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Environment

LID Implementation in an urban basin: a Brazilian case study

Implementação de LID em uma bacia urbana: caso de estudo brasileiro.

Camila Pires dos Santos Câmara, Sylvana Melo dos Santos[I], Anderson Luiz Ribeiro de Paiva[I], Larissa Ferreira David Romão Batista[I]

[I] Universidade Federal de Pernambuco, Recife, PE, Brasil

ABSTRACT

Problems related to urban drainage systems and the disorderly growth of large urban centers have led to the search for alternative drainage techniques. These techniques have been called Low Impact Development (LID) and generally influence the reduction of peak flow and runoff volume. In an urban sub-basin in the city of Recife, PE, the hypothesis of replacing existing roofs with a green roof (GR) was considered in three scenarios: (1) pre-urbanized, (2) current, (3.1) 30% of GR, (3.2) 50% of GR, (3.3) 75% of GR, and (3.4) 100% of T.V. For this, simulations were carried out in PCSWMM based on the current urbanization situation. Linimetric readings were taken for calibration, obtaining 0.61 NSE and 0.903 R^2. Validation was carried out using images at two points within the basin. The reduction in peak flow values ranged from 0.74 to 2.10 m^3/s, in addition to the time being delayed from 31 to 90 minutes. As for river level values, the variation was between 4 and 13 cm, while volume reductions recorded values between 67.42 and 190.81 m^3. Overall, this proposed methodology can help stormwater managers better evaluate the performance of LID techniques at different hydrological scales, showing the importance of prioritizing urban adaptation and green infrastructure implementation.

Keywords: Green roof; PCSWMM; Urban drainage

RESUMO

Problemas relacionados aos sistemas de drenagem urbana e ao crescimento desordenado dos grandes centros urbanos têm levado à busca por técnicas alternativas de drenagem. Essas técnicas têm sido chamadas de *Low Impact Development* (LID), e em geral influenciam na redução do pico de vazão, volume de escoamento. Em uma sub-bacia urbana da cidade de Recife, PE, foi considerada a hipótese de substituição de coberturas existentes por telhado verde (T.V.) em três cenários: (1) pré-urbanizado, (2) atual, (3.1) 30% de T.V., (3.2) 50% de T.V, (3.3) 75% de T.V, (3.4) 100% de T.V. Para isto, foram realizadas simulações no PCSWMM a partir da situação atual de urbanização. Leituras linimétricas foram realizadas para a calibração, que obteve NSE 0.61 e R^2 0.903. A validação foi realizada por imagens em dois pontos da bacia. Como resultado, a vazão de pico foi reduzida entre 0.74 e 2.10 m³/s, além do tempo ter sido retardado de 31 a 90 minutos. A diminuição do nível do rio no pico variou entre 4 e 13 cm e o volume foi reduzido entre 67.42 e 190.81 m³. Em geral, esta metodologia proposta pode ajudar os gestores de águas pluviais a avaliar melhor o desempenho das técnicas LID em diferentes escalas hidrológicas, mostrando a importância de priorizar a implementação ou adaptação de áreas urbanas com infraestrutura verde.

Keywords: Telhado verde; PCSWMM; Drenagem urbana

1 INTRODUÇÃO

Population growth and the urbanization of cities have led to increased surface area impermeability, directly contributing to more significant volumes of surface runoff and reduced infiltration of rainwater into the soil. In this context, given the complexity of urban development, urban drainage management is a significant challenge for the proper functioning of cities (Fletcher et al., 2015). Several alternative drainage techniques, such as Sustainable Drainage Systems (SuDS) or Low Impact Development (LID), are being studied and implemented to mitigate the adverse effects and create a scenario closer to pre-urbanization conditions. These techniques include green roofs, rain gardens, infiltration wells, retention/detention basins, and permeable pavements, among others.

Like many urban centers worldwide, the Recife city, the capital of the Pernambuco State, suffers from high degrees of impermeability and frequent flooding problems. As the city becomes increasingly urbanized, there is increasing recognition of the need to implement alternative drainage techniques to mitigate the negative impacts of stormwater and climate changes. Currently, various measures have been applied to minimize rainfall and problems related to tides, including a municipal law that requires the implementation of green roofs and detention reservoirs in new buildings with areas greater than 400 m². However, the law still lacks technical information on sizing and incentives to cover existing buildings, especially those located in critical areas exposed to flooding.

Therefore, there is a need to evaluate the actual contribution of the techniques proposed in the green roof law to reduce flooding problems within the scope of urban drainage in existing buildings and the possibility of reducing the contribution of rainwater to the existing drainage system through simulations using software tools.

The Personal Computer Storm Water Management Model (PCSWMM) is a dynamic hydrological-hydraulic and water quality simulation model, especially applied in urban areas for simulations of a single rainy event and continuous events. It is often used for planning and analysis activities, projects related to stormwater runoff, combined systems and sewage, as well as other drainage systems in urban and non-urban areas (Rossman, 2015). The student version of PCSWMM 7.5.3399 corresponds to SWMM versions 5.0.013 – 5.1.015. The PCSWMM features a LID module, specific for modeling alternative drainage techniques that combines several devices in a basin, also verifying its effectiveness. LID controls are represented by performing moisture balance that tracks water movement vertically between different layers. Some of the structures that can be simulated in the LID module are bioretention cells, infiltration ditches, infiltration trenches, permeable pavements, rain gardens, and green roofs (Rossman, 2015; Peng & Stovin, 2017).

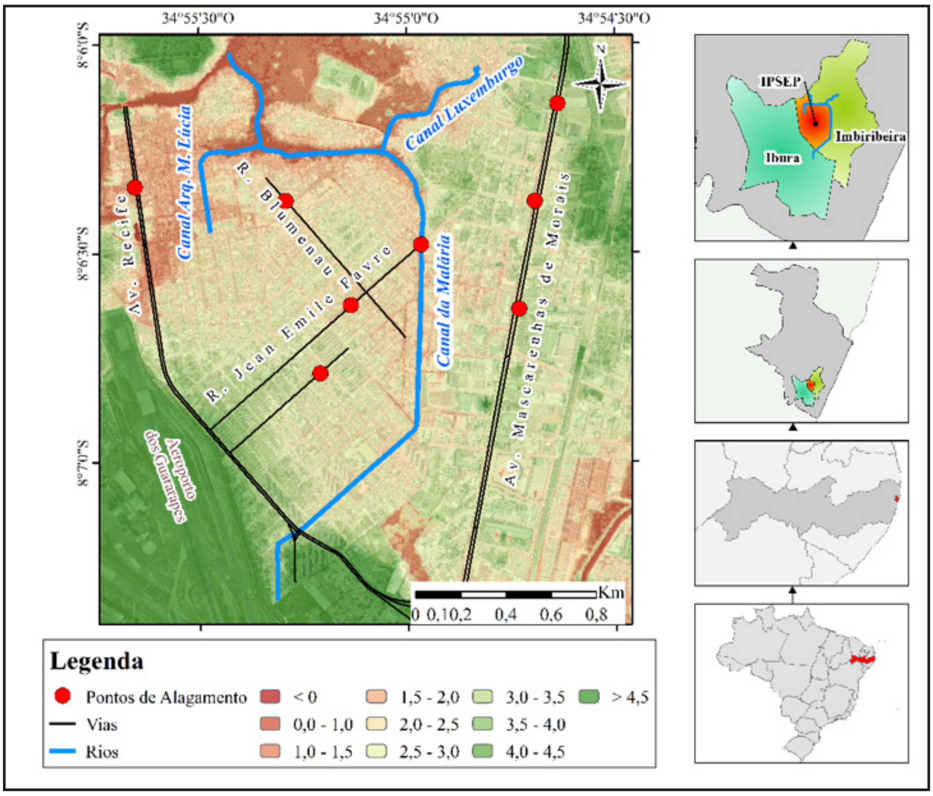
Thus, this study investigates the efficiency of implementing Low Impact Development (LID), specifically green roofs, in an urban sub-basin in the Recife city, Brazil. The assessment focuses on hydraulic-hydrological performance comparing scenarios, including the current situation, the implementation of green roofs in different percentages of the covered area, and a pre-urbanized scenario.

2 METHODOLOGY

2.1 Study Area

The Malaria Canal Basin (Figure 1) is located between the neighborhoods of Ipsep, Imbiribeira, and Ibura, in Administrative Region 6 (RPA 6) of the city of Recife, on the northeast coast of Brazil. The Malaria Canal begins near Guararapes International Airport, in the Ibura neighborhood, and has its exit at the Tejipió River, dividing the neighborhoods of Ipsep and Imbiribeira. Its tributaries include the Architect Maria Lúcia and Luxemburgo Canals. The Ipsep, Imbiribeira and Ibura neighborhoods cover areas of 180, 666 and 1,019 hectares, respectively. Its population is around 25,029 people in Ipsep, 48,512 people in Imbiribeira, and 50,617 people in Ibura. The highest density is found in Ipsep with 139.27 inhabitants/ha, while the lowest is in Ibura with 49.69 inhabitants/ha. Imbiribeira has a population density of 72.85 inhabitants/ha (Recife, 2018a and 2018b).

Figure 1 – Study area – Location map



Source: Authors

As the Malaria Canal is mainly located in the neighborhoods of Ipsep and Imbiribeira, these neighborhoods gained greater prominence in this research due to their flat terrain with elevations below sea level (Figure 1). Annually, flooding occurs on several streets in Ipsep, mainly on Jean Emile Favre Street, Blumenau Street and Raimundo Diniz Avenue (Figures 2a and 2b). In the Imbiribeira neighborhood, the critical point is the Mascarenhas de Morais Avenue in several sections (Figure 2c). In the Ibura neighborhood, the area of research interest has a critical flooding point on Recife Avenue (Figure 2d), close to the entrance to the Ipsep neighborhood, causing interruptions to transport within the city (Alencar et al., 2016).

Additionally, in 2019, an analysis of climate risks and vulnerabilities was carried out for the municipality of Recife, which identified the Ipsep neighborhood as highly exposed to climate risks in both the current and future scenarios. The area was found to have high risks of flooding, communicable diseases, heatwaves and drought. It was classified as the sixth most critical neighborhood in the future scenario, among a list of ten neighborhoods (Recife, 2019).

Figure 2 – Malária Canal basin floods

(a) Street in the Ipsep neighborhood

(b) Arquitect Maria Lúcia Canal

(c) Mascarenhas de Morais Avenue

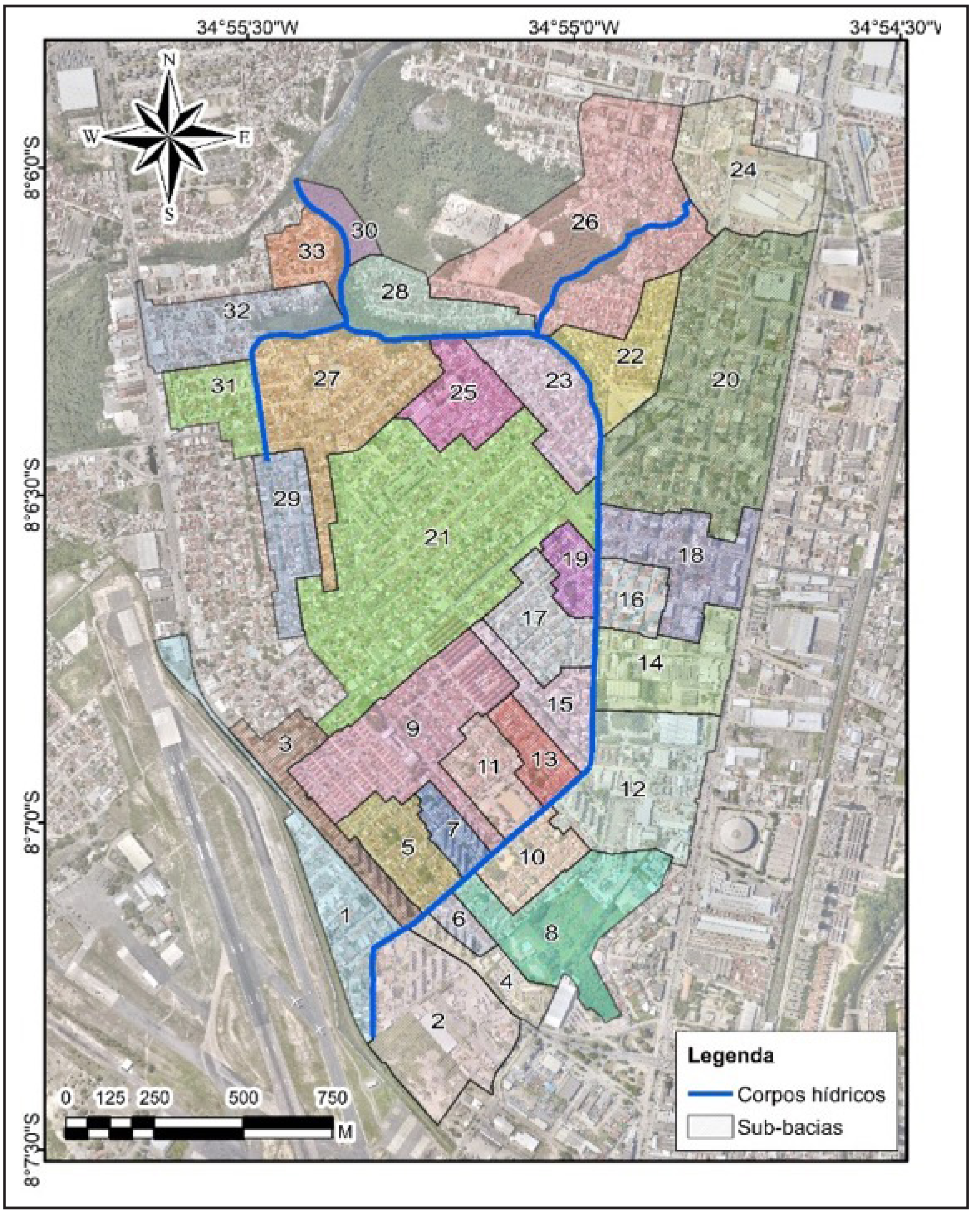
(d) Recife Avenue

Source: G1-PE (2019)

2.2 PCSWMM simulation – input parameters

For simulation in PCSWMM, a series of data is required as model input. The morphometric parameters of the Malária Canal basin were generated from the PE3D Digital Terrain Model (DTM) using minor computational procedures in the ArcGIS software and 33 sub-basins were identified (Figure 3). The delimitation of these sub-basins was based on the Recife Drainage Master Plan and was refined to its current composition with information obtained about the microdrainage network and its destination in the Malária Canal in meetings with the technical team of the Department of Maintenance and Urban Cleaning (EMLURB).

Figure 3 – Delimitation of Malária Canal sub-basin



Source: Authors

From the delimitation of the sub-basins, the average width in each sub-basin was calculated by Silva (2019) using the equivalent rectangle equation, which consists of a rectangle with the same area and perimeter as the original basin, Equation (1).

$$L_{eq} = \frac{K_c\sqrt{A}}{1,12}.\left[1 - \sqrt{1 - \left(\frac{1,127}{K_c}\right)^2}\right] \tag{1}$$

Where:

A – area of the subarea considered, in km²;

P – perimeter of the subarea considered, in km;

Kc – Compactness coefficient, calculated by Equation (2).

$$K_c = 0,282.\frac{P}{\sqrt{A}} \tag{2}$$

To obtain the average slopes, with the PE3D Digital Terrain Model, 3 longitudinal lines were created from the furthest point to the exit of the basin and the PCSWMM DEM Slope tool was applied, which calculates the slope of the sub-basin. According to Alencar et al. (2016), land use and land cover were calculated using the Curve Number (CN) method. The CN values calculated for the Malária Canal basin were 91.31, 86.66, and 91.59, with an average of 89.85, indicating a high degree of soil sealing in the region.

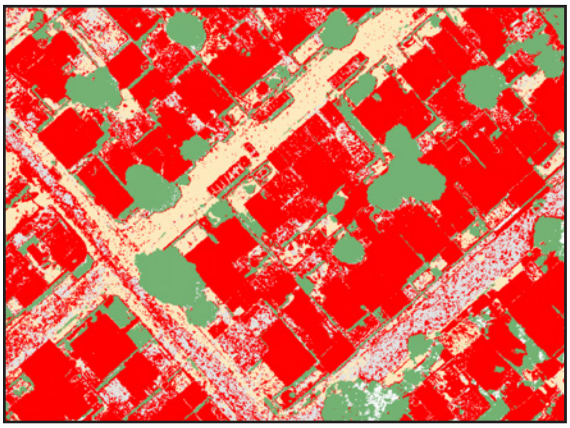
However, to make the classification of soils in the study area more accurate, a supervised classification of soils was carried out using the ArcGIS 10.8 software, using the “Maximum Likelihood Classification” tool. For this classification, a 2013 orthophoto provided by EMLURB (2020) with a resolution of 0.15 m x 0.15 m was used. The classes selected for the research were: 1 – water, 2 – roofs, 3 – exposed soil or dirt roads, 4 – vegetation, 5 – paved roads. This classification identified percentages of impermeable and permeable areas for each sub-basin. Figures 4 and 5 show the soil classification for a small area close to the control point. The total percentage of observed areas is displayed.

For the pre-urbanization scenario, soil classification was also carried out using orthophotos from 1974 obtained from the Condepe FIDEM database (Figure 6). As these images were in black and white and there were no other images with good resolution at the studied scale, it was not possible to apply the same supervised classification tool. Vectorization was then applied. During this period, it was observed that only Mascarenhas de Morais Avenue and Jean Emile Favre Street were paved and their impact on the classification was minimal. Therefore, only the vectorization of blocks fully or partially occupied by buildings was considered.

Figure 4 – Orthophoto of the year 2013

Source: EMLURB (2020) edited by Authors

Figure 5 – Supervised soil classification



Source: Authors

In the blocks with buildings, a sampling vectorization of the coverage areas was also carried out to evaluate the degree of occupation in 1974. The average percentage of land occupation in the blocks was 42.70%.

Manning’s roughness coefficient for permeable and impermeable areas was estimated based on the characteristics of soil cover of the area under study, with a value of 0.024 for impermeable areas and 0.15 for permeable areas, according to Canholi (2015), Silva and Cabral (2014) and Silva Junior (2017).

For the storage height parameter in depressions in permeable areas, which consists of the conditions of retaining rainwater on the surface, we used that suggested by the model of 2.54 mm (0.10 in.) for impermeable areas and 5 mm (0.20 in.) for permeable areas (Silva Junior, 2017). The topographic survey of the cross-sections of the Malária Canal was carried out to prepare stormwater management and urban drainage project in Recife (EMLURB, 2018) and for the development of the Urban Drainage Master Plan for the City of Recife (ALENCAR et al., 2016).

Figure 6 – Orthophoto of 1974

(a) Orthophoto

(b) Delimitation of blocks with buildings

(c) Blocks configuration

(d) Demarcation of occupied blocks

Source: CONDEPE-FIDEM (2023) edited by Authors

The rainfall stations that influence the Malária Canal basin are Areias (Code 261160621A – Latitude 34º55'44.4" South and Longitude 8º6'7.2" West) and Imbiribeira (Code 261160609A – Latitude 34º54'50.339" South and Longitude 8º7'15.51" West) of the National Center for Monitoring and Alerting of Natural Disasters (CEMADEN, 2019). In addition to proximity, stations were selected because they present hourly data at 10-minute intervals. The months selected for modeling were July and August 2019, the rainy season in the region.

To calibrate the model, a monitoring point of the Malária Canal was chosen between 20 and 23 sub-basins, where two linimetric rulers of 1.0 m each were installed, totaling 2.0 m in height, on a coated wall of the Malária Canal, next to a bridge with defined cross-section at the intersection of Malária Canal and Jean Emile Favre Street, a critical flooding point and easy access for data collection (Figure 7a and Figure 7b). The monitoring point was observed manually during the daytime period in July and August 2019, due to the lack of local lighting after sunset. During the period, the maximum level recorded was 1.18 meters on July 24, 2019, at a high tide of 1.84m, during a rainfall event of 71.60 mm in 24 hours, this being the event selected for calibration of the model modeling. Figure 8 shows the number of daily measurements carried out in the period, as well as the daily volume of accumulated precipitation. The event on June 13, 2019, was chosen to validate the mode.

Figure 7 – Malária Canal level

(a) Survey of orthometric altitudes and geometric leveling of the monitoring point

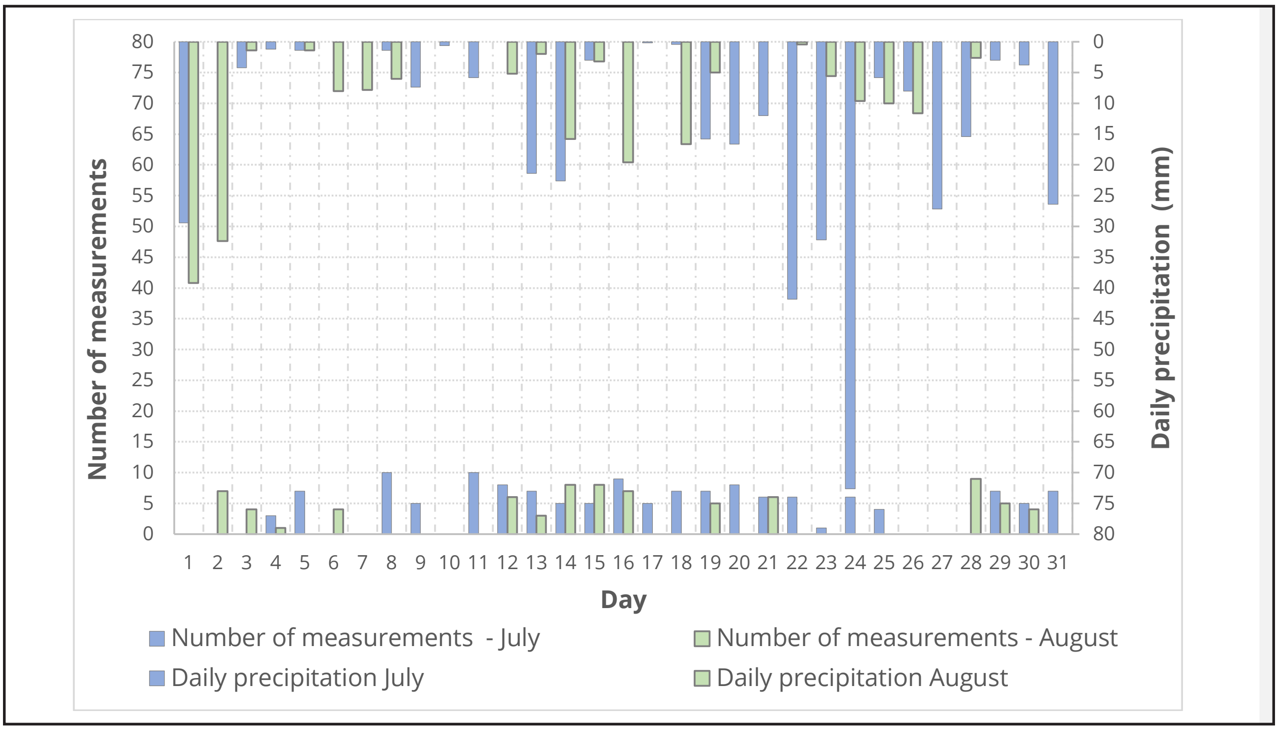
(b) Installation of linimetric rulers at the monitoring point

Source: Authors / Authors' private collection (June 2019)

The tide influences the Malária Canal basin for much of its length, including the Arquiteta Maria Lúcia and Luxemburgo Canals. Due to the low slope of the region, it was observed, through visits to the study site, that even on days without rain, there is an accumulation of water on some streets (Figure 9) depending on the tide level. In rainy events, high tide intensifies. To evaluate the tidal effect at the site, an estimative was made using the AstGeoTop tidal module (Garnés, 2016) for the heights or tidal levels in the Port of Recife for the year 2019, minute by minute. Data from tide tables with high and low tides (Marinha do Brasil, 2019) was inserted into the tidal analysis module, version 2016.09.01, to generate the tide model for the year 2019 with 37 components.

The model's accuracy about the original decimetric levels is 2.7 cm. In absolute terms, the maximum and minimum discrepancies throughout the year are less than 7 cm. As the tide level data were obtained from the Navy Reference Level System, adjusting the levels by subtracting 1.14 m to align with the IBGE levels was necessary, since the transversal survey was carried out in the IBGE reference system (Silva, 2019).

Figure 8 – Number of measurements and daily precipitation in July and August 2019



Soure: Authors

Figure 9 – Water accumulation on local street on non-rainy days

(a) São Nicolau Street next to the Arquiteta Maria Lúcia Canal

(b) Pampulha Street next to the Malária Canal

Source: Authors / Authors' private collection (June 2019)

2.2.1 Parameters of control alternatives – green roof

The ecological roof structure in PCSWMM comprises three layers: surface, soil and drainage. In the surface layer, the parameters to be filled in are the storage depth (maximum height of water stored before overflow), volumetric fraction of vegetation, Manning coefficient and roof slope. The soil layer parameters to be defined are soil layer thickness, porosity, moisture at field capacity, moisture at wilting point, saturated hydraulic conductivity, hydraulic conductivity curve gradient, capillary suction. The drainage layer has as parameters: thickness, void fraction and Manning roughness coefficient. The parameters used for this study are the same as those used by Peng and Stovin (2017), and are summarized in Table 1. The decision to use these parameters was due to the lack of other references with all the parameters for the LID module.

Table 1 – Input parameters in PCSWMM

Parameter	Used value	Source
Surface layer		
Storage depth	250 mm	Field data
Vegetation cover (fraction)	0	Model pattern
Surface roughness (n Manning)	0.15	Model pattern
Surface slope (%)	2.6%	Stovin, Vesuviano and Kasmin (2012)
Soil (substrate)		
Thickness	200 mm	Field data
Porosity (volumetric fraction)	0.45	Rosa, Clausen and Dietz (2015)
Field capacity (volumetric fraction)	0.3	Pöe, Stovin and Beretta (2015)
Wilting point (volumetric fraction)	0.05	Rosa, Clausen and Dietz (2015)
Hydraulic conductivity	1,000 mm/h	Peng and Stovin (2017)
Conductivity slope	50	Peng and Stovin (2017)
Matrix potential	110 mm	Rosa, Clausen and Dietz (2015)
Drainage layer		
Thickness	25 mm	Field data
Void index	0.6	Peng and Stovin (2017)
Roughness	0.03	Peng and Stovin (2017)

Source: Peng and Stovin (2017) / Organized by Authors

2.3 Simulation scenarios

The method used to calibrate and validate the model was iterative by trial and error, using the data observed between July 22 and 24, 2019 as a comparison. Then, scenarios were simulated with PCSWMM. The latter are very important because they allow us to investigate the current and previous situation, as well as define how it is believed to be possible to apply the LID technologies studied in the research area. Three distinct scenarios were developed and analyzed:

- Scenario 1 – representing the pre-urbanized condition in 1974;
- Scenario 2 – representing the current urbanized condition;
- Scenario 3.1 to 3.4 – with different proportions of green roofs as a mitigation measure.

Scenarios 3.1 to 3.4 evaluate the effects of vegetation coverage on 30%, 50%, 75%, and 100% of the total coverage area, respectively. This systematic approach allows for a comprehensive comparative analysis of the hydrological and hydraulic implications of proposed interventions, contributing to a deeper understanding of the potential benefits of green roofs in sustainable stormwater management in urban areas. The simulations consider factors such as surface runoff, infiltration, retention, and sediment transport, providing valuable information for making informed decisions regarding urban planning and mitigating rainfall impacts.

3 RESULTS

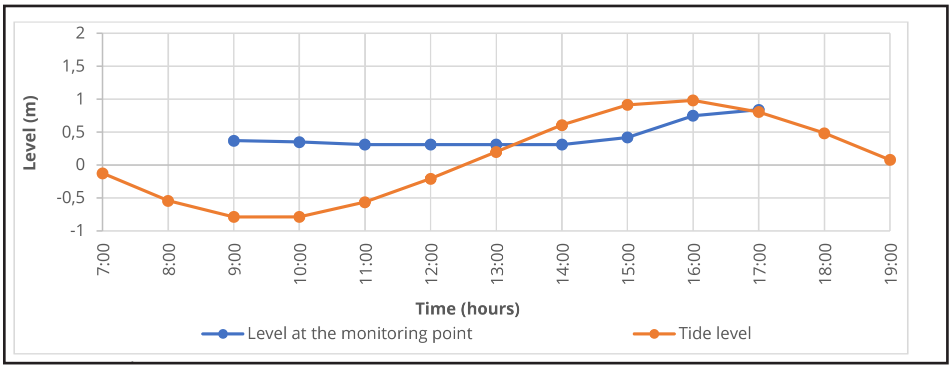
During the period of observation of the water level of the Malária Canal at the monitoring point, the influence of the tide was noted when the tide level reached 1.50 m, based on the tide table, with a delay of 1 (one) hour between the peak event at the Port of Recife and the monitoring point. When the tide was below 1.50 m, the level of the Malária Canal varied between 30 and 40 cm. As the reference tide levels provided by the Brazilian Navy (DHN) differ by 1.14 m above the IBGE reference levels used in this study, an adjustment was made for an adequate comparison. To illustrate this observation, data from July 16, 2019, (Figure 10), without precipitation, are presented. On this date, the peak tide was 2.12 m at 4 pm, DHN reference, or 0.98 m, IBGE reference. The Malária Canal monitoring point peaked at 0.84 m at 17:00 (Table 2).

Table 2 – Tide level discretized every 1 hour and record of the level of the Malária Canal at the Monitoring Point on July 16, 2019

Hour	Malária Canal water leve (m)	Tide DHN (M)	Tide IBGE (m)	Hour	Malária Canal water leve (m)	Tide DHN (m)	Tide IBGE (m)
9:00	0.37	0.35	– 0.79	14:00	0.31	1.75	0.61
10:00	0.35	0.35	– 0.79	15:00	0.42	2.05	0.91
11:00	0.31	0.58	– 0.56	16:00	0.75	2.12	0.98
12:00	0.31	0.93	– 0.21	17:00	0.84	1.95	0.81
13:00	0.31	1.34	0.20				

Source: Authors

Figura 10 – Graphical representation of tide levels recorded at the monitoring point on July 16, 2019



Source: Authors

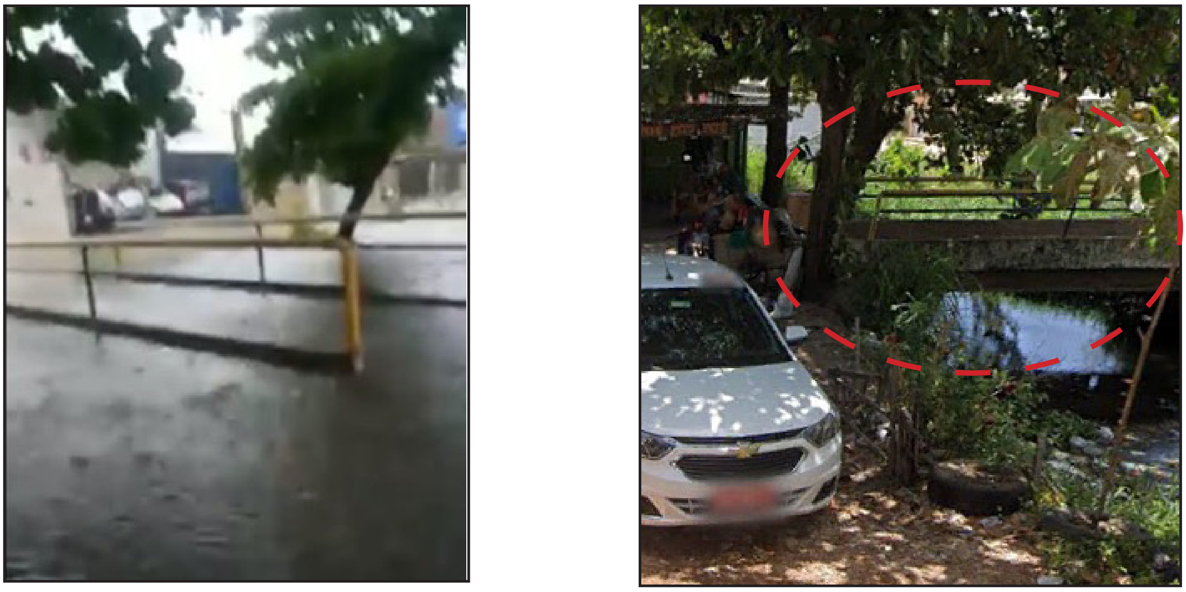
3.1 Model calibration and validation

The model calibration was carried out using data from events that occurred from July 22 to 24, 2019, resulting in a Nash-Sutcliffe efficiency coefficient (NSE) of 0.61 and a coefficient of determination (R^2) of 0.903. These values exceed the metrics established by Dongquan et al. (2009) that an NSE greater than 0.5 indicates acceptable model performance for SWMM simulation. Calibration was carried out using a trial and error method, with additional assistance from the SRTC tool available in PCSWMM.

To validate the model, the event on June 13, 2019, was selected, which recorded precipitation of 193.8 mm. During this event, the local population provided photographic records, contributing images to this research (Figure 11 and Figure 12). Figure 11a shows the river level during the flood, reaching 1.78 m, while Figure 11b represents the natural state of the Malária Canal on a sunny day.

In Figure 12, during the same event, people documented flooding of approximately 40 cm in a company close to the control point. This specific point, being a lower area of the road, revealed flooding, although the river did not overflow in that section, as evidenced by the visible pedestrian crossing and vehicles without water on their wheels. When simulating this event, it was observed that the node corresponding to the pedestrian crossing had a canal level of 1.82 m, while at the control point there was no canal overflow (Figure 13), consistent with the observations in Figures 11 and 12.

Figure 11 – Pedestrian walkway at the crossing between Rio Oceânico and Muritiba Streets



(a) During the rain event on June 13, 2019

(b) On a sunny day

Source: Authors / Authors' private collection (June, 2019)

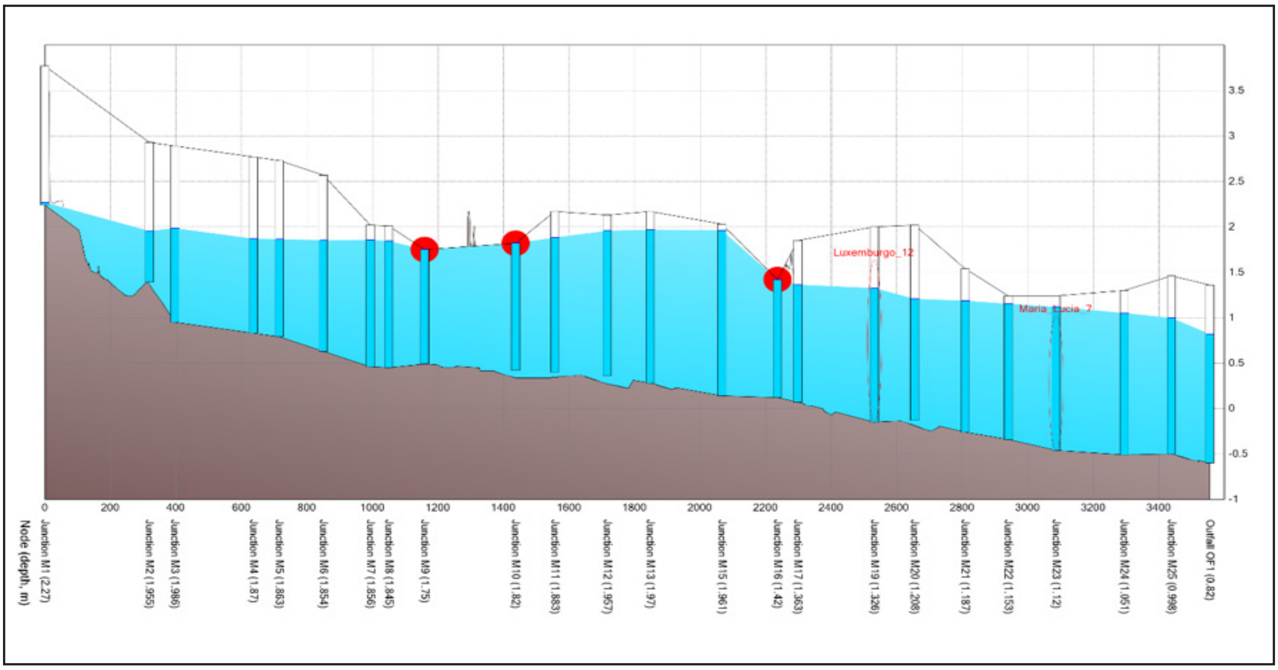
Figure 12 – Flooding on Jean Emile Favre Street, at the control point, during an extreme rain event at high tide on June 13, 2019

(a) Control point

(b) Property close to the control point

Source: Authors

Figure 13 – Longitudinal profile of the Malária Canal during water peaks with markings at the model validation nodes



Source: Authors

3.2 Scenario simulation

3.2.1 Flow

Figure 10 presents the results of each scenario at the outlet, focusing on the flow during the heavy rain event between July 22 and 24, 2019. The peak flow values for each scenario, along with their corresponding times, are summarized in Table 3.

Table 3 – Comparison of the peak flow of scenarios 1, 2, and 3

Scenario	**Peak flow ($m^{3/}s$)**	**Hour**	**Peak anticipation (h)[1]**	**Flow increase[1]**	**Peal flow delay[2] (h)**	**Flow decrease[2] (%)**
1	1,49	7:10				
2	3,86	5:27	1:43:00	158%		
3.1	3,12	5:58	1:12:00	109%	0:31:00	19%
3.2	2,77	6:24	0:46:00	86%	0:57:00	28%
3.3	2,29	6:39	0:31:00	53%	1:12:00	41%
3.4	1,76	6:56	0:14:00	18%	1:29:00	54%

Source: Authors

[1] in comparison with scenario 1

[2] in comparison with scenario 2

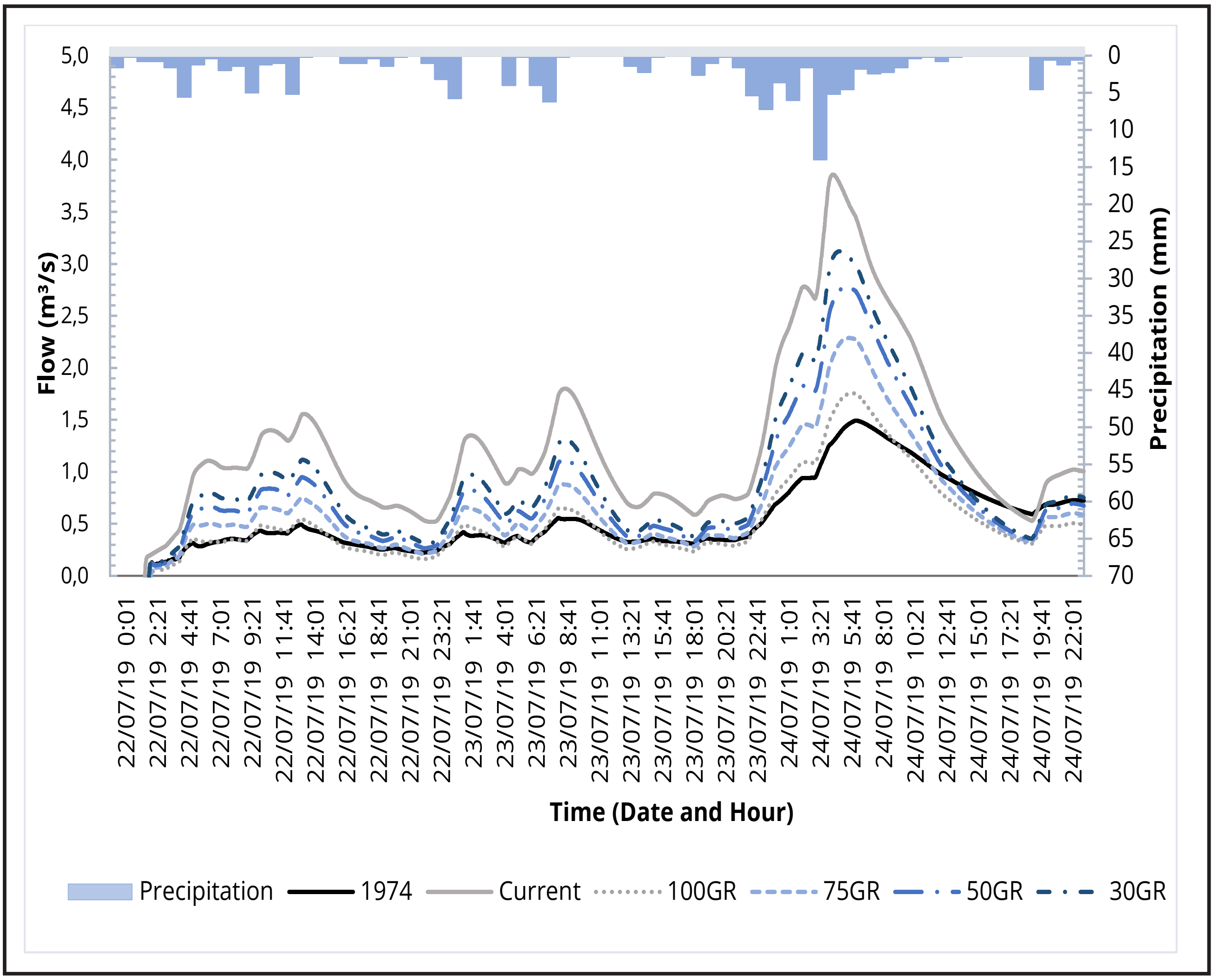
When comparing the current scenario (2) with that of 1974 (1), as shown in Figure 11, the significant impact of urbanization on the flow hydrograph becomes evident. The peak moment advances by almost two hours and surface runoff is 2.5 times greater than in the pre-urbanized scenario (1). These results support Tucci's observation (Tucci, 2002) that urbanization can increase the hydrograph by up to 6 times.

In the proposed scenario of green roofs on 30% of properties (scenario 3.1), a reduction of 19% (0.74 m^3/s) in relation to the current situation is already noticeable, together with a delay in the peak moment of 31 minutes. The average flow reduction in this scenario is 0.34 m^3/s.

Comparing the current situation with the possibility of incorporating green roofs in 50% of the property's coverage (scenario 3.2) reveals a reduction of 28% (1.09 m^3/s) in flow and a delay in the peak moment of almost 1 hour, resulting in an average decrease of 0.43m^3/s at each simulated instant.

If we consider the implementation of green roofs in 75% of the built area (scenario 3.3), it is observed that the peak moment is 0.8 m³/s lower than the 1974 simulation, but 1.57m³/s lower than the situation current, with an attenuation of 41%. In this scenario, the peak moment delay was 1 hour and 12 minutes. The average reduction in river flow was 0.57 m³/s. In the scenario of total replacement of the coverage area with green roofs, there is an increase in the peak flow by just 14 minutes compared to 1974 and a delay of 1 hour and 29 minutes compared to the current situation. There was also an average reduction of 0.72m³/s throughout the hydrograph.

Figure 14 – Flow hydrograph of the Malária Canal in the scenarios simulared during the event from July 22

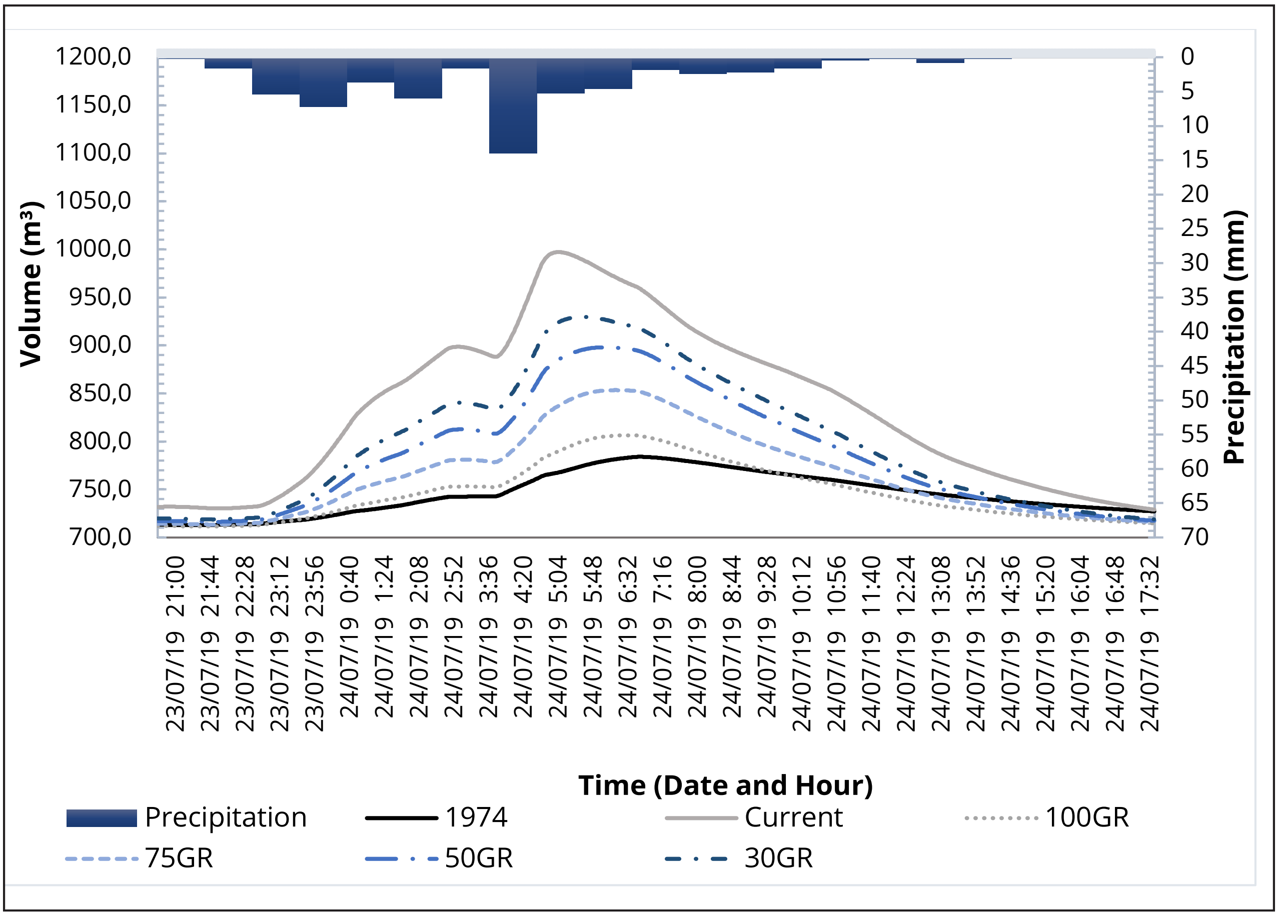


Source: Authors

3.2.2 Water Level

Figure 15 graphically illustrates the discrepancies in river levels under various scenarios, while Table 4 documents a 15-centimeter increase over the years (scenarios 1 and 2). This increment is noteworthy, representing a significant increase of 20% in the Canal's water level at its discharge point. However, when examining the introduction of green roofs, a notable change in outcomes becomes evident.

Figure 15 – Comparative graph of river levels between simulated scenarios



Source: Autors

In the pre-urbanization scenario in 1974 (scenario 1), the river level was recorded at 0.77 meters. In the contemporary urban scenario (scenario 2), this value rises to 0.92 meters.

Table 4 – Comparison of water levels in scenarios 1, 2, and 3

Scenario	Level at peak (m)	Level increase[1] (%)	Level decrease [2] (%)
1	0,77		
2	0,92	20%	
3.1	0,88	14%	5%
3.2	0,85	11%	7%
3.3	0,82	7%	11%
3.4	0,79	2%	15%

Source: Authors

[1] in comparison with scenario 1

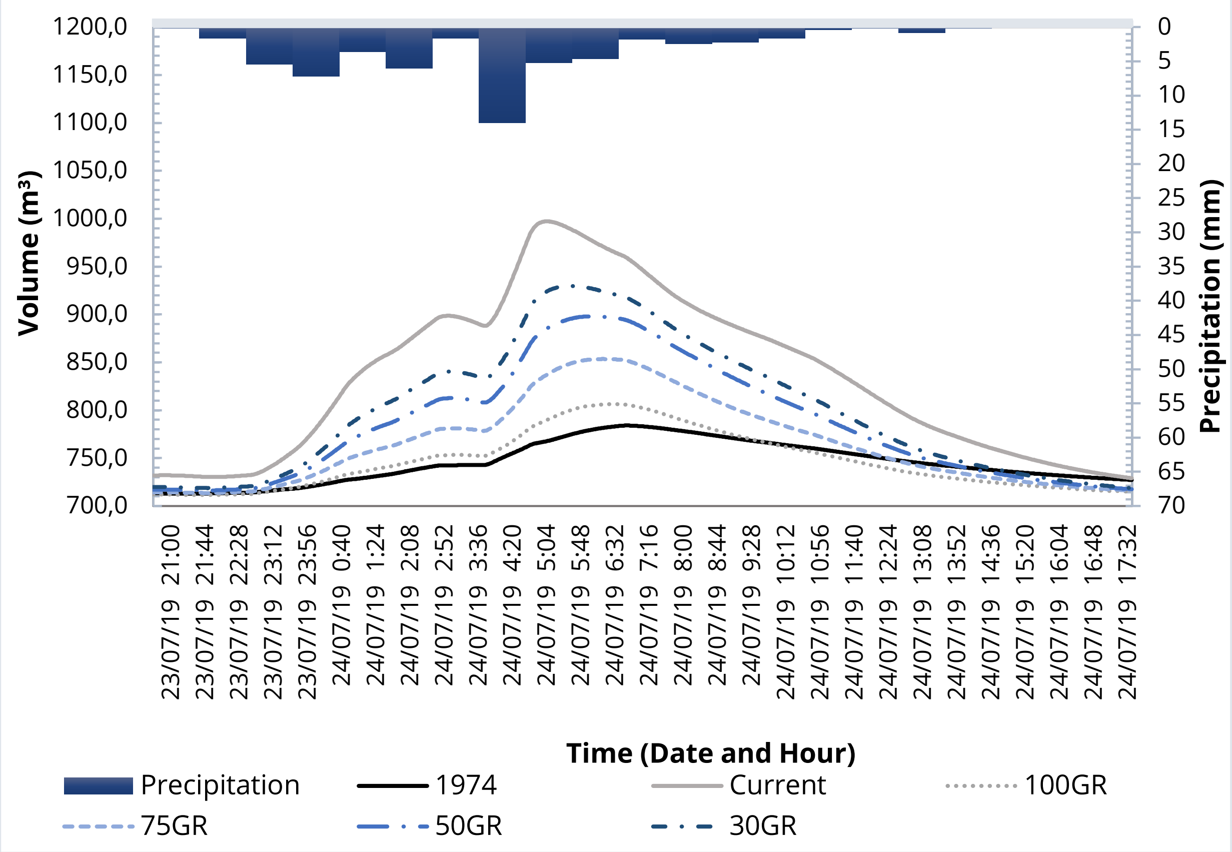
[2] in comparison with scenario 2

In scenario 3.1, with 30% green coverage, the river level decreases to 0.88 meters. This trend continues in subsequent scenarios with additional drops: 0.85 meters in scenario 3.2 (50% green roofs), 0.82 meters in scenario 3.3 (75% green roofs), and 0.79 meters in scenario 3.4 (100% green roofs). These results indicate the importance of green roofs in mitigating the rise in river levels, suggesting an inverse relationship between the extent of these infrastructures and the hydrological impact in the region. This analysis highlights the valuable contribution of green roofs to the sustainable management of water resources in urban environments, demonstrating their promising effectiveness in mitigating the adverse effects of urban development on local water bodies—an aspect worthy of consideration in scientific and applied research contexts.

3.2.3 Detention Volume

Analysis of volume data from the Malária Canal provides crucial information about how water behavior varies in different urban settings, especially with the introduction of green roofs. In the 1974 pre-urbanization scenario (scenario 1), the maximum volume was 784.09 m³. Compared to the current urban scenario (scenario 2), there was an increase of 27%, indicating the effects of urbanization. Figure 15 visually illustrates these volume variations in different scenarios.

Figure 15 – Comparative graph of river volume between simulated scenarios



Source: Autors

Table 5 – Comparison of scenarios 1, 2, and 3

Scenario	Volume at peak (m³)	Detention volume² (m³)	Volume increase¹ (%)	Volume decrease² (%)
1	784,09			
2	997,19		27%	
3.1	929,77	62,42	19%	7%
3.2	897,98	99,21	15%	10%
3.3	853,49	143,70	9%	14%
3.4	806,38	190,81	3%	19%

Source: Authors

[1] in comparison with scenario 1.

[2] in comparison with scenario 2.

When considering scenarios with green roofs, as detailed in Table 5, there is a consistent reduction in the Malária Canal's volume. In scenarios 3.1 to 3.4, with increasing percentages of green roofs, there are drops in volumes compared to the current urban scenario (Scenario 2), ranging from 3% to 19%. This suggests the effectiveness of these structures in mitigating the increase in volume caused by urbanization. Furthermore, detention volumes in green roof scenarios demonstrate the ability of these interventions to retain water during intense rainfall, contributing to sustainable water management in urban environments. These data highlight green roofs' practical and sustainable benefits in managing urban water resources.

3.3 Discussion

In the literature, several experiments have shown a reduction in surface runoff by adding green roofs in different scenarios. Although this study found a reduction in peak runoff ranging from 19% to 54%, with an average reduction of 0.43 to 0.74 m^3/s, Suresh, Pekkat, and Subbiah (2023) in Northeast India observed a reduction of peak flow varying from 38.3% to 84.6% with the implementation of green roofs. Palla et al. (2008) observed a reduction in peak surface runoff ranging from 4.8% to 27%, similar to the findings of Leite, Fujimura, and Fernandes (2016) who observed a flow attenuation of 18% on the Mato Grosso Federal University – UFMT campus, and Schmitter et al. (2016) in Singapore, which achieved a peak reduction in surface runoff of 3% to 12%.

Regarding volume reduction, Schmitter et al. (2016) identified volume reduction ranging from 1% to 5%, slightly lower than the range found in this study (7% to 19%). Palla et al. (2008) observed a volume reduction of 5% to 72% within 15 minutes, depending on the scenario of 10% to 100% replacement by green roofs.

Similar to how this study assessed the reduction in the water level of the Malária Canal in different scenarios, Suresh, Pekkat, and Subbiah (2023) observed a decrease in river levels ranging from 35% to 83.8%.

4 CONCLUSIONS

The growing challenges posed by population growth and urbanization, impermeability and reducing rainwater infiltration, require innovative solutions for urban drainage management. The adoption of Sustainable Drainage Systems (SuDS) or Low Impact Development (LID) techniques appears as a promising way to counter these adverse effects and restore the urban hydrological balance.

The case study of Recife, a city that faces impermeability problems and recurrent flooding, exemplifies the urgency of adopting alternative drainage strategies. While existing measures have demonstrated progress, there remains a critical gap in addressing new and existing structures in vulnerable areas. The integration of green roofs and detention reservoirs required by law represents a vital step, but practical implementation still requires improvement.

This research responds to the evolving paradigm in flood risk management, emphasizing the integration of nature-based solutions alongside conventional engineering approaches. By examining the effectiveness of LID techniques, specifically green roofs, in a real-world urban sub-watershed context, this study highlights the multifaceted benefits they offer.

Incorporating lessons from this research into urban planning and policy-making can lead to a harmonious coexistence between cities and their surrounding environment. The findings not only highlight the technical feasibility of LID techniques, but also emphasize their role in promoting sustainable urban development. As cities continue to evolve and face complex challenges, the insights gained from this study can significantly contribute to creating resilient urban landscapes that effectively manage stormwater, improve water quality, and promote community well-being. By adopting nature-based solutions and innovative urban drainage management, we pave the way for more resilient and liveable cities facing urbanization and climate change.

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AUTHORSHIP CONTRIBUTIONS

1 – Camila Pires dos Santos Câmara

Universidade Federal de Pernambuco, Recife, PE, Brasil
https://orcid.org/0000-0002-6106-0010 • camilla.pires@ufpe.br
Contribuiton: conceptualization, methodology, Software on, validation, formal analysis, data curation, investigations, resource, writing – original draft, data visualization

(infographics, flowcharts, tables, charts).

2 – Sylvana Melo dos Santos

Universidade Federal de Pernambuco, Recife, PE, Brasil
https://orcid.org/0000-0003-3106-5301 • sylvana.santos@ufpe.br
contribuiton: conceptualization, methodology, data curation, investigations, writing – review and editing, supervision, project administration, obtenção de financiamento.

3 –Anderson Luiz Ribeiro de Paiva

Universidade Federal de Pernambuco, Recife, PE, Brasil

https://orcid.org/0000-0003-3475-1454 • anderson.paiva@ufpe.br
Contribuiton: conceptualization, methodology, writing – review and editing, supervision

4 – Larissa Ferreira David Romão Batista

Universidade Federal de Pernambuco, Recife, PE, Brasil
https://orcid.org/0000-0001-8886-234X • larissafbatista@gmail.com

Contribuiton: writing – original draft

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