

HYDROLOGICAL-HYDRODYNAMIC MODEL OF THE TAMANDARÉ CANAL IN BELÉM-PA FOR THE IMPLEMENTATION OF WORKS PRIOR TO COP 30

MODELO HIDROLÓGICO-HIDRODINÂMICO DO CANAL DA TAMANDARÉ EM BELÉM-PA PARA IMPLANTAÇÃO DE OBRA PRÉVIA À COP 30

MODELO HIDROLÓGICO-HIDRODINÂMICO DEL CANAL DE TAMANDARÉ EN BELÉM-PA PARA LA IMPLEMENTACIÓN DE OBRAS PREVIAS A LA COP 30



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ABSTRACT

The implementation of the Tamandaré Linear Park in Belém-PA, in the Amazon, to improve urban infrastructure before COP30 (30th UN Conference of the Parties on Climate Change), was based on a hydrological-hydrodynamic study developed using the free computational code Storm Water Management Model (SWMM), to formulate and propose measures to combat and prevent overflows of the Tamandaré Channel, resulting from intense precipitation events and high tides, acting on highly impermeable terrain with low altimetric elevations (from 0 to 6 m). The hydraulic behavior of the basin was realistically simulated considering a rainfall event with a 50-year return period (172 mm of precipitation in 24 hours), associated with the maximum high tide condition (3.02 m). The results highlighted the susceptibility to flooding in areas with elevations below 3.02 m due to tidal influence and indicated the importance of using floodgates for hydraulic control. It was found that the occupancy of the

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Tamandaré Channel's capacity reached 97%, recommending the use of electric booster pumps as a preventive measure against overflows. The installation of two electric pumps was indicated, each with a flow rate of 1.0 m³/s and a manometric head of 7.2 m, automatically activated when the canal occupancy reaches 85% and deactivated when it reaches 60%. Thus, the computer simulation with SWMM enabled the formulation of engineering solutions for a problem of great relevance in combating and preventing flooding in the city of Belém-PA.

Keywords: Flooding. Urbanization. SWMM. Armas Basin. Amazon.

RESUMO

A implantação do Parque Linear Tamandaré, em Belém-PA, na Amazônia, para melhoria da infraestrutura urbana prévia à COP30 (30^a Conferência das Partes da ONU sobre Mudanças Climáticas), teve por base estudo hidrológico-hidrodinâmico desenvolvido com o uso do código computacional livre Storm Water Management Model (SWMM), para formular e propor medidas de combate e prevenção a transbordamentos do Canal da Tamandaré, decorrentes de eventos de precipitação intensa e maré elevada, atuando sobre terrenos bastante impermeabilizados, com baixas cotas altimétricas (de 0 a 6 m). O comportamento hidráulico da bacia foi simulado de forma realista considerando um evento de chuva com período de retorno de 50 anos (precipitação de 172 mm em 24 horas), associado à condição da máxima preamar (3,02 m). Os resultados evidenciaram a suscetibilidade a alagamentos em áreas com cotas inferiores a 3,02 m devido à influência das marés e indicaram a importância do uso de comportas para controle hidráulico. Verificou-se que a ocupação da capacidade do Canal da Tamandaré atingiu 100% e transbordou, recomendando-se o uso de eletrobombas de recalque como medida preventiva contra transbordamentos, indicando-se instalação de duas eletrobombas, cada uma com vazão de 1,0 m³/s e altura manométrica de recalque de 7,2 mca, acionadas automaticamente quando a ocupação do canal atingir 85% e desligadas ao atingir 60%. Dessa forma, a simulação computacional com o SWMM possibilitou a formulação de soluções de engenharia para um problema de grande relevância no combate e na prevenção de alagamentos na cidade de Belém-PA.

Palavras-chave: Alagamentos. Urbanização. SWMM. Bacia do Armas. Amazônia.

RESUMEN

La implementación del parque lineal de tamandaré en belém-pa, en la amazonia, para mejorar la infraestructura urbana antes de la cop30 (30^a conferencia de las partes de la onu sobre el cambio climático), se basó en un estudio hidrológico-hidrodinámico desarrollado mediante el código computacional libre storm water management model (swmm), para formular y proponer medidas para combatir y prevenir desbordamientos del canal de tamandaré, resultantes de eventos de intensas precipitaciones y mareas altas, que actúan sobre terrenos altamente impermeables y con elevaciones altimétricas bajas (de 0 a 6 m). El comportamiento hidráulico de la cuenca se simuló de forma realista considerando un evento de lluvia con un período de retorno de 50 años (172 mm de precipitación en 24 horas), asociado con la condición de pleamar máxima (3,02 m). Los resultados destacaron la susceptibilidad a inundaciones en zonas con elevaciones inferiores a 3,02 m debido a la influencia de las mareas e indicaron la importancia del uso de compuertas para el control hidráulico. Se constató que el Canal de Tamandaré alcanzó el 100% de su capacidad y se desbordó, por lo que se recomendó el uso de bombas de refuerzo eléctricas como medida preventiva contra desbordamientos. Se indicó la instalación de dos bombas eléctricas, cada una con un caudal de 1,0 m³/s y una altura de bombeo de 7,2 m, que se activan automáticamente cuando la capacidad del canal alcanza el 85% y se desactivan al alcanzar el 60%. De esta forma, la simulación por computadora con SWMM permitió la formulación



de soluciones de ingeniería para un problema de gran relevancia en el combate y la prevención de inundaciones en la ciudad de Belém-PA.

Palabras clave: Inundaciones. Urbanización. SWMM. Cuenca de Armas. Amazonía.

1 INTRODUCTION

Belém, capital of the State of Pará, located in the Brazilian Amazon, hosted the mega event of COP30 (30th UN Conference of the Parties on Climate Change) in 2025. During the preparatory phase, the city received investments to improve its infrastructure and solve important structural problems, including the urban flooding of the Igarapé das Armas basin, where the Nova Tamandaré Linear Park was implemented, based on the hydrological-hydrodynamic study presented below.

The drainage of the Tamandaré canal, in Belém-PA, represents an important urban challenge in the Amazon, due to its overflows that occur due to high tides and/or heavy rains.

The solution studied for the Tamandaré basin, for the implementation of the Nova Tamandaré Linear Park, was developed based on the hydrological-hydrodynamic computer modeling of this basin, using the SWMM software, including the occurrence of intense rainfall simultaneous to high tides, focusing on the recurrent flooding in the Tamandaré Channel, in order to assist in the decisions of projects and works for the implementation of this important work.

Figure 1

Tamandaré Avenue in Belém-PA before the Linear Park



Source: Pará Agency, 2025.

Figure 2

Tamandaré Avenue in Belém-PA after the implementation of the Linear Park. Nova Tamandaré implemented in Belém-PA



Source: Pará Agency, 2025.

Figure 2 shows the Nova Tamandaré Linear Park implemented in Belém-PA.

As can be seen in Figure 1, it is located in a very urbanized area and waterproofed by pavements, buildings and has its outlet in the Guajará Bay.

The functionality of the drainage system of the Tamandaré Basin stands out for the importance of not flooding Tamandaré Avenue, avoiding losses and losses to the city and its inhabitants, especially when there is intense rainfall associated with high tide levels in Guajará Bay.

Figure 3 shows an image of the Tamandaré Channel with overflow due to the effect of high preamar.

Figure 3

Tamandaré Canal with transshipment in March 2013



Source: Vinagre (2013)

Figure 2 shows overflow and flooding in the Tamandaré channel under the effect of heavy rain and high tide level in its outlet in Guajará Bay. It is a very urbanized and waterproofed area.

Figure 3 shows the floodgates of the Tamandaré Canal, on Av. Tamandaré, essential to its functionality.

Figure 4

Floodgates of the Tamandaré Channel



Source: Google (2023)

Figure 4 shows the outlet and the floodgates of the Tamandaré Canal.

The city of Belém-PA has elevation levels between 0 and 16 m (BELÉM, 2020), being rich in water resources, with intense rainfall, and because it is located close to the Equator,

high tide levels. These are decisive factors for the occurrence of important urban flooding.

Thus, the guiding question of the present research is to investigate the possibility of developing a hydrological-hydrodynamic computational model suitable for the formulation of engineering components suitable for the prevention and combat of flooding of the Tamandaré channel in Belém-PA, in the Amazon.

It is justified that this issue is extremely relevant, as the functionality of the drainage system of the Tamandaré Channel reverberates its importance in the prevention and control of flooding in the Tamandaré basin, avoiding losses and losses to the city and its inhabitants, especially when the occurrence of intense rains associated with high tide levels in the Bay of Guajará.

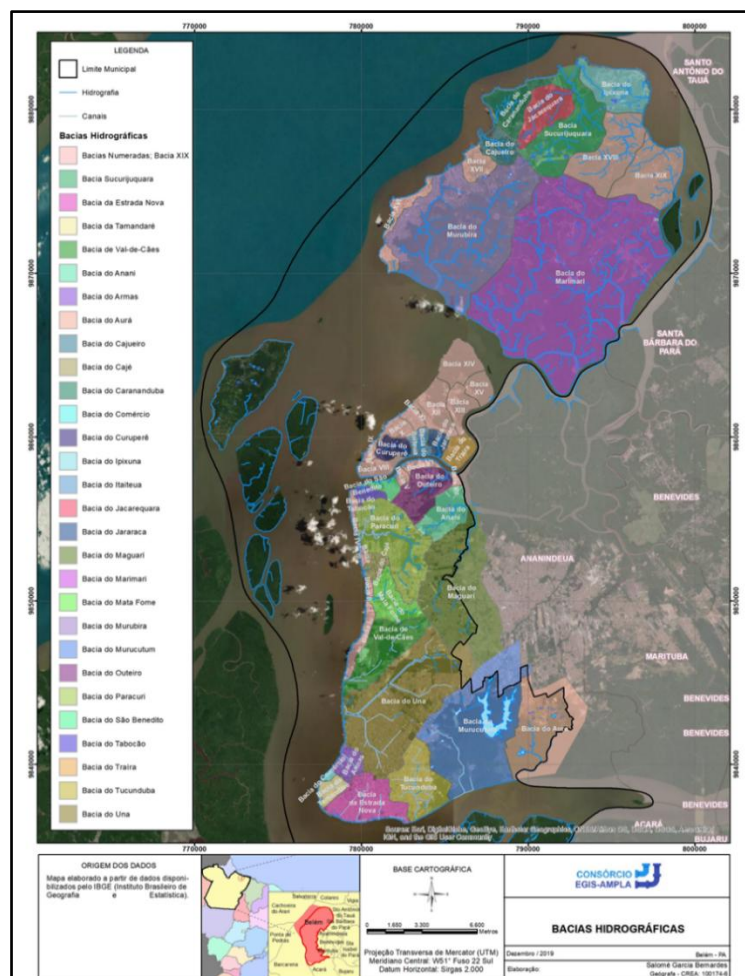
2 THEORETICAL FRAMEWORK

2.1 HYDROGRAPHIC BASINS OF BELÉM-PA

Figure 5 below presents the map of hydrographic basins of Belém-PA.

Figure 5

Map of basins of Belém/PA



Source: Authors (2025)

Figure 5 shows the Tamandaré Basin on the map of hydrographic basins of the city of Belém-PA.

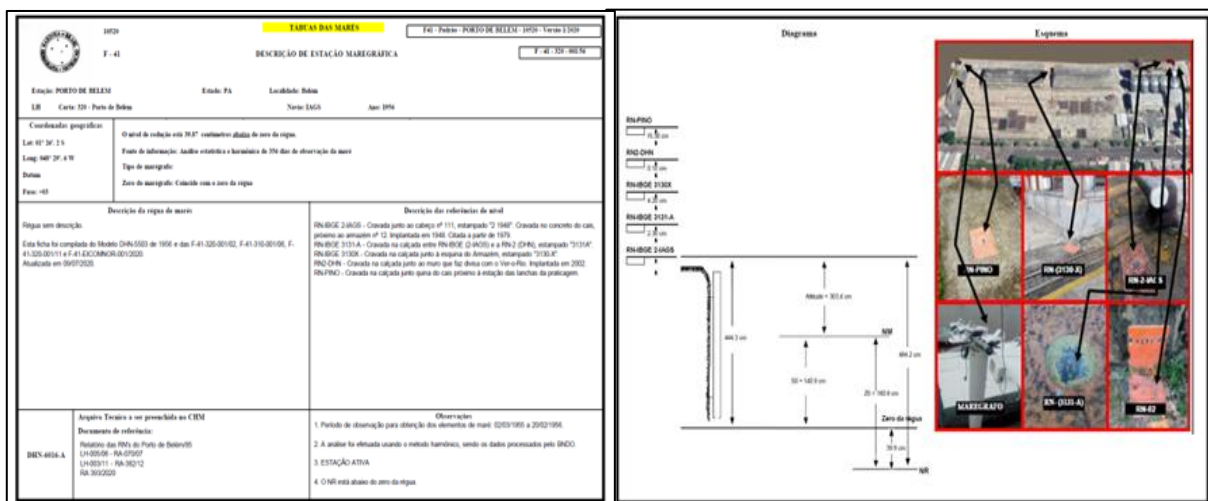
2.2 ALTIMETRY OF THE CHN AND IBGE

The Hydrography and Navigation Center of the Brazilian Navy annually publishes the tide tables of the Port of Belém-PA, with data from the Tide Gauge Station of this port.

Figure 6. shows information regarding the Tide Gauge Station of the Port of Belém-PA.

Figure 6

Information from the Tide Gauge Station of the Port of Belém-PA



Source: CHN (2025)

Figure 6 shows information from the tide gauge station of the port of Belém-PA, which measures the tide level by the reduction level methodology, and not by the Brazilian altimetric datum (IBGE, 2009).

2.3 BRAZILIAN ALTIMETRIC DATUM

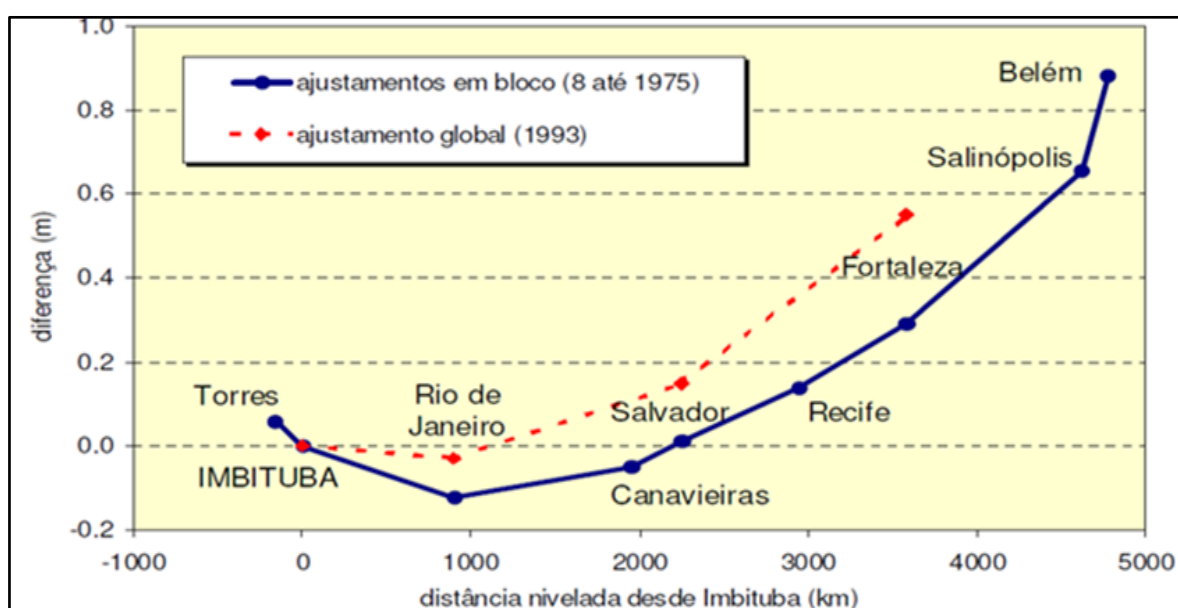
According to the IBGE (2009), the link between the Vertical Datum of the Brazilian Geodetic System, represented by the Imituba and Santana data, and the Reduction Levels and Hydrographic Zeros along the Brazilian coast is established from the information available in the Geodetic Database (BDG). This bank provides essential geodetic subsidies for applications in engineering, cartography, and scientific studies. Among the most requested products, the altitudes of the SGB Level References (RRNN) stand out, widely used in analyses involving altimetric variations, especially in urban drainage projects in coastal regions under the influence of tides. The official altitudes of the SGB are referenced to two

distinct values of the mean sea level (NMM): the Imbituba Datum, defined based on tide gauge series observed in the period from 1949 to 1957, and the Santana Datum, established from observations carried out between 1957 and 1958 (Alencar, 1990; FEMAR, 2000; Luz and Guimarães, 2003). In the context of tide gauge information, the main source for the Brazilian coast is the Tide Table, prepared and published annually by the Hydrography and Navigation Center of the Brazilian Navy.

Figure 7 shows the differences in the altitudes of the RRNN of the IBGE Brazilian Altimetric Datum, referred to Imbituba, in relation to the local NMM.

Figure 7

Differences in altitudes of RRNN of SGB in relation to local NMM



Source: IBGE (2009); Alencar (1990)

Figure 7 summarizes the global adjustment of the RAAP geometric leveling data, completed in 1993, which produced altitudes of a significantly higher number of RRNNs than the manual adjustments made periodically between 1948 and 1975 (Alencar, 1968; Luz and Guimarães, 2001; Luz et al., 2002).

Thus, the port of Belém presents a tide gauge reading +0.8808 m above the IBGE level (Alencar, 1990) for the terrain, where the positive sign shows that the plane of the mean sea level recorded by the observations of the local Tide Gauge is higher than that determined in Imbituba, and transported by the leveling.

2.4 COMPUTATIONAL MODELING USING SWMM SOFTWARE

The *Storm Water Management Model* (SWMM), in Portuguese, consists of a free computational code for hydrological-hydrodynamic computational modeling, developed by

the United States Environmental Protection Agency (USEPA) in 1971. According to Garcia (2005) it is the most widely used software worldwide for urban drainage simulation. It is a distributed, physical model of discrete temporal simulation, in which a hydrographic basin is represented by a series of elements such as sub-basins, junctions, conduits, enabling the continuous simulation of hydrological-hydrodynamic events and processes (BELING, 2013).

This computational tool has many uses, being able to describe various hydrological processes such as surface runoff, infiltration, groundwater contribution, flow propagation, surface accumulation, and water quality propagation (SHINMA, 2011).

3 METHODOLOGY

The hydrological-hydrodynamic computational model of the Tamandaré Basin, developed through the free software SWMM, was structured from a sequence of methodological procedures. Initially, the tide curve and the precipitation time series were elaborated. Then, the identification and quantification of the constituent elements of the basin were carried out, including sub-basins, nodes and conduits, as well as the characterization of their physical attributes, such as shape, type and use of the soil, slope, cross-sections, extensions, elevation elevations and roughness coefficients, based on topographic surveys and available cartographic documents. Subsequently, the data was entered into the SWMM environment for the configuration of the model. Finally, the model was executed and its results were critically analyzed.

4 RESULTS AND DISCUSSION

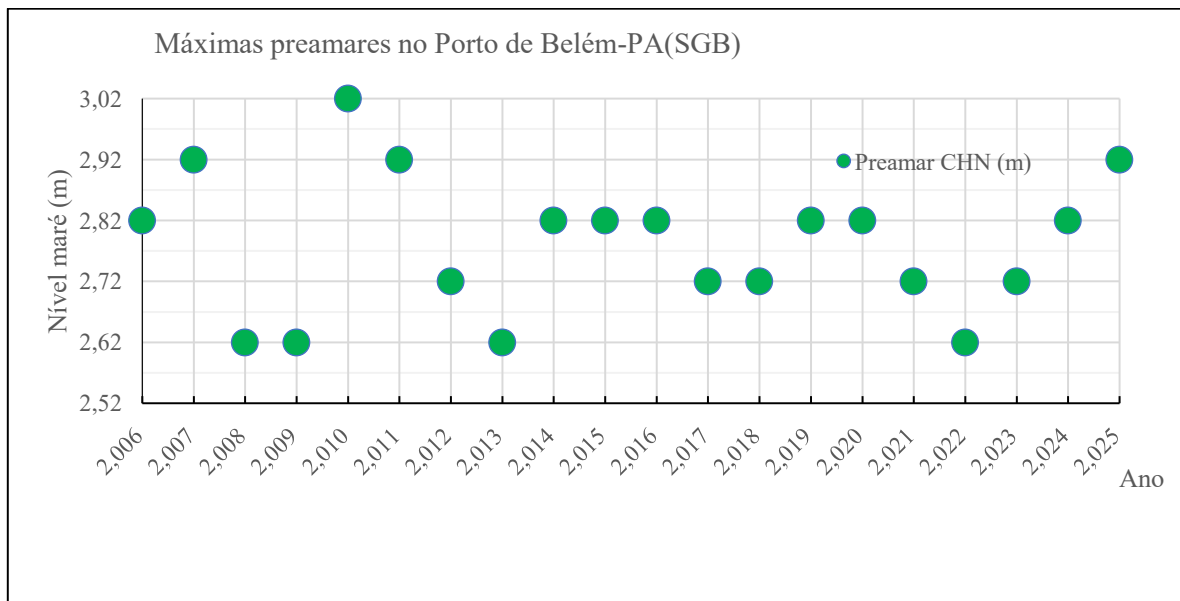
4.1 RESULTS

4.1.1 Tidal Curve and Precipitation Time Series

Figure 8 shows the levels of maximum preamares of the port of Belém-PA informed by the Tide Gauge Station of the Brazilian Navy and transposed to the ground level according to the Brazilian Altimetric Datum of the IBGE.

Figure 8

High tides reported by the Brazilian Navy for Belém-PA



Source: Authors (2025)

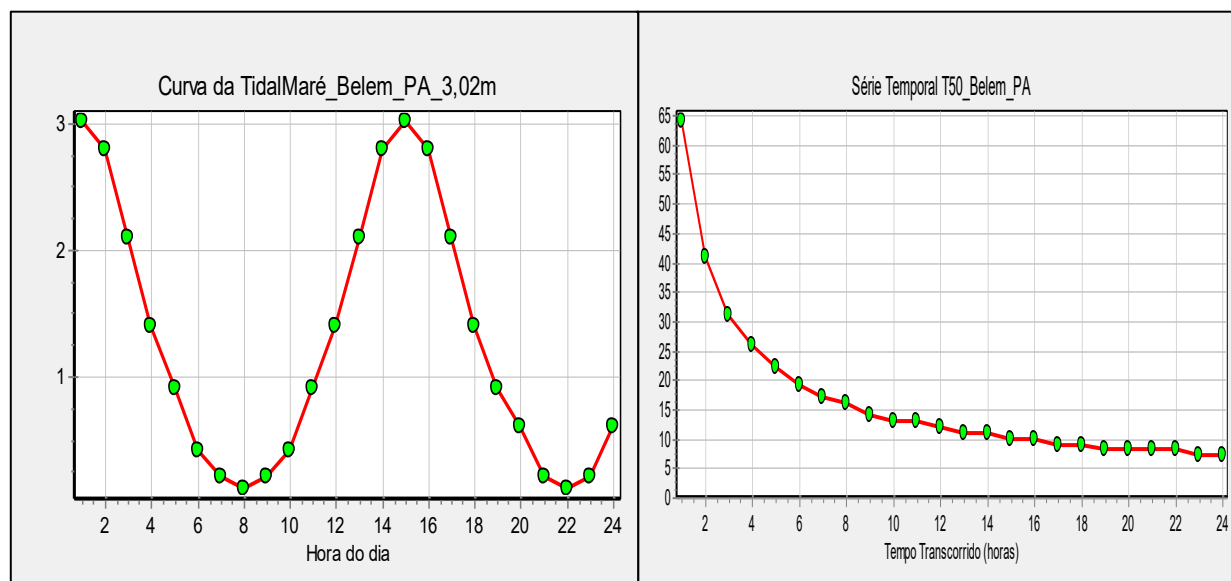
Figure 8 shows the levels of the maximum annual preamares provided by the Center for Hydrography and Navigation of the Brazilian Navy (CHN), referenced to the Brazilian Altimetric Datum of the IBGE. It is observed that the highest tide recorded corresponds to the elevation of 3.02 m, which occurred exclusively in 2010. Based on these data, the maximum annual preamar of 3.02 m was adopted for the present study as a reference condition. Thus, areas with elevation levels lower than this value are considered susceptible to flooding due to the direct influence of the tide.

Regarding the time series of precipitation with a return period of 50 years for the municipality of Belém-PA, used in the design of urban macro-drainage works, this was defined based on Souza *et al.* (2012). The rainfall event adopted presents a total precipitation of 172 mm, with a duration of 24 hours, and the temporal distribution of the rainfall was obtained through the methodology of time disaggregation applied to the 24-hour event analyzed.

Figure 8 illustrates the tidal curve corresponding to the 3.02 m high tide and the precipitation time series, both used as input data in the hydrological-hydrodynamic modeling.

Figure 9

Tidal curve and precipitation time series used in the simulation.



Source: Authors with data from CHN/SGB, 2025.

Figure 9 shows the tide curve of the maximum tide of 3.02m and the time series of rainfall with a return period of fifty years (T50) used in the computer model.

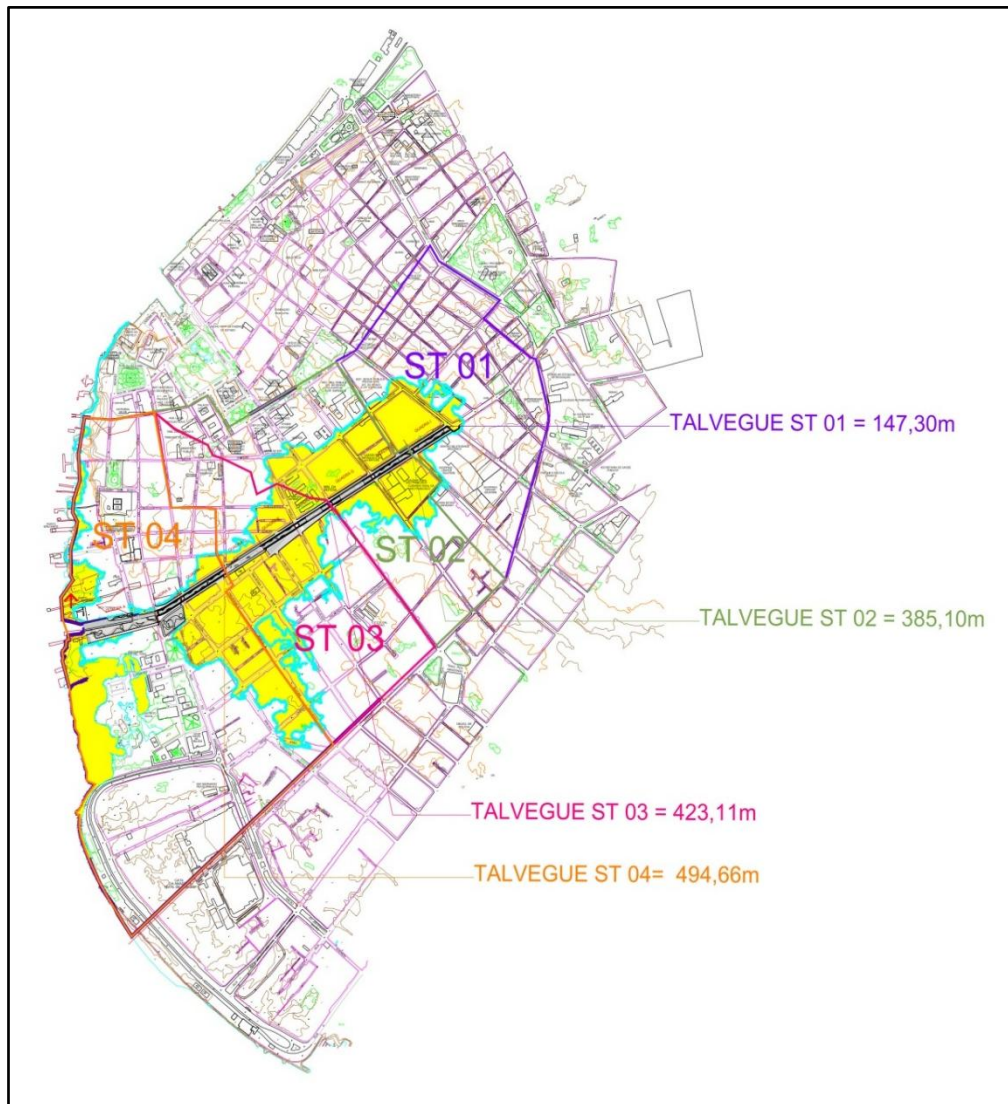
4.1.2 Tamandaré Basin

The Tamandaré basin has an area of 2.8km² with great waterproofing, low altitude (0 and 8 m), high rainfall, tidal influence and for these reasons it has frequent urban flooding. It includes two sub-basins, Tamandaré (area of 1.7 km²) and Reduto (area of 1.1 km²), which are interconnected by an existing pluvial gallery on Rua da Municipalidade. The Tamandaré Canal, with a length of 1.1 km, is located at Av. Tamandaré is lined in concrete and equipped with floodgates implemented in the 1960s (PMSB, 2020).

Figure 10 shows the Tamandaré Basin with its channel.

Figure 10

Tamandaré Basin



Source: Authors (prepared using the free software QGIS).

Figure 10 shows the Tamandaré Basin, with its four sub-basins.

Table 1 lists sub-basins, areas, nodes and conduits of the Tamandaré basin.

Table 1

Data from the Tamandaré basin

DATA	SUB-BASINS	CONDUIT	Span (m)	Input Node	Radier elevation NE (m)	Exit Node
Denomination Channel	ST01	C1_ST01	68,60	N1_ST01	0,90	N2_ST01
		C2_ST01	96,50	N2_ST01	0,90	N1_ST02
Area(ha)	36,01					
Perimeter(m)	2.725,45					
Swev(m)	147,30					
Width (m)	2.444,67					
Solo use	90% urb					
Exutory	N1_ST01					
			165,10			
Denomination Channel	ST02	C1_ST02	98,00	N1_ST02	0,21	N2_ST02
		C2_ST02	14,50	N2_ST02	0,05	N3_ST02
Area(ha)	32,23	C3_ST02	90,00	N3_ST02	0,46	N4_ST02
Perimeter(m)	3.241,43	C4_ST02	30,00	N4_ST02	0,21	N5_ST02
Swev(m)	385,10	C5_ST02	29,00	N5_ST02	0,20	N6_ST02
Width (m)	836,93	C6_ST02	15,00	N6_ST02	0,46	N1_ST03
Solo use	90% urb					
Exutory	N1_ST02					
			276,50			
Denomination Channel	ST03	C1_ST03	25,00	N1_ST03	0,46	N2_ST03
		C2_ST03	60,00	N2_ST03	0,46	N3_ST03
Area(ha)	36,33	C3_ST03	24,00	N3_ST03	0,23	N4_ST03
Perimeter(m)	3.002,73	C4_ST03	16,00	N4_ST03	0,10	N5_ST03
Swev(m)	423,11	C5_ST03	58,00	N5_ST03	0,10	N6_ST03
Width (m)	858,64	C6_ST03	3,00	N6_ST03	0,09	N7_ST03
Solo use	90% urb	C7_ST03	60,00	N7_ST03	0,10	N8_ST03
Exutory	N1_ST03	C8_ST03	130,00	N8_ST03	0,10	N1_ST04
			376,00			
Denomination Channel	ST04	C1_ST04	80,00	N1_ST04	0,18	N2_ST04
		C2_ST04	3,00	N2_ST04	0,18	N3_ST04
Area(ha)	78,92	C3_ST04	85,00	N3_ST04	0,39	N4_ST04
Perimeter(m)	4.159,88	C4_ST04	13,50	N4_ST04	0,78	N5_ST04
Swev(m)	494,66	C5_ST04	82,50	N5_ST04	0,78	N6_ST04
Width (m)	1.595,44	C6_ST04	13,50	N6_ST04	0,17	N7_ST04
Solo use	90% urb	C7_ST04	49,50	N7_ST04	0,17	N8_ST04
Exutory	N1_ST04	C8_ST04	6,00	N8_ST04	0,17	N9_ST04
		C9_ST04	6,00	N9_ST04	-1,48	OUTUSE
			339,00			
Area (ha)	183,49		1156,60			

Source: Authors, 2025

Table 1 shows data from the Tamandaré basin.

4.1.3 Feeding the Computational Model in Swmm

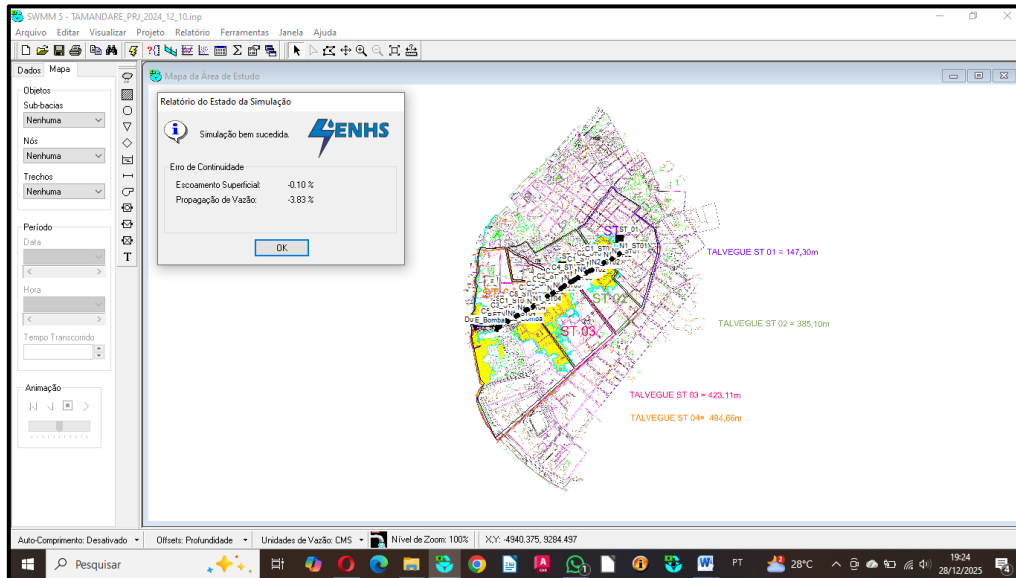
The information collected was inserted into the hydrological-hydrodynamic model of the Tamandaré basin, enabling the execution of the simulation.

4.1.4 Execution and Analysis of the Results Obtained

Figure 11 below shows the result of the simulation of the Tamandaré basin under the effect of rainfall with a recurrence period of 50 years and a pre-tide of 3.02 m.

Figure 11

Simulation result of the Tamandaré basin in Belém-PA



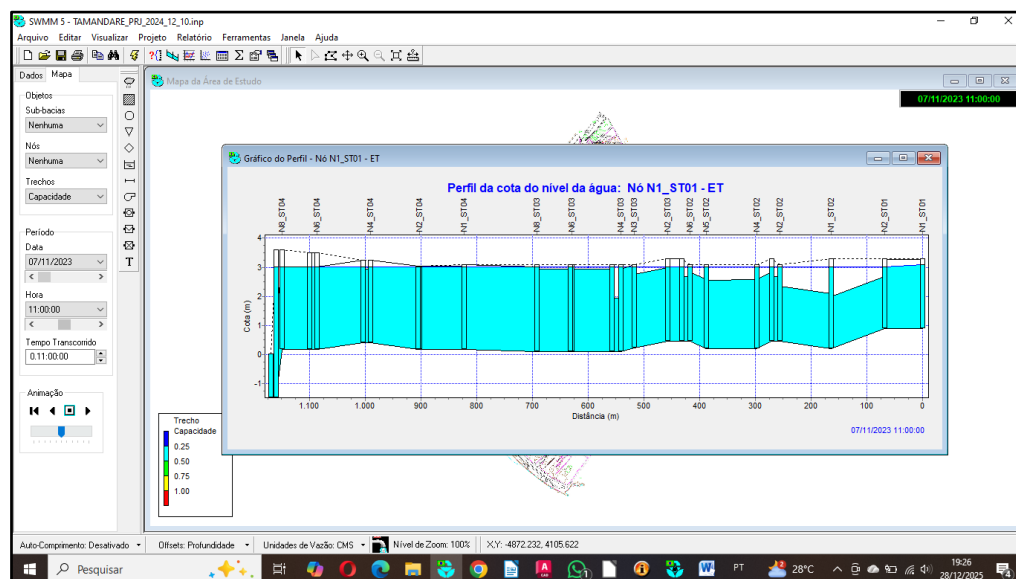
Source: Authors, 2025.

Figure 12 shows the successful result of the simulation of the Tamandaré basin with SWMM, with very small errors, of -0.10% for surface runoff and -3.83% for flow propagation.

Figure 12 shows the Tamandaré Channel at the moment of maximum water depth.

Figure 12

Profile of the Tamandaré channel at the moment of maximum water depth



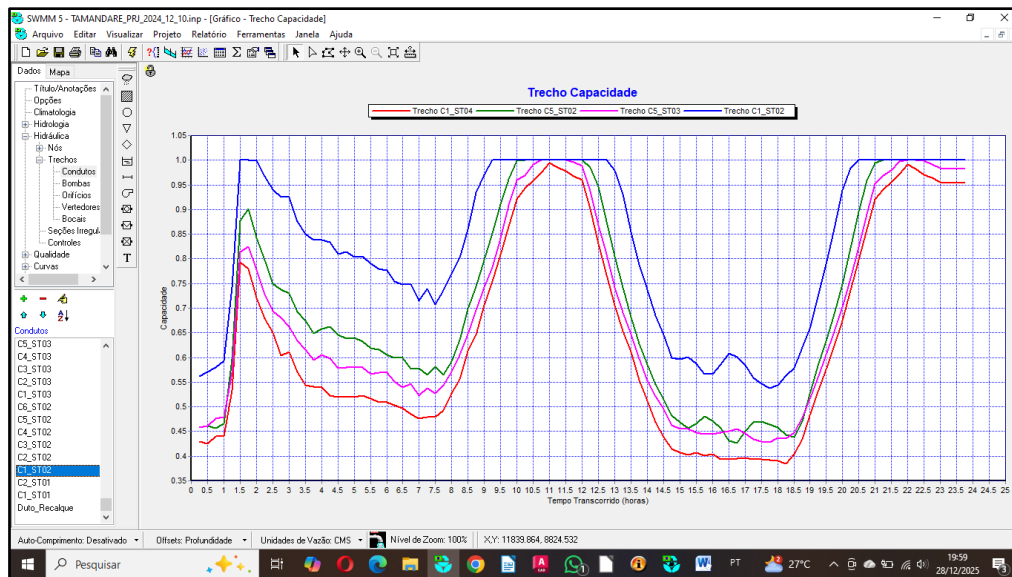
Source: Authors, 2025.

Figure 13 shows that the intermediate stretches of the canal, which have a lower elevation of the terrain, present a higher risk of flooding than the inlet and the spring.

Thus, the analysis of the flow with the help of the computational model elaborated in the SWMM results in the intermediate stretches being more susceptible to overflows and flooding, as shown in Figure 12.

Figure 13

Time series of the capacity and flow of stretches of the Tamandaré canal



Source: Author (2025)

Figure 14



Source: Author (2025)

Figure 12 shows that among the stretches that reach 100% of capacity and overflow, C1_ST04 is the one with the highest flow, and thus becomes the most critical for this

overflow. It exceeds 85% of capacity in the interval between 9.5 and 12.5 hours after the start of the event, with a flow of 8m³/s. In order to reduce the used capacity of these stretches to up to 85%, in this interval of greater risk of overflow, it is recommended to insert two units of electric pumps, for settlement heights of 7.2mca and individual flows of 1.0m³/s. As an operating rule, they must be activated when the water depth in the section of the lift reaches 85% of the capacity of the section and turned off when it reaches 60%, preventing overflows.

4.2 DISCUSSION

The computational modeling of hydrological-hydrodynamic events in urban drainage basins is extremely useful for urban management, especially for preventing and combating flooding, by demonstrating quantitatively that the association of high rainfall, topography, tidal rise and intense waterproofing can result in the occurrence of overflows and flooding.

The annual tide of the year 2010 reached the altimetric level of 3.02m, showing the importance and usefulness of the floodgates of the Tamandaré channel, which constitute a necessary control mechanism to prevent the entry of water from the bay at times of high tide, avoiding the overflow of the channel at points of topographic levels lower than tide levels, especially in the points of lower elevations, in the order of 2.6 to 2.8m, in the vicinity of Blocks D, E and F (near Tv. Ângelo Custódio), where flooding currently occurs due to high tide, and even more, thus providing useful volume in the channel for the reception of rainwater.

5 CONCLUSION

Thus, to obtain the functionality of the Av. Tamandaré based on the Hydraulic-Hydrological Model of the Tamandaré basin studied here, it is recommended that elevations equal to or greater than the maximum annual tide of 3.02 m be used throughout the Park, where possible 3.02 m + 0.20 m.

The successful implementation of the Nova Tamandaré Linear Park, in Belém-PA, as an intervention to improve urban infrastructure in the preparatory period for COP30, was based on the hydrological-hydrodynamic study developed through computer modeling in the SWMM software, as described in this work.

The main constraints associated with urban flooding in the study area consist of the low elevation of the terrain, the high degree of surface waterproofing and the high tide levels, factors that highlight the need for the adoption of hydraulic control devices, such as floodgates, as well as the use of pumping systems for rainwater settlement. aiming at preventing overflows and floods.

The results of the study demonstrated the high utility of the proposed modeling, by realistically reproducing the hydraulic behavior of the Tamandaré basin when subjected to a rainfall event with a return period of 50 years, characterized by a total rainfall of 172 mm in 24 hours, concomitantly with the occurrence of the maximum tide recorded, observed in 2010. One of the relevant conclusions refers to the identification of susceptibility to tide-induced flooding in areas with elevation levels below 3.02 m, a value corresponding to the level of the maximum tide considered.

The simulations indicated the achievement of 100% of the hydraulic capacity of the Tamandaré Canal, a result that reinforces the need to use electric pumps as an essential measure to prevent overflows. From an operational point of view, it is recommended that the occupied capacity of the channel be maintained at levels below 85%, as a criterion of hydraulic safety.

In this context, the implementation of the Tamandaré Rainwater Pumping Station is a strategic equipment for the mitigation of overflows and flooding in the Tamandaré Channel — and, by extension, in this basin — acting in periods of rising water levels, together with altimetric control and the proper operation of the floodgates. In this way, the Tamandaré basin now has effective mechanisms for the prevention and control of urban flooding.

For the implementation of the pumping station, with the objective of reducing the hydraulic occupation of the channel to values below 85%, preventing overflows, it was recommended the installation of two electric pumps operating in parallel, each with a pumping capacity of 1.0 m³/s, for a settlement head of 7.2 mca. The system must be operated automatically, with activation of the pumps when the hydraulic occupation of the channel reaches 85% and shutdown when it reaches 60%.

Thus, the computational modeling carried out with SWMM proved to be an effective tool for the analysis of a problem of high urban relevance in Belém-PA, allowing the evaluation of critical scenarios and the proposition of technically adequate engineering solutions for the prevention and control of flooding.

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