v. 4, n. 13, 2024

Journal of
Engineering
Research

URBAN FLOODING: A CASE STUDY IN SWMM IN ``*LAGOA DO SAPO*`` IN BATAYPORÃ – MS

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Journal of Engineering Research ISSN 2764-1317 DOI https://doi.org/10.22533/at.ed.31741324290410

Abstract: In recent years, society has experienced more intense and recurring extreme hydrological precipitation events. The study area presents several flood events in its past and present. The rainfall event that occurred on October 12, 2022, reached a height of 120mm, triggering a flood scenario that caused significant commotion among residents. ``*Lagoa do Sapo*`` presents a relief susceptible to the occurrence of this flood, as it is located in a topographic depression, where all surface runoff is directed to the lagoon site. The present study aims to explore the extent of flooding in the city through 5 precipitation scenarios, seeking to provide decision makers with pertinent information to address the problem in the city. The *software* adopted was the *Storm Water Management Model* (SWMM), the model calibration was based on a simplified methodology using two approaches, the first consists of comparing the simulated flood spot with the photographic records of the event and the second in an own program parameter, continuity error, this approach was adopted due to the lack of data collected during the flood event. With the calibrated model, it was possible to estimate the number of affected residences and flood areas for the different scenarios. Based on the results of this work, it is concluded that the ``*Lagoa do Sapo*`` region needs hydraulic interventions in its drainage system to delay surface runoff and increase the capacity of the existing overflow.

Keywords: Urban flooding, simulation, urban drainage

INTRODUCTION

The management and drainage of rainwater are part of the infrastructure of the complex urban organism of contemporary cities, playing a fundamental role in the harmony of human agglomeration, especially in large urban centers and in the environment.

The increasing occupation of river basins significantly changes their characteristics, resulting in a shorter concentration time and increasing the volume drained. Even though a sustainable approach to urban drainage is already widespread in academia, many projects and planning still have outdated beliefs (TUCCI et al., 2014).

The traditional methodology is supported by capture and transportation quickly and efficiently to reduce the aggravating effects of rainfall at the local level, passing on its effects downstream. However, due to urban expansion, several areas begin to suffer from the massive arrival of volumes of water. (PINHEIRO AND FRANK, 2003; BOTELHO, 2017).

In this sense, simulations of historical events can provide useful data for water management (SHAKTI, KAMIMERA AND MISUMI, 2020). Through flood mapping, it is possible to create models to understand the unfolding of floods, which in turn will serve as a basis for public policies, planning in emergency/evacuation situations and for estimating damages (KOBAYASHI et al., 2019).

Thus, it is possible to zone risk areas to better apply public resources in planning (HORA E GOMES, 2009). According to Tucci et al. (2014), measuring future situations at different moments of urbanization can provide solutions in urban occupation planning, anticipating and minimizing future flooding problems, thus avoiding spending large amounts of investment on late solutions. Therefore, several Brazilian cities have applied flood mapping (SOUZA, CRISPIM E FORMIGA, 2012; HIRATA ET AL., 2013; GOERL, MICHEL E KOBIYAMA, 2017; SILVA, 2019).

According to the UFSC University Center for Studies and Research on Disasters (CEPED UFSC) (2013), the Brazilian territory showed a tendency towards an increase in natural disasters, in the period from 1991 to 2012. The Brazilian Institute of Geography and Statistics (IBGE) and the National Center for Natural Disaster Monitoring and Alerts (CEMADEN) (2018) show that, in the 2010 census, the country had around 8.2 million people living in areas at risk of flooding or landslides.

A point that reinforces data presented by UNESCO and UN-Water (2020), that global floods and extreme precipitation events have increased by more than 50% this decade, and are now occurring at a rate four times greater than in 1980.

Therefore, urban flooding events tend to grow in scale and quantity, pointing to a future in which events that would previously have little impact start to trigger countless financial and human losses, especially in more vulnerable regions. Furthermore, there is still a certain lack of information regarding the events, something that hinders a more precise and effective approach by public managers and the scientific community in Brazil.

Several authors have presented a comparative approach between computational methods, where flood occurrences are evaluated in a given study area. However, in these applications more robust software is often used, which sometimes requires a subscription and requires a large amount of Input. On the other hand, the SWMM program has played an important role in the assessment of floods occurring in urban basins.

However, there are still few studies and a lack of procedures and protocols that enable a more dynamic and simplified assessment of urban flooding events, which when carried out would give decision makers confidence in using these tools, data and information available for event management.

Thus, the present analysis seeks to evaluate urban flooding for different precipitation scenarios, through a case study carried out in a computational environment, in the city of Batayporã – MS.

METHODOLOGY

The study area is located in the municipality of Batayporã, located south of the Central-West region of Brazil, east of Mato Grosso do Sul, on the border of Paraná/São Paulo. It is located at latitude 22º32'45" South and longitude 55°09'00" West, 313 km from the state capital (Campo Grande) and 1,182 km from the federal capital (Brasília).

The lagoon is an important tourist spot in the city, presenting itself as an administrative landmark and a reference leisure place for the population. From a hydrological perspective, the city is under the influence of the Rio Pardo basin, which belongs to the Paraná River macrobasin, flanked by the Escondido and Ribeirão Esperança streams.

The case study corresponds to the event that occurred on October 12, 2022. According to the report made available by Civil Defense, at around 3:00 pm there was precipitation that developed for approximately 40 minutes, totaling 120mm of accumulated precipitation. This height was enough to trigger an intense flood event in the vicinity of ``*Lagoa do Sapo*``, occupying a large part of the center and entering homes and businesses, causing great social and administrative commotion. Figure 2 presents photographic records of the event that occurred.

Journal of Engineering Research ISSN 2764-1317 DOI https://doi.org/10.22533/at.ed.31741324290410

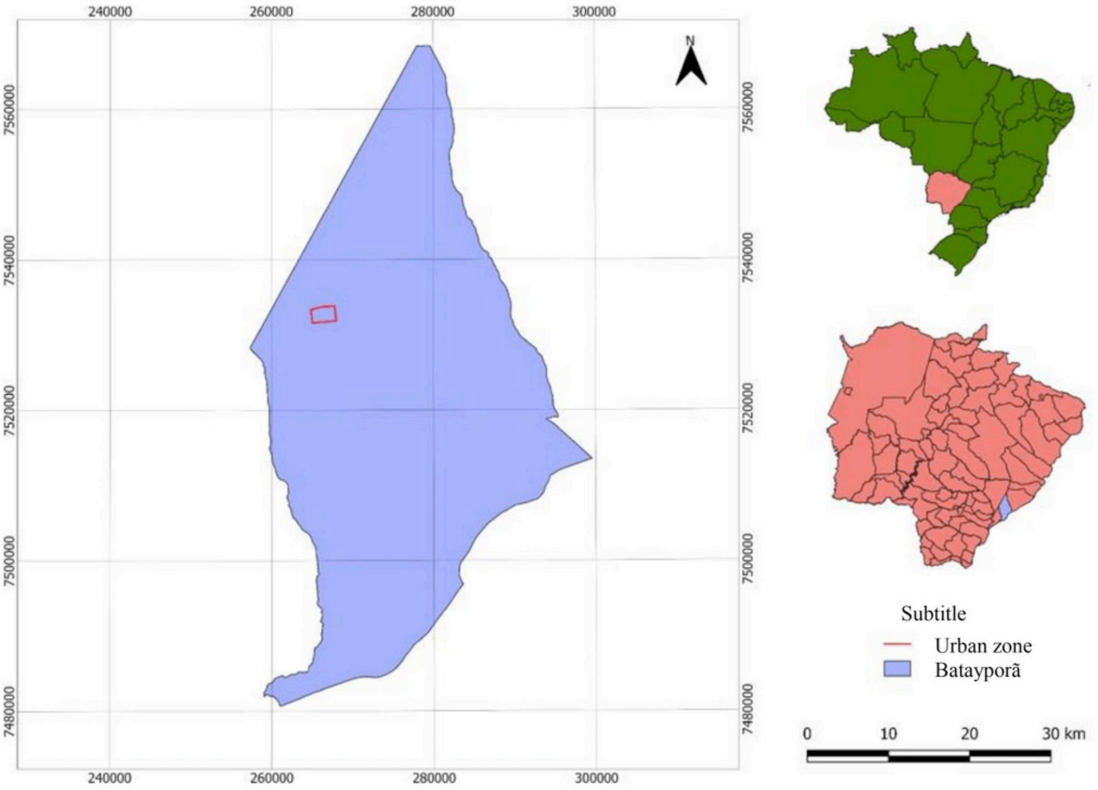

Figure 1 - Location map of Batayporã/MS

Figure 3: Flood occurred on October 12, 2022

Through the topographic record provided by Schettini Engenharia Ltda, it was possible to observe that the region presents a mostly flat relief with slight presences of smooth to wavy in the northern region of the city, and, due to the topographic profile of the region, it is possible to observe that the city is located in a topographic depression directed, all surface runoff is destined for the lagoon.

``*Lago do Sapo*`` has a contribution area of 7.77 km², the portion to the north of the basin (rural area) has soil cover such as fields dedicated to pasture and plantations on contour lines, while the urban area of the city is marked mainly by single-family residences without the presence of buildings and with most of the roads paved.

The city of Batayporã is mostly on a Red Latosol – Dark Alic, with a clayey texture, with geological characteristics of the Caiuá Formation, (Ks), on sandy/quartz rocks, altered to residual or colluvial fine to medium sands, extremely vulnerable to erosion arising from hydrological agents (SEPLAN – MS).

Regarding precipitation, the IDF equation presented by Figueiredo and Miyasato (2013) was adopted, where the study presents equations for all cities in the state of Mato Grosso do Sul, based on the formulations presented by Otto Pfasfsteter, with the study site is present in isozone 32, under the regime of Equation (1).

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Element	Data	Definition
Basin	Area	Basin area
	Width	Average basin width
	Slope	Average slope of the basin in percentage
	Impermeable area	Percentage of impervious area in the basin
	n Imper.	Manning number referring to the impermeable portion of the basin
	n Perm.	Manning number referring to the permeable portion of the basin
Conduit	Form	Cross section shape
	Maximum Depth	Maximum cross section depth
	Length	Conduit length between downstream and upstream nodes
	n Manning	Manning number assigned to the conduit
	Input Offset	However, quota in relation to the upstream raft
	Output Offset	Dimension of the however in relation to the downstream raft
Node	Radier quota	Radier quota

Table 2 – SWMM input data

$$I = \frac{1.331{,}82 \times Tr^{0{,}142}}{(tc + 13)^{0{,}801}} \tag{1}$$

Where I is the intensity of the precipitation, Tr refers to the return time and t is the duration of the event.

On the hydraulic side of the drainage system, ``*Lagoa do Sapo*`` plays the role of a buffer basin, having an overflow in a concrete gallery with a diameter of 1.20m, this device located 1.50m from the bottom of the basin, where the catchment is made by a water intake, leading the flow over Avenida Antonia Spinosa Mustafá to the rural area, flowing into a small concrete channel for approximately 450m until it reaches a natural channel that ends in a pasture, draining superficially to the Samambaia River.

For hydrological and hydraulic simulations, the *software Storm Water Management Model* (SWMM), from *United Enviromental Protection Agency* (EPA), the program works with 1D simulations, where the reported precipitation is received by the basin and subsequently carried to the node, these devices receive this outflow and the volume is carried through the conduits to the outlet, within the model the surface runoff is calculated by the difference between the precipitation, evaporation and infiltration, where the excess volume is transformed into surface runoff (Rossman, 2015). Figure 3 presents a basic model of how the simulation works.

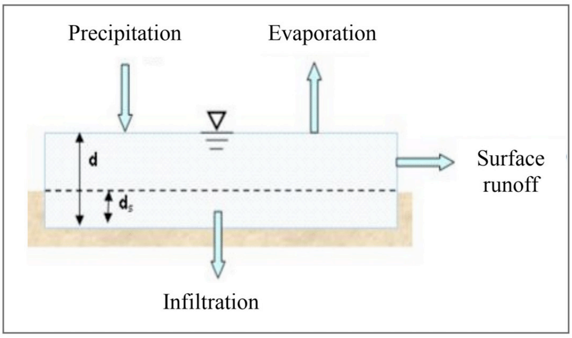

Figure 3 – Basic functioning of the river basin in SWMM

Therefore, the study proposed 5 simulation scenarios with different intensities, which are presented in Table 1.

Scenario	CN01	CN02	CN03	CN04	CN05
Precipitation (mm)	10	50	100	120	150

Table 1: Proposed scenarios

To build the digital model of the river basin, the following data were collected, described in Table 2.

Journal of Engineering Research ISSN 2764-1317 DOI https://doi.org/10.22533/at.ed.31741324290410

The Manning coefficient adopted for the study was based on values suggested by Porto (2006) and adopted by Souza, Crispim and Formiga (2012) and Silva (2019) for studies similar to the one proposed. The respective values adopted can be seen in Table 3.

Manning coefficient			
Waterproof Basins	Permeable Basins	Channeled Conduit	Natural Conduit
0,012	0,150	0,014	0,025

Table 3: Manning coefficient used.

MODEL CALIBRATION

When the event under study occurred, there was not even any type of measurement of elevations on the corners taken by water or any other type of survey that would corroborate the calibration of the model, by the public entities of Batayporã.

This way, a more simplified calibration process was followed, carried out in two stages.

The first method considered that the excess volume found by SWMM represents a simulated flood level. To determine this value, the volume between a plane (flood level) and the MDE was calculated. Once this topographic value is determined, it is possible to draw an intersection line, thus finding the simulated flood line. This flood boundary line was compared with photographic records of the event.

To carry out the calibration at this stage, it was adopted to change the waterproof storage height, since the other input data values do not leave room for manipulation without significantly distorting the study area.

The second approach considered the continuity error reported by SWMM, Rossman (2015), classifies values -0.05% and -0.064%, for flow error and flow respectively, as negligible and can be understood as excellent or very good values. On the other hand, Silva (2019) considered that acceptable values are within the limit of 10% error, therefore, the present study was based on these two ranges to validate the simulations. Table 4 presents the maximum error values adopted.

Classification	Continuity error		Bibliographic source
	Flow rate	Surface runoff	
Very good	±0,5%	±0,05%	(Rossman, 2015)
Acceptable	±10%	±10%	(Silva, 2019)

Table 4: Continuity error classification.

RESULTS AND DISCUSSIONS

With the river basin characterized and the other data necessary to carry out the simulation determined, the model was built in SWMM. Table 5 presents the input data for the model and Figure 4 presents the river basin of the study area.

Using the calibration methodology adopted, after successive rounds of adjustments to the proposed calibration parameters, it was defined that to better represent the event that occurred, the value of 0mm must be assigned to the storage depth of the impermeable area, this was transcribed in the stain. flood observed in Figure 5.

With the calibration carried out, simulations were carried out for the other scenarios, with CN04 showing a flood peak of 64,610.31m^3, indicating that the water depth in the event reached 316.330m. Figure 6 shows the volume and elevation obtained for the simulation scenarios.

These levels represented the flood spots shown in Figure 7, where it is observed that the precipitation from CN01 does not have the capacity to flow over the crest of the lagoon in a significant way, on the other hand higher events, such as 50mm, have a water depth of enough flooding to reach homes and businesses in the vicinity of ``*Lagoa do Sapo*``.

Journal of Engineering Research ISSN 2764-1317 DOI https://doi.org/10.22533/at.ed.31741324290410

Bowl	Area (ha)	L (m)	I (m/m)	%Imp	SCS CN	n-Imp	n-Per
1	95,944	921,6	0,011	72,53%	89,25	0,011	0,025
2	20,844	204,2	0,010	76,90%	89,69	0,011	0,025
3	11,796	107,4	0,009	69,78%	88,98	0,011	0,025
4	9,11	83,9	0,008	82,66%	90,27	0,011	0,025
5	5,96	58,6	0,008	66,28%	88,63	0,011	0,025
6	3,824	73,8	0,007	85,60%	90,56	0,011	0,025
7	8,269	74,2	0,008	52,96%	87,30	0,011	0,025
8	2,168	40,9	0,005	92,17%	91,22	0,011	0,025
9	20,535	173,6	0,007	49,71%	86,97	0,011	0,025
10	1,519	14	0,005	95,00%	91,50	0,011	0,025
11	0,613	41	0,002	91,80%	91,18	0,011	0,025
12	0,623	39,3	0,010	91,94%	91,19	0,011	0,025
13	0,526	36,8	0,011	94,34%	91,43	0,011	0,025
14	0,614	39,6	0,005	80,65%	90,06	0,011	0,025
15	0,599	38,7	0,005	95,00%	91,50	0,011	0,025
16	52,968	365,3	0,005	68,42%	88,84	0,011	0,025
17	1,317	24,9	0,003	89,57%	90,96	0,011	0,025
18	3,917	73	0,003	88,49%	90,85	0,011	0,025
19	3,663	69	0,004	85,79%	90,58	0,011	0,025
20	32,64	200,3	0,005	69,10%	88,91	0,011	0,025
21	30,338	183,3	0,007	69,13%	88,91	0,011	0,025
22	113,548	812,8	0,011	43,76%	86,38	0,011	0,025
23	2,145	37,8	0,005	92,52%	91,25	0,011	0,025
24	24,628	161,3	0,009	71,51%	89,15	0,011	0,025
25	266,357	964,8	0,009	32,38%	85,24	0,011	0,025
26	64,148	502,7	0,012	35,54%	85,55	0,011	0,025

Table 5: SWMM input data

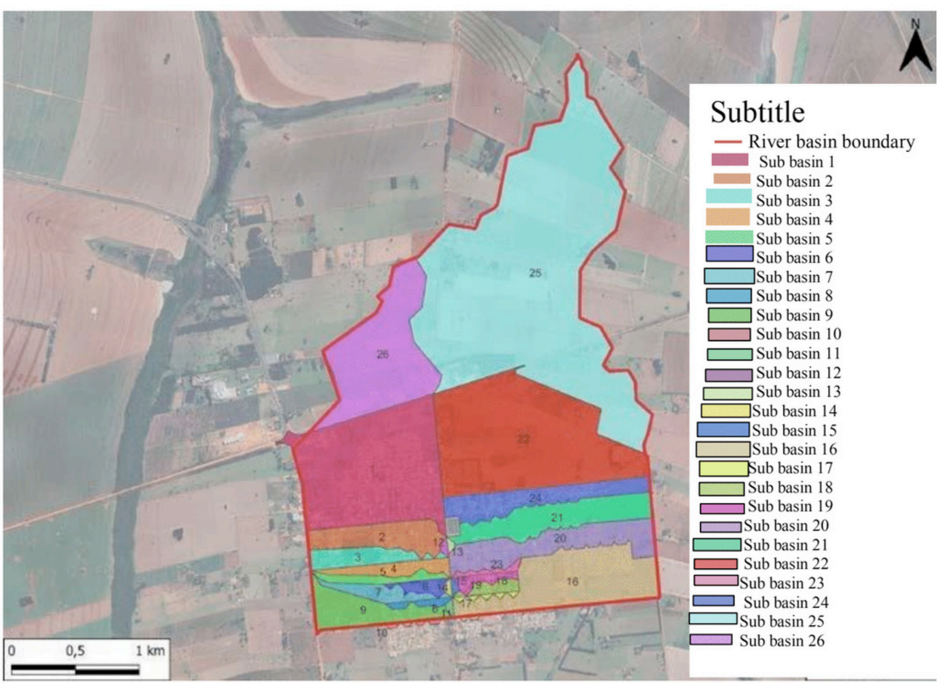

Figure 4: Lago do Sapo watershed

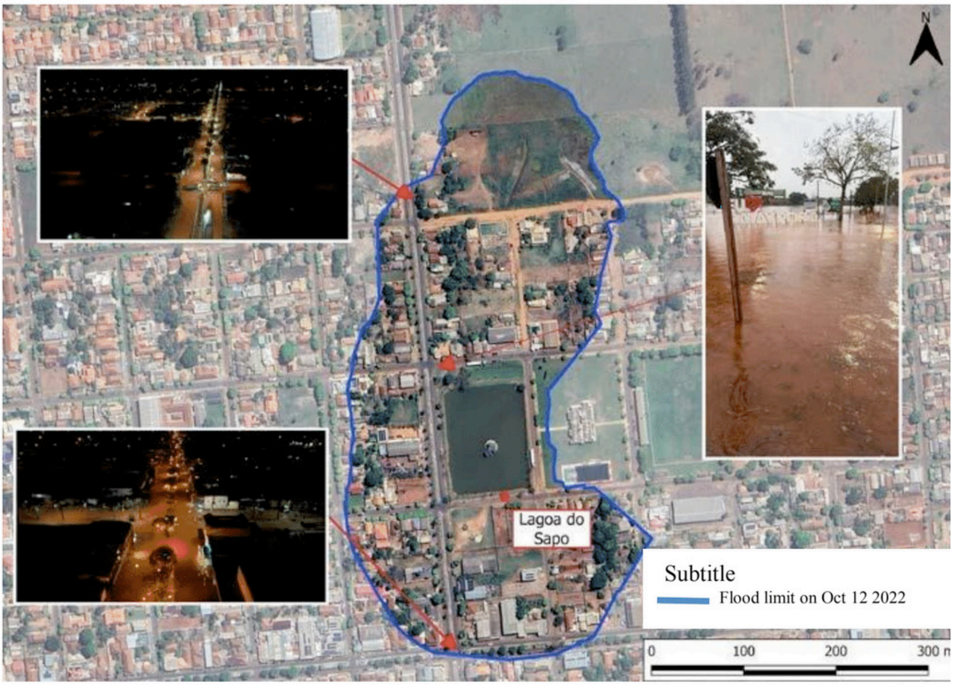

Figure 5: Flood stain for system calibration

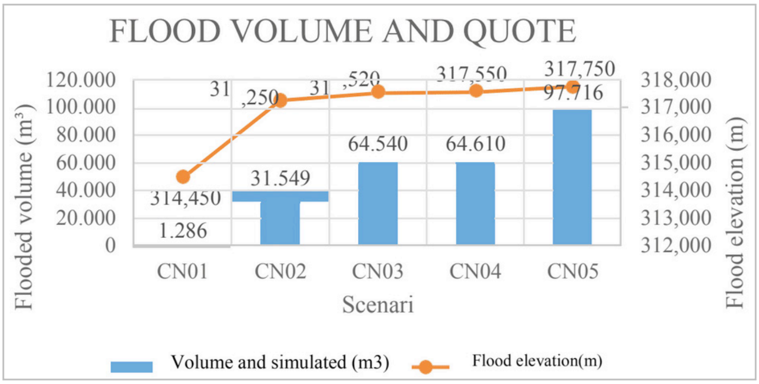

Figure 6: Flood volume and elevation relationship

With the flood spots in hand, the number of potentially affected residences was counted for each of the proposed scenarios, and for the event that occurred (CN04), it was estimated that 97 residences were affected. At the time of carrying out the study, there is no information from public or journalistic sources on the exact number of people or residences affected by the rain that occurred on October 12, 2020.

Table 6 presents the count of affected residences for each of the proposed scenarios.

Scenario	Area flooded (ha)	Volume flooded (m³)	Affected homes
CN01	1,05	5.416,83	0
CN02	8,69	31.548,56	45
CN03	13,75	64.540,10	91
CN04	14,36	64.610,31	97
CN05	18,50	97.716,49	143

Table 6: Flooded areas and volumes for the proposed scenarios.

Among the intervention possibilities proposed to solve the problem is the expansion of the lagoon's spill system and the

Journal of Engineering Research ISSN 2764-1317 DOI https://doi.org/10.22533/at.ed.31741324290410

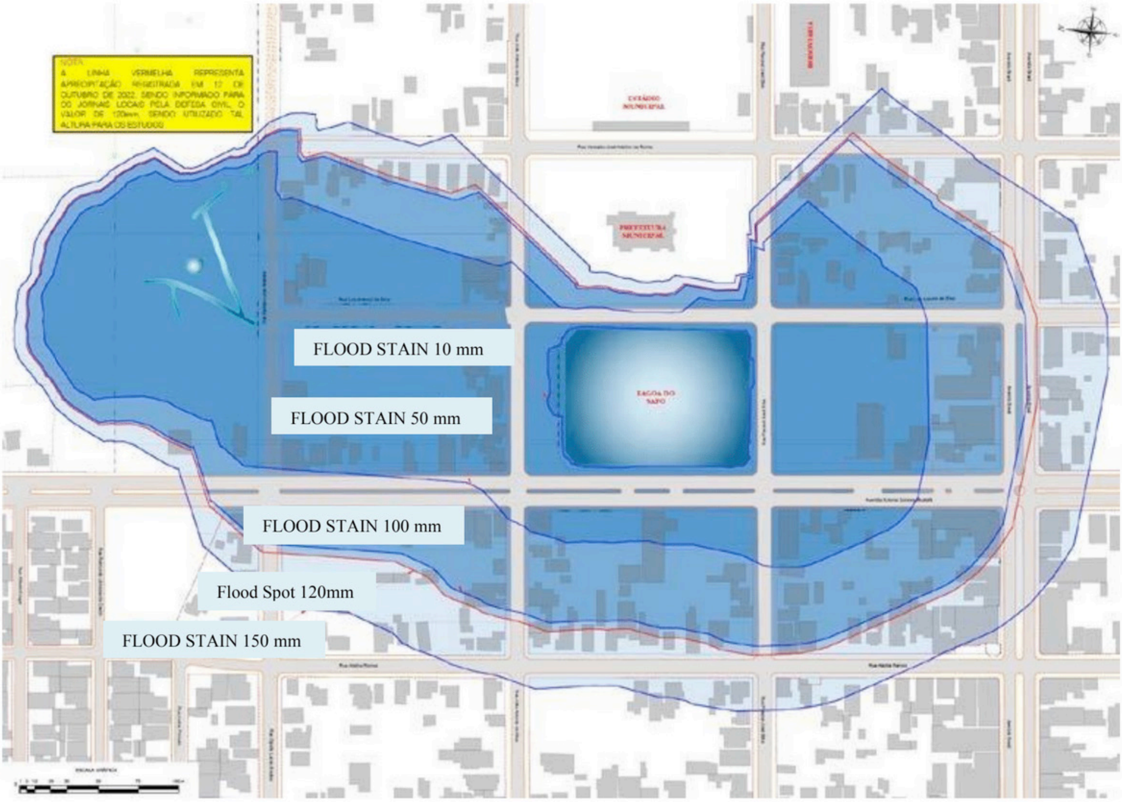

Figure 7 – Flood spot for the proposed scenarios

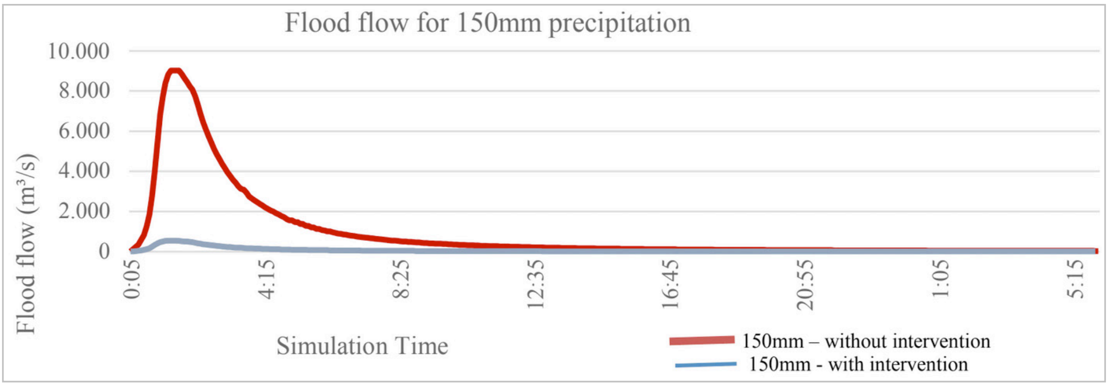

Figure 8: Flood flow for 150mm precipitation

construction of 4 buffer basins, which aim to capture the surface runoff generated by the northern portion of the city to dampen the peak flow directed to the lagoon.

The proposed spill system is composed of a water intake at the same topographic level as the existing spillway with a diameter of 1.50m in HDPE, on the other hand, the buffer basins, with locations defined by the Municipality of Bataypora, must have approximately 19,300.00 m^3 of total storage capacity. Figure 8 shows the influence of these devices on the overflow flow of ``*Lagoa do Sapo*`` for the most critical scenarios investigated.

Therefore, with the implementation of the proposed system, the peak overflow flow of ``*Lagoa do Sapo*``, which occurs one hour and twenty minutes after the start of precipitation, where this value would be attenuated from 2,705.33m^3/s to 535,34m^3/s.

CONCLUSION

Based on the results of the study carried out, it was possible to conclude that flooding in ``*Lagoa do Sapo*`` tends to increase its impact due to the increase in precipitation, affecting several homes and businesses in the vicinity of the site.

It must be noted that due to constant precipitation events that trigger scenarios similar to what happened, it is necessary to plan hydraulic interventions in the drainage system. Where, the proposed solution presents a residual risk of flooding, but in common agreement with the City of Batayporã is acceptable due to budgetary issues to solve the problem.

Future studies of flooding in the region must focus on complementary solutions for mitigating measures on a smaller scale, such as micro storage in lots and the adoption of *Low Impact Development* (LIDs), which were not the scope of this study.

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