

Article

Performance Analysis of Residential Detention Tanks Based on Spatial Arrangement in an Urbanized Basin in the Federal District, Brazil

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Abstract: This study evaluated the allocation of residential detention tanks in the Alto da Boa Vista Condominium, Federal District, Brazil, using hydrological and hydraulic modeling using the PCSWMM software (version 7.6.3610). The objective was to investigate the impact of urbanization on local hydrology, considering the occurrence of erosive processes in the area. Critical points in the infrastructure and regions susceptible to flooding were identified. The methodology involved implementing residential detention tanks in different allocation scenarios, including the use of isochrones. Isochrones, which represent lines of equal concentration time in the drainage network, were employed to segment the basin into three main regions: upstream (ISO 1+2), central (ISO 3+4), and downstream (ISO 5+6). The isochrone-based scenarios enabled the assessment of the impact of concentrating residential detention tanks in these specific zones. Additionally, two other scenarios were analyzed: one with the residential detention tanks uniformly distributed throughout the basin and another without the presence of these devices. Finally, a scenario with a random distribution of residential detention tanks was tested, encompassing a total of 54 distinct configurations, to investigate the influence of different spatial arrangements on the basin's hydraulic performance. The results indicated that the number of residential detention tanks installed is the main determinant for peak flow attenuation at the basin's outlet. It was observed that, regardless of the distribution of the devices, whether in concentrated scenarios (upstream, central, and downstream, as defined by the isochrones) or in randomly distributed configurations, the results were similar. In all cases, installing residential detention tanks in more than 30% of the basin area resulted in an approximately 5% reduction in peak flow at the outlet. It is concluded that implementing residential detention tanks is an effective and feasible solution for sustainable stormwater management, significantly contributing to surface runoff control and peak flow mitigation in urbanized areas.

Keywords: stormwater management; source control; morphometry



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1. Introduction

Urbanization and land impermeabilization often increase surface runoff, leading to issues such as flooding and erosion. To mitigate these effects, Low Impact Development (LID) techniques have become increasingly popular in urban areas, complementing traditional urban drainage systems.

Residential detention tanks are LID devices typically constructed from concrete or masonry, which can be surface-level or underground. Their primary function is to temporarily store stormwater, reduce surface runoff velocity, and attenuate peak flows. These

tanks aim to maintain outflows close to the natural pre-urbanization conditions. Water is directed to an outlet pipe with a smaller cross-section than the inlet, restricting flow and promoting storage when inflows exceed outlet capacity. Emergency outlets, such as overflow or spillway structures, are essential to ensure the tank's functionality under extreme conditions [1–4].

Palla and Gnecco (2015) [5] emphasize that runoff reduction is directly related to the retention capacity of LID techniques. Hydrological performance, including peak flow reduction, volume detention, and hydrograph lag, depends linearly on the remaining impervious area. Complementarily, Gilroy (2009) [6] and Qin et al. (2013) [7] highlight that these techniques reach their maximum performance limit when the retention volume is filled.

Wang et al. (2023) [8] identify two critical parameters for designing residential detention tanks. The first is the return period of the design storm used to determine the tank's capacity to manage expected precipitation events. The second is the outlet flow rate, which ensures controlled release of the stored water, preventing overload in downstream drainage systems.

Other studies suggest that the performance of LID techniques depends not only on the retention capacity of the devices but also on their location within the urbanized watershed. Wang et al. (2017) [9] and Ravazzani et al. (2014) [10] argue that the placement of detention tanks within a watershed significantly influences downstream impacts. According to these authors, the isolated installation of these devices may sometimes be insufficient to mitigate flooding and, in certain situations, may even exacerbate it. This underscores the necessity for proper spatial planning for interventions.

According to Liang et al. (2019) [11], the spatial distribution of LID installations plays a role in flood reduction, although the complexity of urban system patterns makes it challenging to assess their impact at the watershed scale. Their analysis recommends concentrating LID techniques in the mid-section of sub-basins, covering approximately 30% of their area. Installations in downstream portions should be limited to about 20% of the area, while the remaining regions should include devices covering at least 5% of the sub-basin's extent to ensure effectiveness.

Tansar et al. (2022) [12] found that among four allocation strategies for LID techniques evaluated, the uniform (distributed) strategy was the most effective in reducing surface runoff. In contrast, the three concentrated strategies—upstream, central, and downstream—showed lower performance, with insignificant differences among them.

Conversely, Helfer (2019) [13] and da Silva (2024) [14] highlight that the low implementation rate of LID techniques in sub-basins was a determining factor in the lack of significant impacts on peak flow attenuation. These studies reinforce the idea that the performance of these techniques is directly related to the number of devices installed in the basin, while their specific location plays a secondary or limited role.

According to Zhang et al. (2018) [15], no specific sequence exists for determining the optimal spatial allocation. However, project history, established objectives, and stakeholder preferences play a crucial role in defining the components to be prioritized.

For these analyses, the cited authors used the Storm Water Management Model (SWMM) (version 7.6.3610), widely recognized for hydraulic and hydrological modeling in urban systems. SWMM is a dynamic rainfall-runoff model extensively employed in urban drainage system management due to its ability to comprehensively simulate runoff in urban areas. It utilizes robust algorithms for surface runoff and flow routing, enabling analysis of the implementation of LID stormwater management techniques [16].

The studies presented here converge on an approach that seeks to maximize device performance, considering the specific characteristics of each watershed section. This

perspective highlights the importance of strategic planning that accounts for factors such as spatial distribution, physical basin features, and the quantity and type of techniques implemented to optimize surface runoff reduction.

This study aims to analyze the impact of residential detention tank allocation in an urbanized area using the PCSWMM software (version 7.6.3610). Scenarios with different residential detention tank allocation strategies were simulated: isochrone-based scenarios, which connect points with the same time of concentration within the watershed to identify areas with similar runoff characteristics, and random allocation scenarios. The objective was to evaluate the performance and impact of this LID technique's location within the basin. This study was conducted in the Alto da Boa Vista Condominium, located in the Federal District, Brazil, and aims to contribute to understanding the best practices for residential detention tank allocation in urban areas, promoting the development of more effective stormwater management strategies.

2. Materials and Methods

The Alto da Boa Vista Condominium (CABV) is located northwest of the Sobradinho Administrative Region, to the left of the BR-020 highway, heading from Sobradinho to Planaltina, near Km 12.50. It belongs to the Alto da Boa Vista Housing Sector, as defined in the Federal District's Territorial Planning Master Plan (Figure 1).

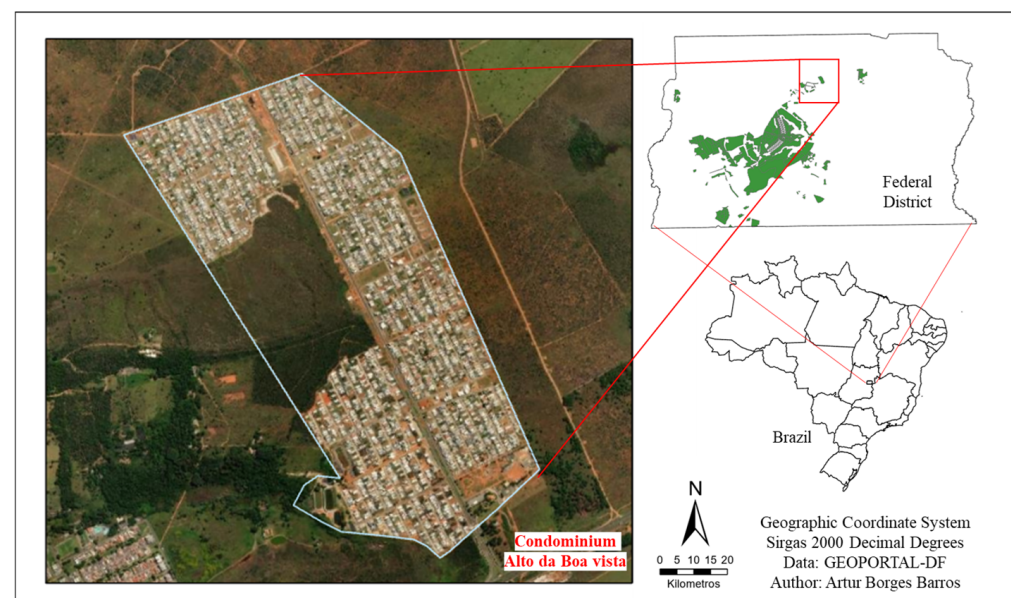


Figure 1. Location map of the Alto da Boa Vista Condominium, Federal District, Brazil.

The Federal District features a high-altitude tropical climate, specifically classified as a tropical savanna climate (Aw in the Köppen classification). This indicates the region experiences two well-defined seasons throughout the year: a rainy season in the summer and a dry season in the winter. Between December 2023 and March 2024, the conventional weather station in Brasília, operated by INMET, recorded 48 days of precipitation (rain) equal to or greater than 1.0 mm, totaling 678.1 mm. This value represents a 9% surplus compared to the historical seasonal average of 621.7 mm (1991–2020), resulting in a positive balance of 56.4 mm in terms of rainfall volume [17].

In 2024, the condominium housed approximately 4,000 residents. Upon completion of the infrastructure, the population is expected to reach 10,170.80 residents, with a total of 2,705 planned residential units [18].

The division of the system into six sub-basins followed the delimitation established in the drainage project of the Alto da Boa Vista Condominium (CABV), considering the natural outfalls of the existing network. The drainage network of CABV consists of 718 manholes and a total of 28,575.089 m of PVC pipes, with diameters ranging from 0.4 m to 1.5 m (Figure 2a).

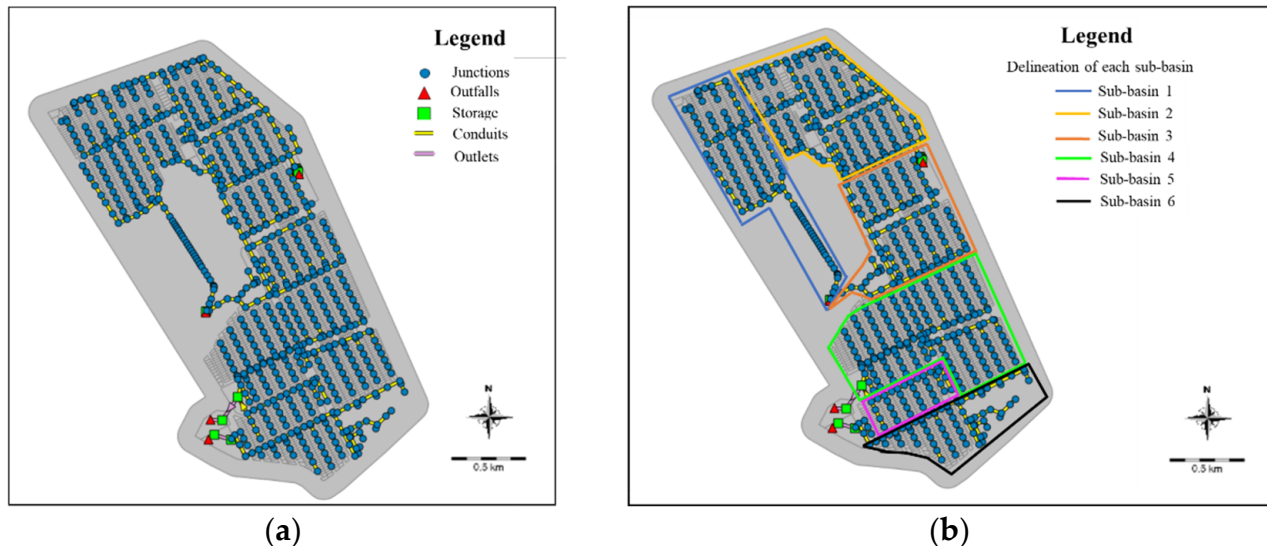


Figure 2. (a) Existing drainage network in the Alto da Boa Vista Condominium; (b) delimitation of sub-basins.

Although some sub-basins discharge into the same outfall, it is important to highlight that each has its own independent drainage network, without direct connections between their pipes. That is, the connection occurs exclusively at the discharge point and not along the system, ensuring that the hydraulic effects of interconnections between sub-basins do not interfere with the internal dynamics of each individual network. During the modeling in PCSWMM, this characteristic was preserved, ensuring that the hydraulic calculations respected the real configuration of the drainage system.

The outfall configuration in CABV follows the following structure: sub-basins 1 and 3 discharge into two attenuation basins that operate in parallel, with respective volumes of 8027 m³ and 6510.84 m³. Sub-basin 2 discharges into a quality reservoir of approximately 6000 m³, followed by four parallel reservoirs of about 1000 m³ each. Sub-basins 4 and 5 discharge into the same attenuation basins, totaling a volume of approximately 8644.37 m³, which flows into an attenuation reservoir of 7960.46 m³. Finally, sub-basin 6 discharges into a quality reservoir of 4382.65 m³, which then flows into an attenuation reservoir of 4657.42 m³ (Figure 2b).

This structure ensures that each sub-basin operates independently until the discharge point, allowing the evaluation of the effects of the distribution of residential detention tanks without interference from hydraulic interconnections between sub-basins.

With the project data collected and organized, modeling in PCSWMM began. The residential lots in the CABV have a standard area of 504 square meters (14 × 36 m). The lot slope was determined based on an average calculated using a PCSWMM tool with the Digital Terrain Model (DTM); it was assumed that each lot occupies 70% of the area, resulting in 70% impermeable surface area.

The soil classification for the study area was conducted based on the hydrological groups proposed by the CN-SCS method, using values suggested by [18]. The hydrological classification of the soil was performed following [19], considering the classes proposed by [20], as recommended by [21].

The water storage height in permeable areas was calculated using the initial abstraction of the Curve Number (CN) method according to land use and its hydrological group.

For the simulations, precipitation data were obtained using the alternating block rainfall method, as recommended by the Federal District's Urban Stormwater Management Guidelines [1]. The design storm was configured for a duration of 24 h with a return period of 10 years, following the guidelines of [1] (Figure 3). The event was discretized into 5 min intervals, with uniform precipitation distribution across the basin. The design storm quantification was based on the specific IDF curve for Brasilia, as established by the Urban Development Master Plan (PDDU) of 2009 [22] (Equation (1)).

$$I = \frac{1574.70 * Tr^{0.207}}{(d + 11)^{0.884}} \quad (1)$$

where I = intensity (mm/h) d = duration, in minutes; Tr = Return Period.

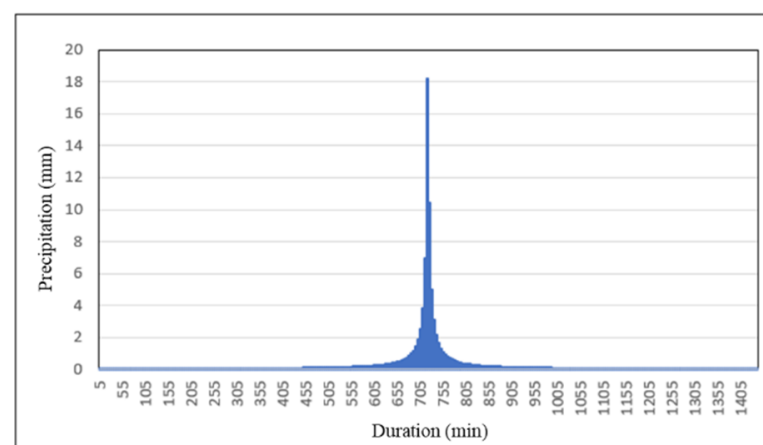


Figure 3. Design rainfall for a return period of 10 (ten) years and a duration of 1440 min (24 h).

To size the residential detention tanks, the outflow rate is a critical parameter. In this study, the pre-urbanization flow rate of 24.4 L/s·ha was adopted as the tank's outflow rate [22].

The residential detention tanks were assumed to be dry at the beginning of each precipitation event, ensuring their maximum peak flow attenuation capacity. These tanks were modeled as impermeable structures, built with concrete, and did not allow infiltration into the soil, meaning that drainage occurs exclusively through the controlled hydraulic outlet. To determine the outflow rate, the pre-urbanization flow rate of 24.4 L/s·ha (liters per second per hectare) [1] was adopted, resulting in an outflow of 1.23 L/s (liters per second) for a standard residential lot in CABV, which is 504 m² (14 × 36 m). To achieve this flow, the smallest commercially available diameter for the outlet pipe, a 20 mm PVC pipe, was used. Considering the impervious area of the lot and the need for flow control, the calculated volume for the residential detention tank was 18.97 m³, rounded to 20 m³ to facilitate construction. Therefore, the following dimensions were adopted for a rectangular tank: a usable height of 2.5 m, a width of 2.00 m, and a length of 4.00 m, compatible with the dimensions of the residential lots in CABV (Figure 4). The dry initial condition reflects a favorable scenario for flow control, aligning with studies that consider efficient runoff between events. If the tanks were not completely dry at the beginning of the event, their attenuation capacity would be reduced, impacting the results.

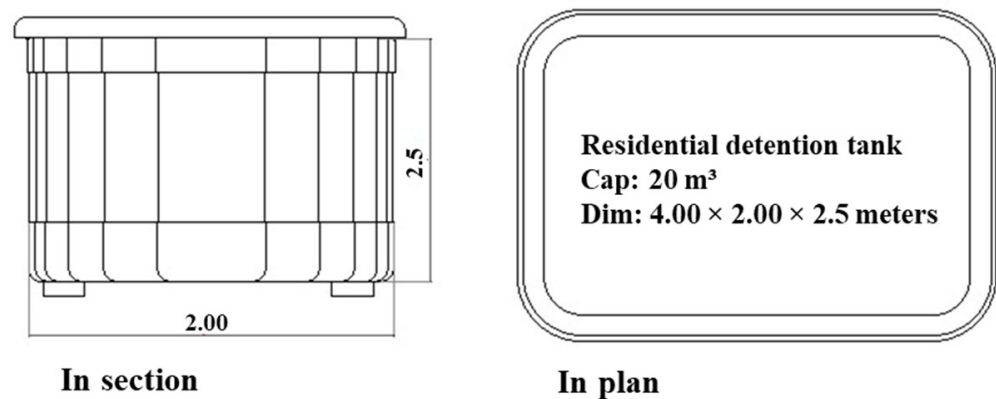


Figure 4. Model and dimensions of the adopted rain barrel.

To evaluate the efficiency of the residential detention tanks in the sub-basins, hydrological–hydraulic modeling was conducted. Initially, to understand the surface runoff dynamics in the area and construct the isochrones, water velocity data from the conduits were exported, converting the average velocities into specific velocities for each manhole in the sub-basins. The isochrone map represented contour lines connecting points in the geographical space with equal travel times for water to reach each manhole from a specific origin. These lines allowed the visualization of areas with similar runoff times across different parts of the watershed. This delineation was used to identify strategic locations for installing the residential detention tanks, whether upstream, centrally, or downstream.

For scenarios involving isochrones, a strategy of combining isochrones was adopted to optimize performance. The combinations were as follows: isochrone 1 combined with isochrone 2, isochrone 3 combined with isochrone 4, and isochrone 5 combined with isochrone 6. To assess the performance of the residential detention tanks, five scenarios were simulated (ISO 1+2, ISO 3+4, and ISO 5+6), focusing on reducing water discharge downstream, specifically at the final outlet of each sub-basin. Two main scenarios were developed: one where the residential detention tanks were distributed throughout the basin and another without any tanks.

The analysis of peak flow attenuation at the outlet of the sub-basins included a scenario in which the residential detention tanks were randomly distributed. The selection of lots for installation followed a completely random criterion, implemented through a Python (version 3.10.9) code (Appendix A). Each lot had a unique identifier, allowing it to be marked on the map and ensuring traceability of the distribution. The use of Python (version 3.10.9) enabled precise and replicable random distribution, facilitating the execution of multiple simulations to evaluate different allocation scenarios.

Initially, the residential detention tanks were allocated to lots within the specific isochrone areas. Subsequently, to evaluate the efficacy and flexibility of this approach, these tanks were redistributed throughout the sub-basin randomly three times, repeated for the other isochrones, resulting in 54 possible residential detention tank configurations. This analysis aimed to determine whether the residential detention tank placement significantly influenced the condominium’s drainage system performance.

Finally, as noted by Kourtis et al. (2017, 2018, and 2020) [23–25], when comparing different scenarios without testing model performance, the absence of calibration does not pose a significant limitation. The use of a 2D hydrodynamic model to simulate flood extent enables analyzing combinations of LID measures and conventional drainage solutions, as well as performing optimization procedures to identify ideal locations, quantities, and combinations of flood mitigation measures.

3. Results

3.1. Analysis of Flow Attenuation at the Outfall by Isochrones

3.1.1. Sub-Basin 1+3

Sub-basin 1 has a total area of 37.83 hectares and was divided into six isochrones, which were grouped into three scenarios: ISO 1+2, ISO 3+4, and ISO 5+6. The distribution of lots in the isochrones is as follows: 59 lots in isochrone 1 (red), with a concentration time of 4.1 to 5.7 min; 102 lots in isochrone 2 (orange), with a concentration time of 2.9 to 4.1 min; 130 lots in isochrone 3 (yellow), with a concentration time of 1.9 to 2.9 min; 90 lots in isochrone 4 (light green), with a concentration time of 1.1 to 1.9 min; 8 lots in isochrone 5 (green), with a concentration time of 0.53 to 1.1 min; and 0 lots in isochrone 6 (dark green), with a concentration time of 0.012 to 0.5 min (Figure 5a).

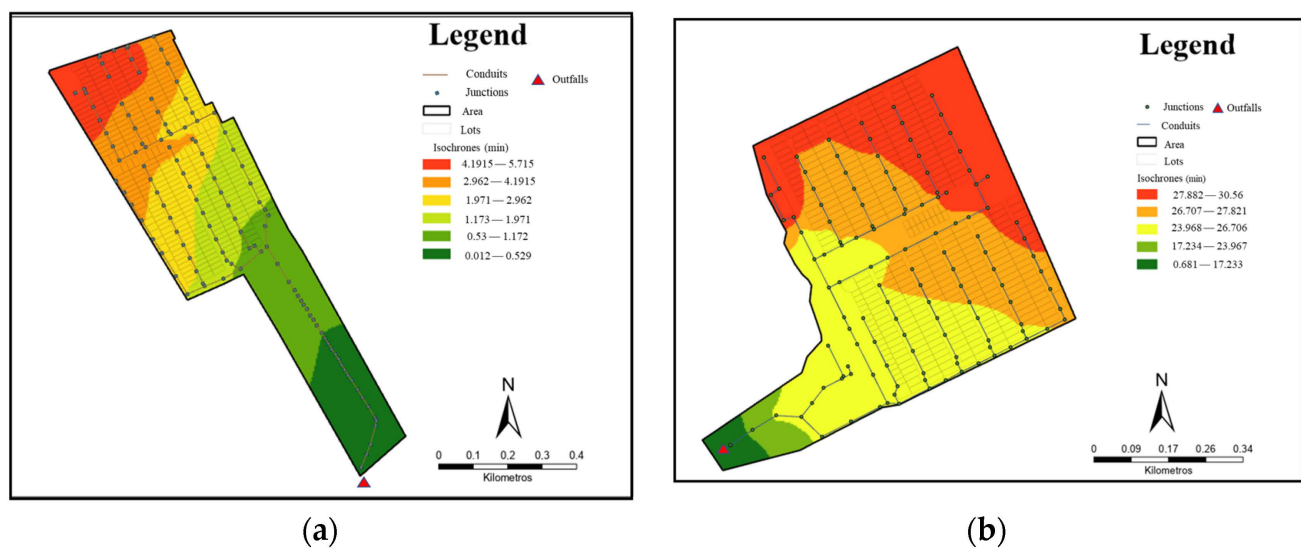


Figure 5. (a) Concentration time of sub-basin 1; (b) concentration time of sub-basin 3.

Sub-basin 3 has 40.8 hectares and was segmented into five isochrones. The lot distribution is as follows: 107 lots in isochrone 1 (red), with a concentration time of 27.8 to 30.5 min; 184 lots in isochrone 2 (orange), with a concentration time of 26.7 to 27.8 min; 111 lots in isochrone 3 (yellow), with a concentration time of 23.9 to 26.7 min; 0 lots in isochrone 4 (green), with a concentration time of 17.2 to 23.9 min; and 0 lots in isochrone 5 (dark green), with a concentration time of 0.6 to 17.2 min (Figure 5b).

The sub-basins were organized into three isochrone scenarios: ISO 1+2 (452 lots), ISO 3+4 (331 lots), and ISO 5+6 (8 lots), in addition to a scenario with residential detention tanks implemented in all 791 lots and another without their application (Figure 6).

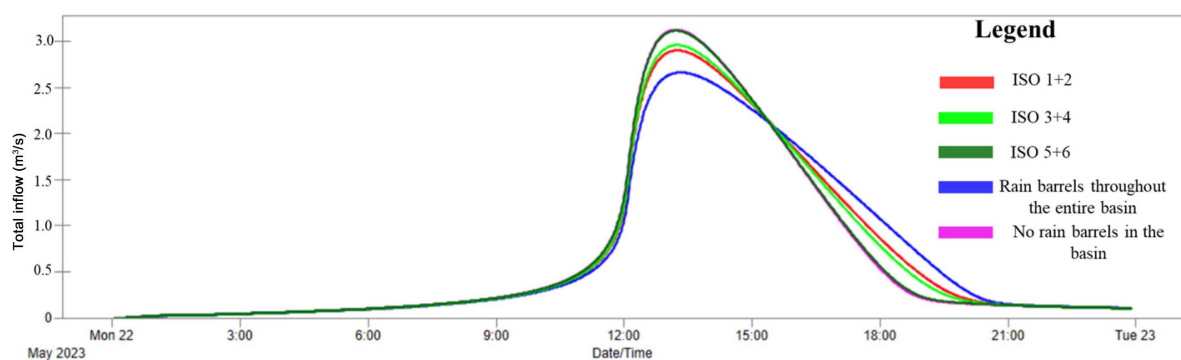


Figure 6. Results of the application of isochrones for flow attenuation in sub-basins 1 and 3.

In the “ISO 1+2” scenario, representing the upstream isochrones with 57.14% of the lots where the residential detention tanks were installed, the peak flow was attenuated by approximately 7.22%.

In the “ISO 3+4” scenario, representing the central isochrones with 41.85% of the lots where the residential detention tanks were installed, a reduction of approximately 5.3% in peak flow was observed.

In the “ISO 5+6” scenario, representing the downstream isochrones with only 1.01% of the lots where the residential detention tanks were installed, the peak flow was attenuated by approximately 0.33%.

Furthermore, implementing residential detention tanks in all 791 lots of sub-basins 1 and 3 (referred to as the “With Residential Detention Tanks” scenario) reduced peak flow by approximately 15%.

3.1.2. Sub-Basin 2

Sub-basin 2 covers an area of 46.95 hectares, with lots distributed as follows: 105 lots in isochrone 1 (red), with a concentration time ranging from 17.1 to 19.4 min; 100 lots in isochrone 2 (orange), with a concentration time ranging from 14.5 to 17.1 min; 119 lots in isochrone 3 (yellow), with a concentration time ranging from 11.7 to 14.5 min; 86 lots in isochrone 4 (light green), with a concentration time ranging from 8.5 to 11.7 min; 114 lots in isochrone 5 (green), with a concentration time ranging from 5.7 to 8.5 min; and 106 lots in isochrone 6 (dark green), with a concentration time ranging from 3.1 to 5.7 min (Figure 7).

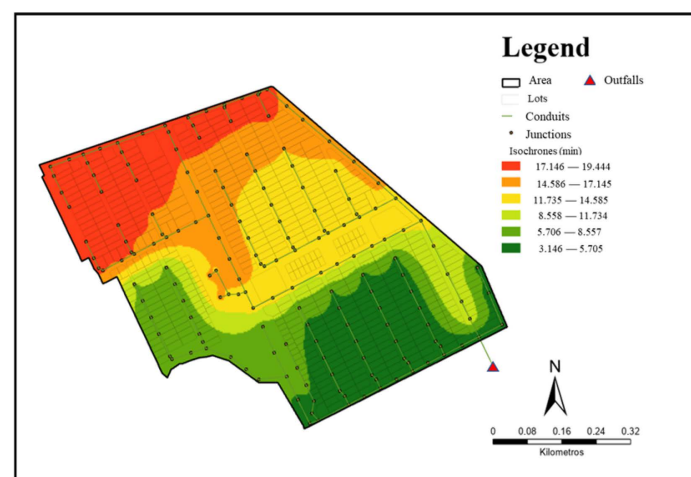


Figure 7. Concentration time of sub-basin 2.

The data for Sub-basin 2 were organized into three isochrone scenarios: ISO 1+2 (205 lots), ISO 3+4 (205 lots), and ISO 5+6 (220 lots) (Figure 8).

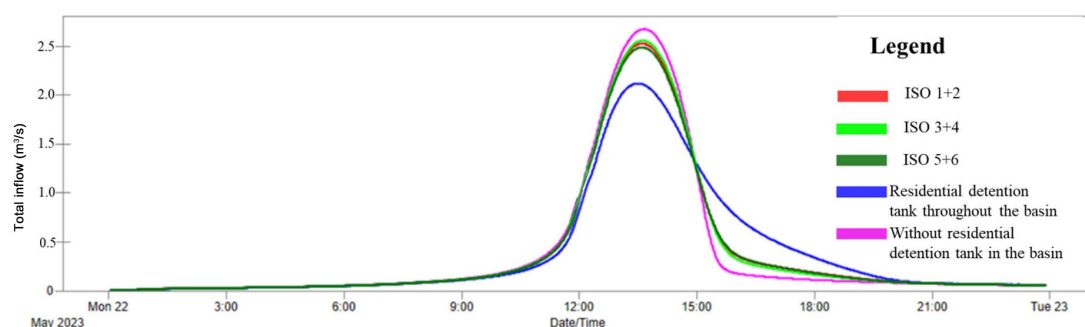


Figure 8. Results of the application of isochrones for flow attenuation in sub-basin 2.

In the “ISO 1+2” scenario, representing the upstream isochrones with 32.54% of the lots where the residential detention tanks were installed, the peak flow was attenuated by approximately 5.5%.

In the “ISO 3+4” scenario, representing the central isochrones with 32.54% of the lots where the residential detention tanks were installed, a reduction of approximately 5.4% in peak flow was observed.

In the “ISO 5+6” scenario, representing the downstream isochrones with 34.92% of the lots where the residential detention tanks were installed, the peak flow was attenuated by approximately 7%.

Furthermore, implementing residential detention tanks in all 630 lots of the sub-basin reduced the peak flow by approximately 21%.

This sub-basin exhibits a uniform distribution of lots per area across the isochrones. Once again, it is evident that the location of these lots does not influence the attenuation of peak surface runoff flow, as the values were identical across all three scenarios.

3.1.3. Sub-Basin 4+5

Sub-basin 4 has an area of 57.83 hectares and is divided into 5 isochrones. The lot distribution per isochrone is as follows: 168 lots in isochrone 1 (red), with a concentration time ranging from 15.7 to 19.7 min; 121 lots in isochrone 2 (orange), with a concentration time ranging from 6.6 to 15.7 min; 174 lots in isochrone 3 (yellow), with a concentration time ranging from 2.6 to 6.6 min; 214 lots in isochrone 4 (green), with a concentration time ranging from 0.8 to 2.6 min; and 168 lots in isochrone 5 (dark green), with a concentration time ranging from 0.0007 to 0.8 min (Figure 9a).

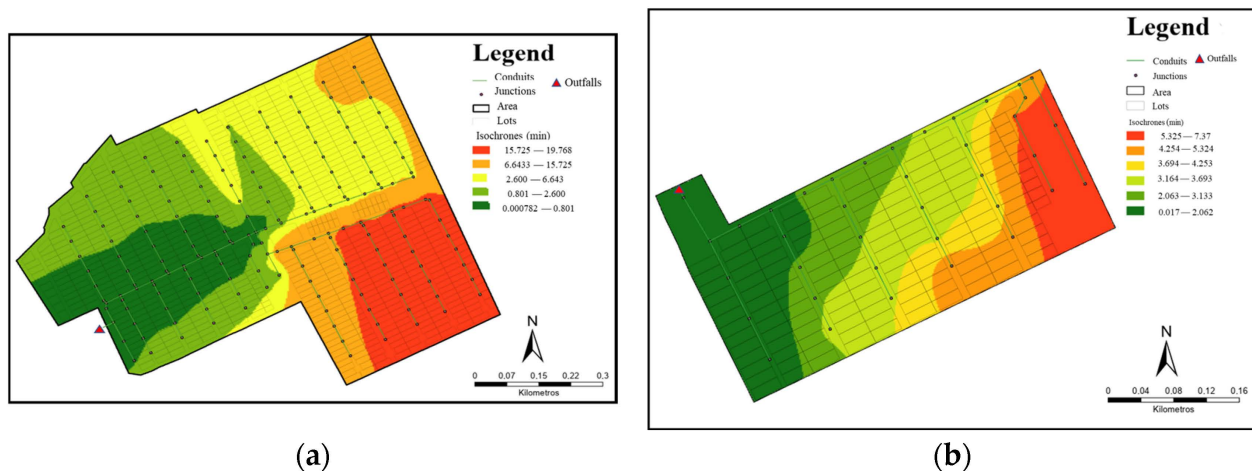


Figure 9. (a) Concentration time of sub-basin 4; (b) concentration time of sub-basin 5.

Sub-basin 5 covers a total area of 10.8 hectares and is subdivided into 6 isochrones. The lot distribution is as follows: 6 lots in isochrone 1 (red), with a concentration time ranging from 5.3 to 7.3 min; 28 lots in isochrone 2 (orange), with a concentration time ranging from 4.2 to 5.3 min; 16 lots in isochrone 3 (yellow), with a concentration time ranging from 3.6 to 4.2 min; 43 lots in isochrone 4 (light green), with a concentration time ranging from 3.1 to 3.6 min; 21 lots in isochrone 5 (green), with a concentration time ranging from 2.6 to 3.1 min; and 48 lots in isochrone 6 (dark green), with a concentration time ranging from 0.017 to 2 min (Figure 9b).

The data for sub-basins 4 and 5 were organized into three isochrone scenarios: ISO 1+2 (323 lots), ISO 3+4 (447 lots), and ISO 5+6 (237 lots), in addition to scenarios with residential detention tanks applied to all 1007 lots and scenarios without their application (Figure 10).

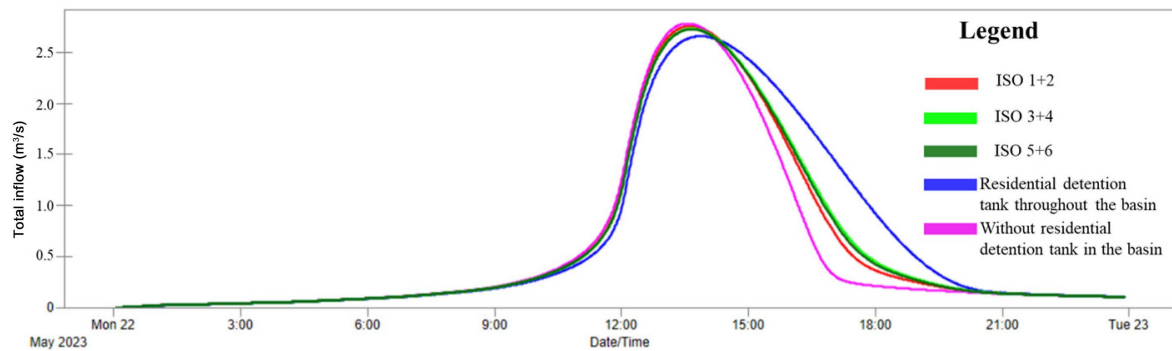


Figure 10. Results of the application of isochrones for flow attenuation in sub-basins 4 and 5.

In the “ISO 1+2” scenario, representing 32% of the lots where the residential detention tanks were implemented in the upstream isochrones, the peak flow was attenuated by approximately 1.6%.

In the “ISO 3+4” scenario, representing 44.37% of the lots where the residential detention tanks were implemented in the central isochrones, a peak flow reduction of approximately 1.8% was observed.

In the “ISO 5+6” scenario, representing 23.53% of the lots where the residential detention tanks were implemented in the downstream isochrones, the peak flow was attenuated by approximately 1.3%.

When all 1007 lots were equipped with residential detention tanks, the peak flow attenuation was 4.25%.

In this sub-basin, the intermediate area had the largest number of lots, where the attenuation was slightly higher than in the other areas.

3.1.4. Sub-Basin 6

The lot distribution in Sub-basin 6 is as follows: 0 lots in isochrone 1 (red), with a concentration time ranging from 6.2 to 15.2 min. 11 lots in isochrone 2 (orange), with a concentration time ranging from 2.9 to 6.2 min. 58 lots in isochrone 3 (yellow), with a concentration time ranging from 1.6 to 2.9 min. 48 lots in isochrone 4 (light green), with a concentration time ranging from 1.2 to 1.6 min. 50 lots in isochrone 5 (dark green), with a concentration time ranging from 0 to 1.2 min (Figure 11).

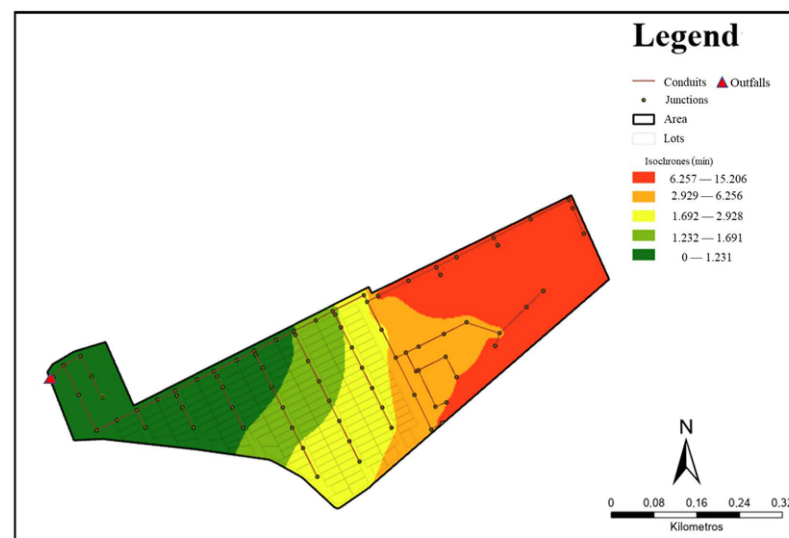


Figure 11. Concentration time of sub-basin 6.

The data for Sub-basin 6 were organized into three isochrone scenarios: ISO 1+2 (11 lots), ISO 3+4 (106 lots), and ISO 5+6 (50 lots), in addition to scenarios where residential detention tanks were applied to all 167 lots and scenarios without their application (Figure 12).

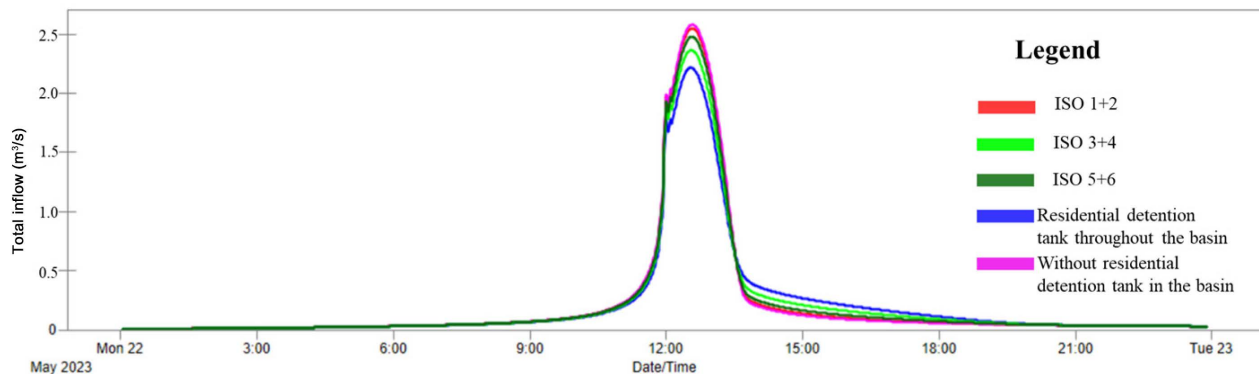


Figure 12. Results of the application of isochrones for flow attenuation in sub-basin 6.

In the “ISO 1+2” scenario, which includes 6.57% of the lots, where residential detention tanks were implemented in the upstream isochrones, a peak flow attenuation of approximately 1.3% was observed.

In the “ISO 3+4” scenario, which includes 63.47% of the lots, where residential detention tanks were implemented in the central isochrones, a reduction of approximately 8.4% in peak flow was observed.

In the “ISO 5+6” scenario, which includes 29.94% of the lots, where residential detention tanks were implemented in the downstream isochrones, a peak flow attenuation of approximately 4% was observed.

Additionally, implementing residential detention tanks across all 167 lots in the sub-basin resulted in a peak flow attenuation of approximately 14%.

For this sub-basin, the relationship between the percentage of lots and the percentage of reduction in flow follows a general trend: as the percentage of lots increases, the reduction in flow tends to be more significant.

3.2. Analysis of Peak Flow Attenuation at the Outfall with a Random Redistribution

An analysis of peak flow attenuation at the outlet was conducted by applying a random distribution of residential detention tanks among the lots. Each isochrone scenario (ISO 1+2, ISO 3+4, and ISO 5+6) was simulated three times, resulting in nine distinct configurations per sub-basin, totaling 54 simulations across the basin.

In the ISO 1+2 scenario, the 991 lots from the isochrones were randomly redistributed among the 2595 lots in the basin. The same process was repeated for the 1089 lots in the ISO 3+4 scenario and the 515 lots in the ISO 5+6 scenario.

This study encompasses six sub-basins and 54 distinct configurations for redistributing residential detention tanks. The simulations revealed consistent patterns among the sub-basins. To avoid redundancy and ensure a more concise presentation, only the peak flow graphs at the outlets shared by sub-basins 1 and 3, sub-basins 4 and 5, and the individual outlets of sub-basins 2 and 6 will be shown. These graphs correspond to the three simulation scenarios of lot redistribution within “ISO 1+2” and the concentrated scenario for this isochrone (Figures 13–16).

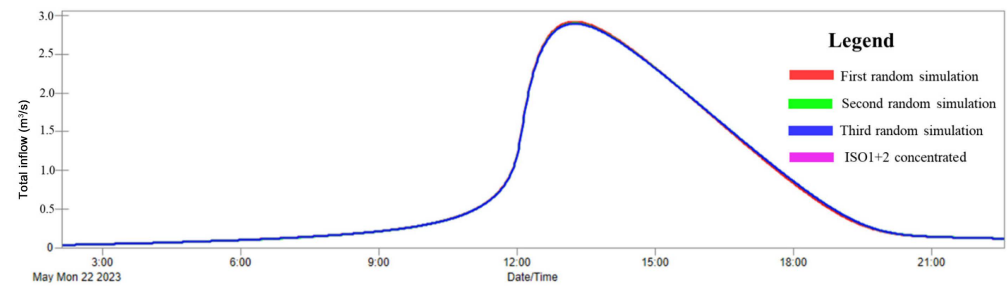


Figure 13. Peak flow results from the three simulations of lot redistribution for the “ISO 1+2” scenario and the scenario concentrated at the outlet of sub-basin 1 and sub-basin 3.

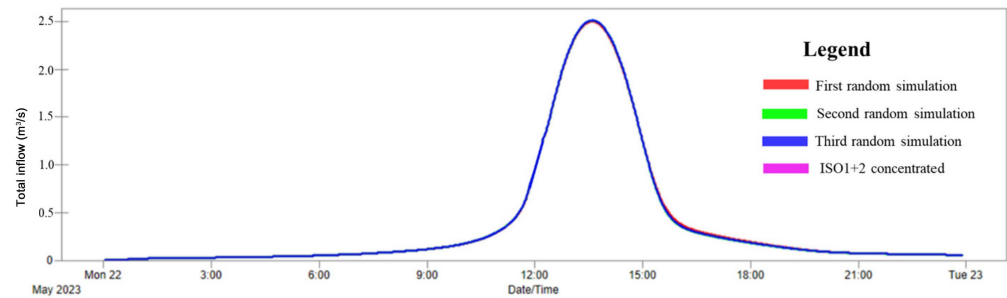


Figure 14. Peak flow results from the three simulations of lot redistribution for the “ISO 1+2” scenario and the scenario concentrated at the outlet of sub-basin 2.

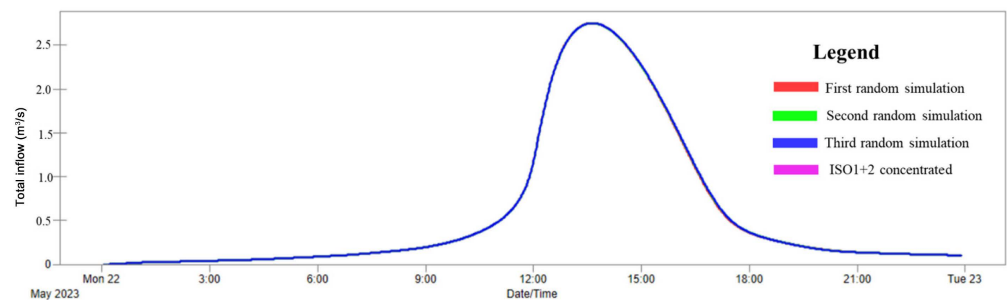


Figure 15. Peak flow results from the three simulations of lot redistribution for the “ISO 1+2” scenario and the scenario concentrated at the outlet of sub-basin 4 and sub-basin 5.

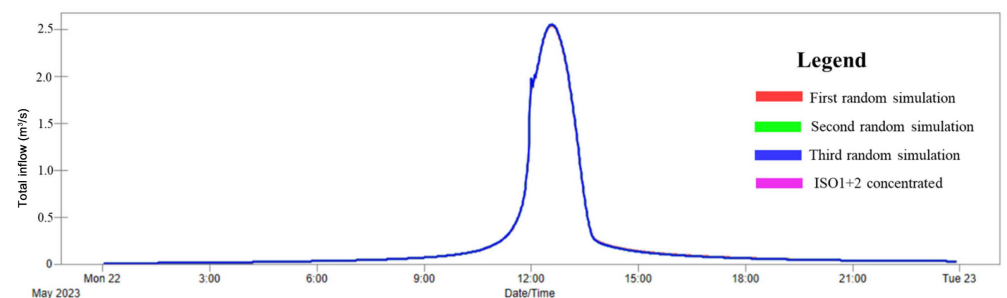


Figure 16. Peak flow results from the three simulations of lot redistribution for the “ISO 1+2” scenario and the scenario concentrated at the outlet of sub-basin 6.

This behavior suggests that the location of residential detention tanks within the basin does not significantly influence peak flow reduction, reinforcing that the performance of these devices is consistent regardless of their spatial distribution.

The analyses indicate that the number of residential detention tanks installed in each sub-basin is the determining factor for peak flow control, while the specific location of the lots has a secondary impact. Table 1 presents the relationship between the percentage of

lots occupied by residential detention tanks and the percentage of peak flow attenuation at the outlet of each sub-basin.

Table 1. Summary of the relationship between the percentage of lots in the sub-basins and peak flow attenuation.

Scenarios	Sub-Basin 1+3		Sub-Basin 2		Sub-Basin 4+5		Sub-Basin 6	
	% of Lots with Residential Detention Tanks	% of Peak Flow Attenuation	% of Lots with Residential Detention Tanks	% of Peak Flow Attenuation	% of Lots with Residential Detention Tanks	% of Peak Flow Attenuation	% of Lots with Residential Detention Tanks	% of Peak Flow Attenuation
ISO 1+2	57.14%	7.22%	32.54%	5.5%	32%	1.6%	6.57%	1.3%
ISO 3+4	41.85%	5.3%	32.54%	5.4%	44.37%	1.8%	63.47%	8.4%
ISO 5+6	1.01%	0.33%	34.92%	7%	23.53%	1.3%	29.94%	4%

In Sub-basin 6, for example, in the ISO 1+2 scenario, 63.47% of the lots had residential detention tanks, resulting in the highest flow attenuation recorded (8.4%). In the ISO 5+6 scenario, when the proportion of lots with detention tanks decreased to 29.94%, the attenuation also significantly reduced to 4%, demonstrating that the coverage of these devices is a determining factor for the hydraulic efficiency of the system. A similar trend is observed in Sub-basin 1+3, where the ISO 1+2 scenario showed the highest rate of lots with detention tanks (57.14%), corresponding to a flow attenuation of 7.22%. In contrast, in the ISO 5+6 scenario, with only 1.01% of the lots covered, the flow reduction was almost negligible (0.33%).

This relationship is also evident in Sub-basin 2, where maintaining approximately 32.54% of the lots with detention tanks in the ISO 1+2 and ISO 3+4 scenarios resulted in very similar attenuations (5.5% and 5.4%, respectively). On the other hand, in Sub-basin 4+5, despite a slight variation in the percentage of lots with detention tanks between scenarios, the flow attenuation remained low, suggesting that the density of devices in this region was still insufficient for a more significant effect.

The data highlight that the efficiency in reducing peak flow is directly related to the number of lots with residential detention tanks, reinforcing the importance of widespread adoption of these structures for sustainable stormwater management in urbanized areas. This finding supports the observations of Da Silva (2024) [14], who emphasized the influence of the low implementation rate of compensatory techniques in mitigating surface runoff.

Therefore, this study concludes that, although the installation of residential detention tanks in the central isochrones (ISO 3+4) and the downstream isochrones (ISO 5+6) shows superior performance in peak flow attenuation, this result is directly related to the number of detention tanks in these scenarios. When the residential detention tanks were randomly distributed, the peak flow attenuation was similar to that observed in the isochrone-based allocation. These results suggest that, as long as the detention capacity is maximized without device overflow—and considering only the total number of residential detention tanks in each sub-basin, regardless of their spatial distribution, even at lot level—a greater reduction in peak flow at the outlet can be achieved.

3.3. Specific Discharge

The specific discharge, defined as the ratio between flow rate and the sub-basin area, was analyzed to compare the peak discharges at the outlet among sub-basins of different sizes. The analysis covered scenarios with residential detention tanks installed in isochrone-based groupings (ISO 1+2, ISO 3+4, and ISO 5+6), evaluating their impact on runoff and device performance.

Figure 17 illustrates the specific discharge at the outlet of Sub-basins 1 and 3, which share the same discharge point. A progressive increase in specific discharge is observed across the analyzed scenarios. In the ISO 1+2 scenario, the specific discharge is approximately 3700 L/s/km², whereas in the ISO 5+6 scenario, it reaches about 3950 L/s/km². This increase is directly related to the number of residential detention tanks installed in each scenario. In the ISO 5+6 scenario, only 1.01% of lots are equipped with detention tanks, resulting in low performance. In contrast, in the ISO 1+2 scenario, 57.14% of lots have detention tanks, enhancing runoff retention and consequently reducing specific discharge in this sub-basin.

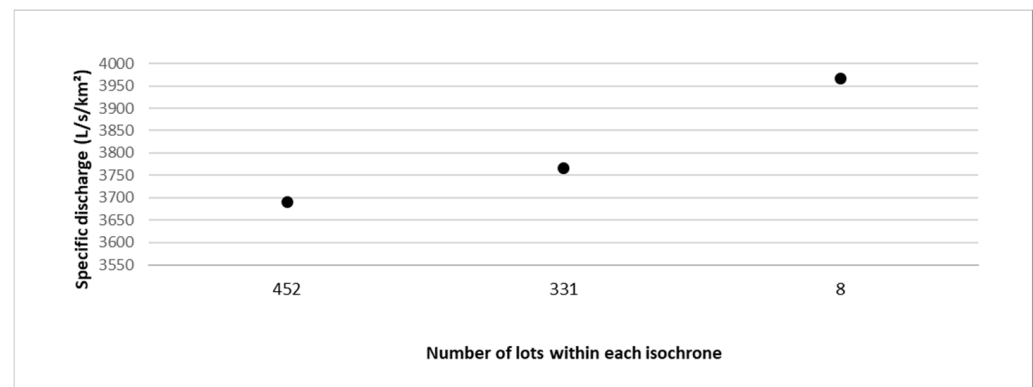


Figure 17. Specific discharge at the outfall of sub-basin 1 and sub-basin 3.

As shown in Figure 18, Sub-basin 2 exhibits a behavior opposite to that of Sub-basins 1 and 3. Specific discharge decreases across the analyzed scenarios from approximately 5450 L/s/km² in the ISO 1+2 scenario to about 5300 L/s/km² in the ISO 5+6 scenario. This reduction is directly associated with the increase in the number of lots with residential detention tanks, which rises from 205 in ISO 1+2 and ISO 3+4 to 220 in ISO 5+6. The graph emphasizes that the performance in controlling specific discharges depends more on the number of detention tanks installed than on their spatial distribution within the isochrones.

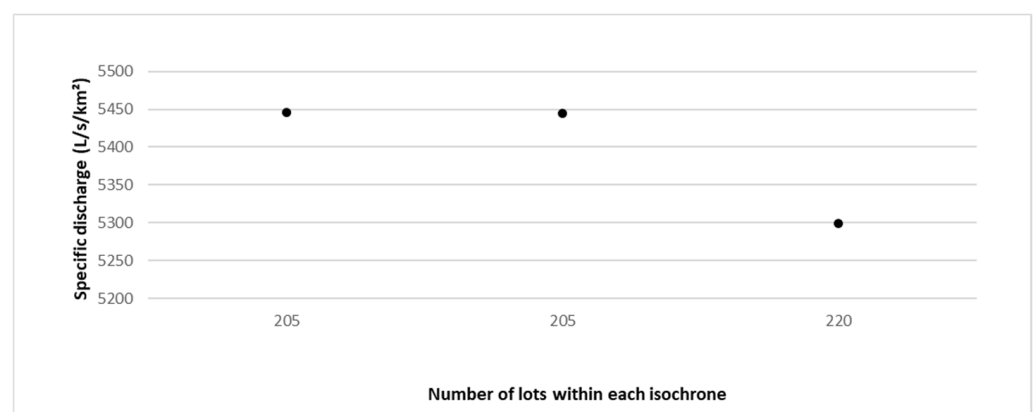


Figure 18. Specific discharge at the outfall of sub-basin 2.

For Sub-basins 4 and 5 (Figure 19) and Sub-basin 6 (Figure 20), it is evident that the installation of detention tanks in the central isochrones (ISO 3+4) results in the highest flow attenuation. This behavior is associated with the greater concentration of detention tanks in this group of isochrones.

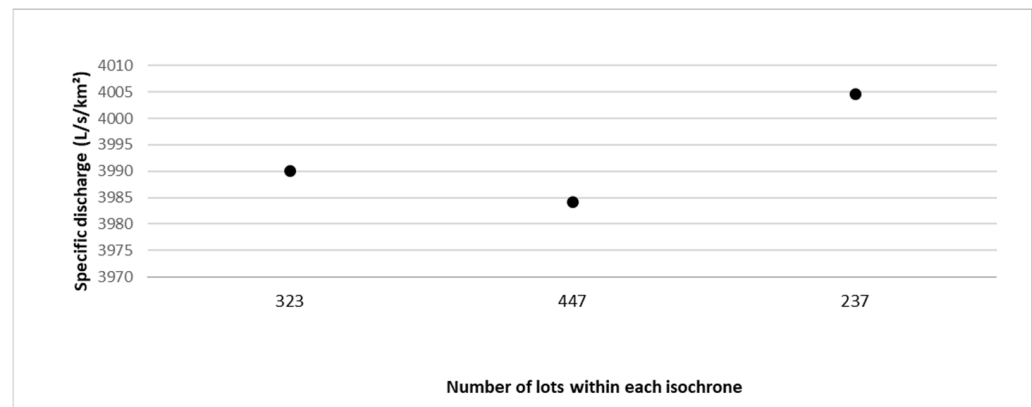


Figure 19. Specific discharge at the outfall of sub-basin 4 and sub-basin 5.

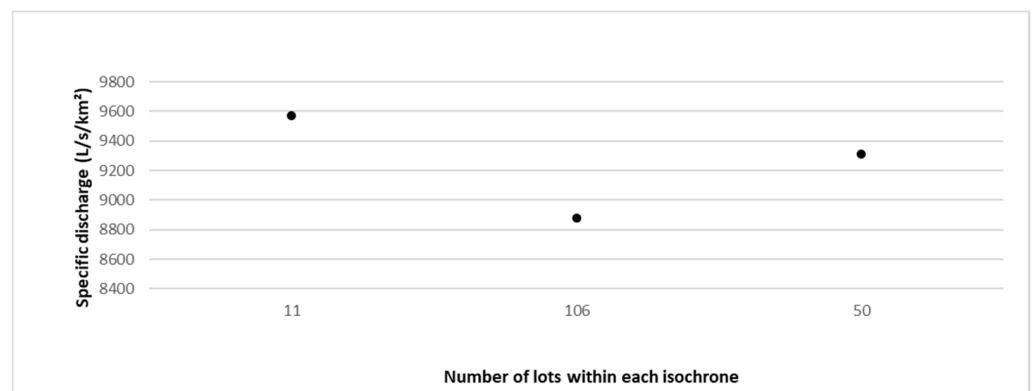


Figure 20. Specific discharge of sub-basin 6.

The results obtained through the analysis of specific flow rate graphs reinforce the idea that the location of residential detention tanks within the basin does not significantly influence peak flow at the outlet, contradicting the assumption that their upstream installation would provide superior performance. However, this study confirms that the key factor for peak flow attenuation is the total number of residential detention tanks, regardless of their spatial distribution within the basin.

4. Conclusions

This study investigated the influence of residential detention tank allocation on peak flow reduction in an urbanized basin, using hydrological and hydraulic modeling in the PCSWMM software (version 7.6.3610). This research aimed to answer the following scientific question: does the spatial distribution of these structures significantly impact urban drainage performance, or is the total number of lots with residential detention tanks the determining factor?

The results demonstrated that, regardless of the allocation strategy, the most significant factor in peak flow control was the total number of lots with residential detention tanks within the basin. This finding suggests that, in similar urban contexts, prioritizing the widespread adoption of these systems may be more effective than focusing solely on their strategic distribution.

Furthermore, the findings reinforce the effectiveness of residential detention tanks as a viable solution for sustainable stormwater management, contributing to mitigating the impacts of urbanization on urban drainage. This information can support guidelines for implementing urban drainage policies, guiding projects that seek greater efficiency in surface runoff management.

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Appendix A

```
# import random # List of numbers from 0 to "n" numbers = list(range(0, "n"))
# Randomly selecting "n" numbers selections = random.sample(numbers, "x")
# Sorting the selected numbers in ascending order sorted_selections = sorted(selections)
print(sorted_selections)
```

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