	1.5
7	9.88	754.20	2.48
8	2.38	325.47	1.46
9	2.29	262.75	1.84
10	6.99	558.88	2.6
11	6.40	533.40	2.15
12	7.42	353.33	5.11
13	4.70	494.92	2.77
14	6.78	615.92	4.08

Source: elaborated by the authors.

In comparison to the current scenario, the critical scenario presents changes only in the parameters of impervious area and CN. For the compensatory techniques scenario, the main difference is in the depression storage of the pervious area parameter (above the 5.08 mm of the current scenario). However, there is a change in the CN, since this option has layers that allow greater permeability, even with the same impervious area of the critical scenario. There is also a difference in the type of flow propagation, which in some subcatchments has changed from impervious (IMP.) to pervious (PER.). These changes are presented in Table 3.

As mentioned in the methodology, a flexible method to assess the impact of the compensatory techniques was used. To do that, it was enough to survey the total area available for infiltration wells and trenches. Then, with the 1 m cross section, it was possible to obtain the total volume and distribute it over the pervious area (Table 4). The result is the storage pervious to be added at the 5.08 mm default.

Comparison of hydrographs, hydrological, and hydraulic parameters

A summary of the results obtained in this section can be visualized in Table 5. It presents the values of the water balance, flow coefficient, maximum flow, and maximum outfall height for all simulated scenarios, considering the rainfall with 2 and 100 years return period, providing a more direct and synthetic comparison.

Comparing the peak flow values between the critical and current scenarios, there is an average increase of 11.12 and 9.82% of the former in relation to the latter, for the return periods of 2 and 100 years. This increment can be better visualized in Figure 3, which compares the hydrographs of both scenarios for these return periods. It is curious to note that there is no relevant anticipation of the peak time and that the increase in flow is not very significant. This is due to the fact that the watershed is very impervious in both scenarios.

For the compensatory techniques scenario, the changes are more significant. The peak flow rate is 17.46% lower when compared to the current scenario, for the return period of 2 years. This reduction is lower for the 100-year return period — 4.59%. This is mainly because in more intense precipitations there is less time of storage and the capacity of the compensatory techniques is reached quickly.

Nevertheless, even for the most critical storm, the flow reduction is 15.10% compared to the critical scenario. In addition to the low variation of the outfall

Table 4 - Available area for compensatory techniques and added store pervious.

Subcatchment	Available area (m ²)	Pervious area (%)	Added storage pervious (mm)
1	103,551.60	51%	84.31
2	75,928.92	35%	245.90
3	63,169.82	34%	216.82
4	21,294.97	30%	153.26
5	0	83%	0
6	22,611.83	29%	157.61
7	26,661.04	33%	82.91
8	0	13%	0
9	0	32%	0
10	18,204.38	36%	72.43
11	1,455.86	25%	9.27
12	0	88%	0
13	12,901.41	24%	116.08
14	3,659.99	73%	7.45

Source: elaborated by the authors.

Table 3 - Parameters changes for critical and compensatory techniques scenarios.

Sub.	Current			Critical		Compensatory Techniques		
	Propagation	CN	Impervious Area (%)	CN	Impervious Area (%)	Propagation	CN	Storage Pervious (mm)
1	IMP.	93.96	43%	94.19	49%	PER.	93.85	89.39
2	PER.	93.57	39%	95.25	65%	PER.	94.57	250.98
3	IMP.	94.55	56%	94.99	66%	IMP.	94.45	221.90
4	IMP.	94.81	64%	95.00	70%	PER.	94.64	158.34
5	PER.	87.28	15%	87.53	17%	PER.	87.53	5.08
6	IMP.	95.09	66%	95.25	71%	PER.	94.89	162.69
7	IMP.	94.15	41%	95.90	67%	IMP.	93.84	87.99
8	IMP.	97.40	83%	97.59	87%	PER.	97.59	5.08
9	IMP.	95.83	54%	96.77	68%	PER.	96.77	5.08
10	IMP.	94.39	48%	95.62	64%	PER.	95.42	77.51
11	IMP.	96.34	68%	96.71	75%	IMP.	96.69	14.35
12	PER.	85.82	11%	86.02	12%	PER.	86.02	5.08
13	IMP.	95.70	75%	95.73	76%	IMP.	95.53	121.16
14	PER.	87.30	6%	88.79	27%	PER.	88.75	12.53

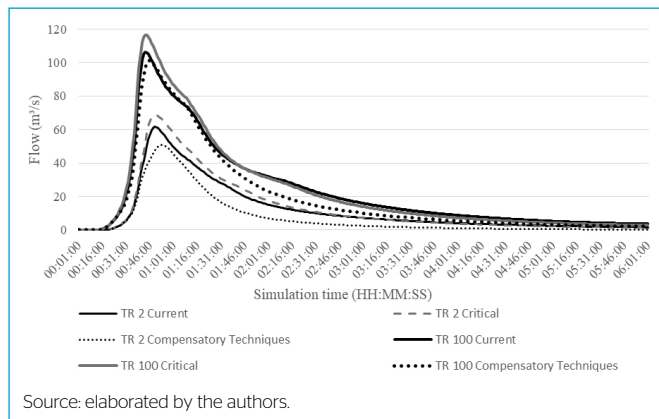
Sub: subcatchment; CN: curve number; PER.: pervious; IMP: impervious.

Source: elaborated by the authors.

Table 5 - Scenarios results summary for 2 and 100 return period.

Parcel	Return Period (years)					
	2			100		
	Scenarios					
	Current	Critical	Compensatory Techniques	Current	Critical	Compensatory Techniques
Total rainfall (mm)	46.79	46.79	46.79	86.14	86.14	86.14
Infiltration (mm)	12.76	9.97	10.41	12.96	10.1	10.54
Runoff (mm)	28.07	31.91	15.45	64.02	68.83	42.14
Final storage (mm)	5.98	4.93	20.94	9.21	7.26	33.51
Flow coefficient (%)	60	68	33	74	80	49
Maximum flow (m ³ /s)	61.58	68.47	50.83	106.12	116.54	101.25
Variation in Maximum flow (% Current)	-	+11.12	-17.46	-	+9.82	-4.59
Maximum outfall height (m)	214.98	215.02	214.91	215.20	215.25	215.18

Source: elaborated by the authors.



Source: elaborated by the authors.

Figure 3 - Hydrographs comparison of different scenarios.

height and the absence of network overloads, the scenario with compensatory techniques proved to be able to maintain security against extreme events, even with the watershed full occupation.

The macrodrainage network inserted in the model only presented overloads in two mainholes of its 32 nodes, which was observed in a critical scenario and for the return period of 100 years. As they manifest themselves only with a return period of 100 years, it is understood that there is no need for interventions. Moreover, even in comparison with the current scenario, the variation in outfall heights for the critical scenario is insignificant. Table 6 shows a summary of the results for the critical scenario in all the return periods simulated.

The cross-sections of the main river were also sufficient to accommodate the flows without overflow heights, but this can be mainly explained by the connection arrangement between the different stretches of the network, in which the model considers the possibility of increasing the level amount. The greatest width of flooding of the main river was 17.50 m from its axis, while the smallest width of the reserved green areas, from the axis, is approximately 75 m. As shown in Figure 4, this flooding width is not sufficient to impact the nearest residential, public administration, and commercial areas.

Table 6 - Summary of critical scenario.

Parcel	Return Period (years)				
	2	10	25	50	100
Total rainfall (mm)	46.79	60.14	69.39	77.31	86.14
Infiltration (mm)	9.97	10.1	10.1	10.1	10.1
Runoff (mm)	31.91	44.13	52.81	60.36	68.83
Final storage (mm)	4.93	5.95	6.52	6.90	7.26
Flow coefficient (%)	68%	73%	76%	78%	80%
Maximum flow (m ³ /s)	68.45	83.85	95.16	105.25	116.54
Maximum outfall height (m)	215.02	215.10	215.15	215.20	215.25

Source: elaborated by the authors.

DISCUSSION AND RECOMMENDATIONS

The results were compared with the PMSB (PREFEITURA DE PALMAS, 2014) and the *Plano de Ação Palmas Sustentável*, on its vulnerability and risk analysis study (IDOM; COBRAPE, 2014). Table 7 shows the results presented by both studies and in this work for the current scenario.

The results are consistent, considering the model parameters of each study. The reduced maximum flows in the PMSB were mainly explained by the low CN adopted, where the AMC II moisture condition and a simple division of the land occupation between urbanized (CN 85) and non-urbanized areas (CN 62) were considered (PREFEITURA DE PALMAS, 2014).

On the other hand, results of IDOM and COBRAPE (2014) were more similar to those achieved with this work model. This was possible due to the CN was adjusted for AMC III moisture condition in both. The difference could be explained by the significantly greater time of concentration used, as previously mentioned in this study. Considering all these points, it is possible to assume that the results achieved in this model are coherent.

The green areas adjacent to the main stream contemplated since the basic plan of the Grupo Quatro (1989) and respected over time allow for occupancy



Figure 4 - Flooded Area on Suçupara Watershed.

Table 7 - Results compared with other studies in Suçupara Watershed.

Parameter	Current Scenario	PMSB	Palmas Sustentável
Maximum Flow (m³/s) - TR 2	61.58	28.24	40.40
Maximum Flow (m³/s) - TR 10	76.66	38.5	-
Maximum Flow (m³/s) - TR 25	86.85	44.64	73.92
Maximum Flow (m³/s) - TR 50	95.88	50.17	82.42
Maximum Flow (m³/s) - TR 100	106.12	56.18	90.93
CN	92.93	74.33	91.85
Time of Concentration (min.)	65.84	-	99

CN: curve number; PMSB: Plano Municipal de Saneamento Básico.
 Source: elaborated by the authors.

flexibility options in the rest of the urban area of the watershed under study. Although not yet consolidated, the *Parque Linear dos Povos Indígenas*, a linear park proposal, constitutes a barrier that, in addition to accommodating the increase of the flow coming from the urbanization, is configured in a reserve of green area that could have its infiltration potential increased as it presents itself as necessary. These green areas are particular in contrast with the two previously cited Brazilian examples — Ribeirão Arrudas, in Belo Horizonte, and Rio Tietê, in São Paulo — as largely discussed by Lucas *et al.* (2015) and Tominaga (2013), respectively.

The generated hydrograms analysis shows that there were no major variations of the peak time in the different simulated scenarios. It is necessary to consider, in this regard, and acting in favor of safety, that this is due to the high impervious index of the watershed — expressed in the high values of CN —, as well as of the non-simulation of future conveyance system networks.

According to the PMSB, the Conveyance Network Coverage Ratio in the Suçupara Watershed is 0.79 (PREFEITURA DE PALMAS, 2014). This index represents the ratio between the urbanized area of the basin served by the conveyance system and the total urbanized area of the watershed. The index shows that there is still 21% of urban area currently not served, in addition to the areas that will be urbanized in the future, which will, of course, alter the behavior of the watershed.

The increase in impervious areas was simulated in this work at the critical scenario — elevating the total impervious area from 43.24 to 54.17% of the watershed — which caused significant increments in runoff, flow coefficient, and maximum flow. In any case, although no simulation of the entire conveyance system was made, the inserted sections proved sufficient to drive the watershed flow.

Limitations were observed only in two points of the network and just at the 100-year critical scenario, so the network can then be considered adequate. Compensatory techniques were sufficient to manage that, even if partially used in available green areas.

It was also possible to identify that compensatory techniques have a great potential for use in urban watersheds, especially when they have sufficient green areas for their wide insertion. In light of this, there is some compensation to the impervious areas imposed by the urbanization that, from the point of view of drainage, can be carried out without major negative impacts.

The reduction in peak flow rate comparing the compensatory techniques scenario to the critical scenario (25.76 and 13.12% for 2 and 100 years, respectively) are aligned with the results presented by Silva (2007), that has observed reductions of 23.96% when simulating the use of infiltration trenches in the Córrego dos Buritis watershed, located at Goiânia. Reinforcing this result, Caputo (2012) found reductions ranging from 12 to 29%. These results are similar to those presented by Kusumastuti *et al.* (2014), as they have found reductions nearly above 25% when using infiltration wells with 5-year-return period storms.

With regard to the floods recurrently mentioned by the population and news reports, it can be assigned to the lack of complete coverage of the conveyance system, expressed by its Conveyance Network Coverage Ratio cited before, aggravated by the low average slope found. In this way, there is a tendency for the retention of part of the surface runoff, gradually eliminated by the dispersion of vehicles and by evaporation.

As recommendations, it is necessary to investigate the behavior of the basin with the insertion, minimally, of the whole conveyance system. Invariably, the results obtained will be different and deserve to be investigated. In this sense, a great gain for future studies would be the possibility of using fluvimetric data for calibration and model validation. This use would lead to greater security for decision makers, since the model would be able to present a behavior closer to that actually presented by the watershed.

Another point worthy of further investigation is the use of other infiltration models, such as Horton and Green-Ampt, with the use of local soil data, to investigate the validity of perpetuating the use of the Curve Number model in other watersheds from Palmas, Legal Amazon, and Brazilian cities in general.

It is also noticed the possibility of advances in the analysis of urban planning aspects of the basin and its repercussions to the hydrological-hydraulic behavior. For example, it would be interesting to statistically evaluate the correlation between the different average road and parcel sizes with the flows resulting from each subcatchment. In this sense, there are more refined analyzes regarding the reflexes arising from a possible use of green areas for other purposes or

the transfer of these areas to other localities in the watershed, as well as in the adjacency of the main river.

CONCLUSIONS

Simulations performed using the SWMM model revealed that the occupation guidelines of Palmas, a recently planned city, are more than sufficient to prevent floods on nearby occupations and neighborhoods of the Suçupara stream. The flood width of the stream was 17.50 m from its axis, while the most restrict width of reserved green area along it is approximately 75 m. Also, the adoption of compensatory techniques could result in peak flows reduction varying around 25.76 and 13.12% when compared to the critical scenario, depending on the precipitation intensity. It was also identified that the stretches of the macro-drainage network modeled are capable of conveying the flows of its subcatchments. Two flooding points were observed only in the critical scenario with a 100-year return period, and could be fully controlled with the use, even if partially, of compensatory techniques.

AUTHORS' CONTRIBUTIONS

Mendes, F. C.: Conceptualization, Data Curation, Formal Analysis, Investigation, Methodology, Resources, Software, Writing — Original Draft, Writing — Review & Editing. Andrade, R. S.: Project Administration, Supervision, Validation, Visualization.

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