COMPUTATIONAL MODELING OF THE DOCK CHANNEL IN BELÉM, PARÁ, FOR THE IMPLEMENTATION OF URBAN IMPROVEMENTS PRIOR TO COP30

MODELAGEM COMPUTACIONAL DO CANAL DA DOCA EM BELÉM-PA PARA IMPLANTAÇAO DE MELHORIA URBANA PRÉVIA À COP30

MODELIZACIÓN COMPUTACIONAL DEL CANAL DEL MUELLE EN BELÉM-PA PARA LA IMPLANTACIÓN DE MEJORAS URBANÍSTICAS PREVIAS A LA COP30

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ABSTRACT

The implementation of the New Doca Linear Park in the Armas basin, in Belém-PA, in the Amazon, for urban improvement before 30th UN Conference of the Parties on Climate Change (COP30), was based on a hydrological-hydrodynamic study using the computational code Storm Water Management Model–SWMM. This study formulated ways to prevent overflows in the Doca Channel, due to intense rainfall, low elevation of the terrain (between 0 and 8m), high impermeability, and high tidal levels. The hydraulic behavior of the basin was realistically simulated under the effect of rainfall with a 50- year return period, with 172 mm of precipitation in 24 hours, under the effect of a high tide of 3.02m, indicating the need of floodgates. It is concluded that there is susceptibility to tidal flooding for terrains with elevations below 3.02m. The occupied capacity of the Doca channel reached 97%, suggesting the use of booster pumps to prevent overflows, with the operational

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recommendation to limit the occupied capacity to 85%. The Environmental Protection Agency Network Evaluation Tool (EPANET) software was used to study the installation of 4 electric pumps, with an individual flow rate of 0.4 m³/s and a pumping head of 7.2 m, activated by automation when the channel capacity reaches 85% (level of 2.00 m) and deactivated when it reaches 51% (level of 1.20 m). Thus, the computational simulation with SWMM and the assistance of EPANET allowed the study of engineering solutions for a extremely relevant problem that is preventing flooding in Belém-PA.

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

RESUMO

A implantaçao do Parque Linear Nova Doca, na bacia do Armas, em Belém-PA, na Amazônia, para melhoria urbana previamente à realização da 30ª Conferência das Partes da ONU sobre Mudanças Climáticas (COP30), teve por base o estudo hidrológico- hidrodinâmico com uso do código computacional livre Storm Water Management Model– SWMM. Esse estudo formulou modos de combater e prevenir transbordos no Canal da Doca, devido precipitações pluviométricas intensas, baixas cotas altimétricas do terreno (entre 0 e 8m), muito impermeabilizado, e elevado nível de marés. Foi simulado realisticamente o comportamento hidráulico da bacia sob o efeito de chuva de período de retorno de 50 anos, com precipitação de 172 mm em 24 horas, sob o efeito da preamar de 3,02m, indicando necessidade do uso de comportas. Conclui-se que há suscetibilidade de alagamento por maré para terrenos com cotas inferiores a 3,02m. A capacidade ocupada do canal da Doca atingiu 97%, sugestivo para uso de eletrobombas de recalque para prevenção de transbordos, com o indicativo operacional de limitar a capacidade ocupada a 85%. Utilizou-se o software Environmental Protection Agency Network Evaluation Tool (EPANET), para estudar a instalação de 4 eletrobombas, com vazão individual de 0,4m³/s e altura de recalque 7,2mca, acionadas por automação, quando a capacidade do canal atingir 85% (nível de 2,00m) e desligadas quando atingir 51% (nível de 1,20m). Assim, a simulação computacional com o SWMM e assistência do EPANET permitiu estudar soluções e engenharia para um problema extremamente relevante para o combate e a prevenção de alagamentos em Belém-PA.

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

RESUMEN

La implantación del Parque Linear Nova Doca, en la cuenca del Armas, en Belém-PA, en la Amazonia, para la mejora urbana previa a la celebración de la 30.ª Conferencia de las Partes de la ONU sobre el Cambio Climático (COP30), se basó en el estudio hidrológico-hidrodinámico con el uso del código informático libre Storm Water Management Model (SWMM). Este estudio formuló formas de combatir y prevenir desbordamientos en el Canal da Doca, debido a las intensas precipitaciones pluviométricas, las bajas cotas altimétricas del terreno (entre 0 y 8 m), muy impermeabilizado, y el elevado nivel de las mareas. Se simuló de forma realista el comportamiento hidráulico de la cuenca bajo el efecto de una lluvia con un período de retorno de 50 años, con una precipitación de 172 mm en 24 horas, bajo el efecto de una marea alta de 3,02 m, lo que indica la necesidad de utilizar compuertas. Se concluye que existe susceptibilidad de inundación por mareas en terrenos con cotas inferiores a 3,02 m. La capacidad ocupada del canal del muelle alcanzó el 97 %, lo que sugiere el uso de bombas eléctricas de recalque para evitar desbordamientos, con la indicación operativa de limitar la capacidad ocupada al 85 %. Se utilizó el software Environmental Protection Agency Network Evaluation Tool (EPANET) para estudiar la instalación de 4 bombas eléctricas, con un caudal individual de 0,4 m³/s y una altura de bombeo de 7,2 mca, accionadas por automatización, cuando la capacidad del canal alcance el 85 % (nivel de 2,00 m) y se apaguen cuando alcance el 51 % (nivel de 1,20 m). Así, la simulación computacional con el SWMM y la asistencia del EPANET permitió estudiar

soluciones e ingeniería para un problema extremadamente relevante para el combate y la prevención de inundaciones en Belém-PA.

Palabras clave: Inundaciones. Urbanización. SWMM. Cuenca del Armas. Amazonas.

1 INTRODUCTION

The city of Belém, capital of the State of Pará, located in the Brazilian Amazon, hosted the mega-event of the 30th UN Conference of the Parties on Climate Change (COP30) 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 Doca Linear Park was implemented, based on the hydrological-hydrodynamic study presented below.

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

The city of Belém-PA has elevation levels between 0 and 16 m (Belém, 2020) and receives intense rainfall, decisive factors for the occurrence of important urban flooding.

Thus, the guiding question of the present research is to verify if it is possible to develop a hydrological-hydrodynamic computational model to formulate adequate components to prevent and combat flooding of the Doca channel in Belém-PA.

It is justified that this issue is crucial, as the functionality of the drainage system of the Canal da Doca stands out for the importance of not flooding Avenida Visconde de Souza Franco, avoiding losses and damages to the city and its inhabitants, especially when there is intense rainfall associated with high tide levels in Guajará Bay.

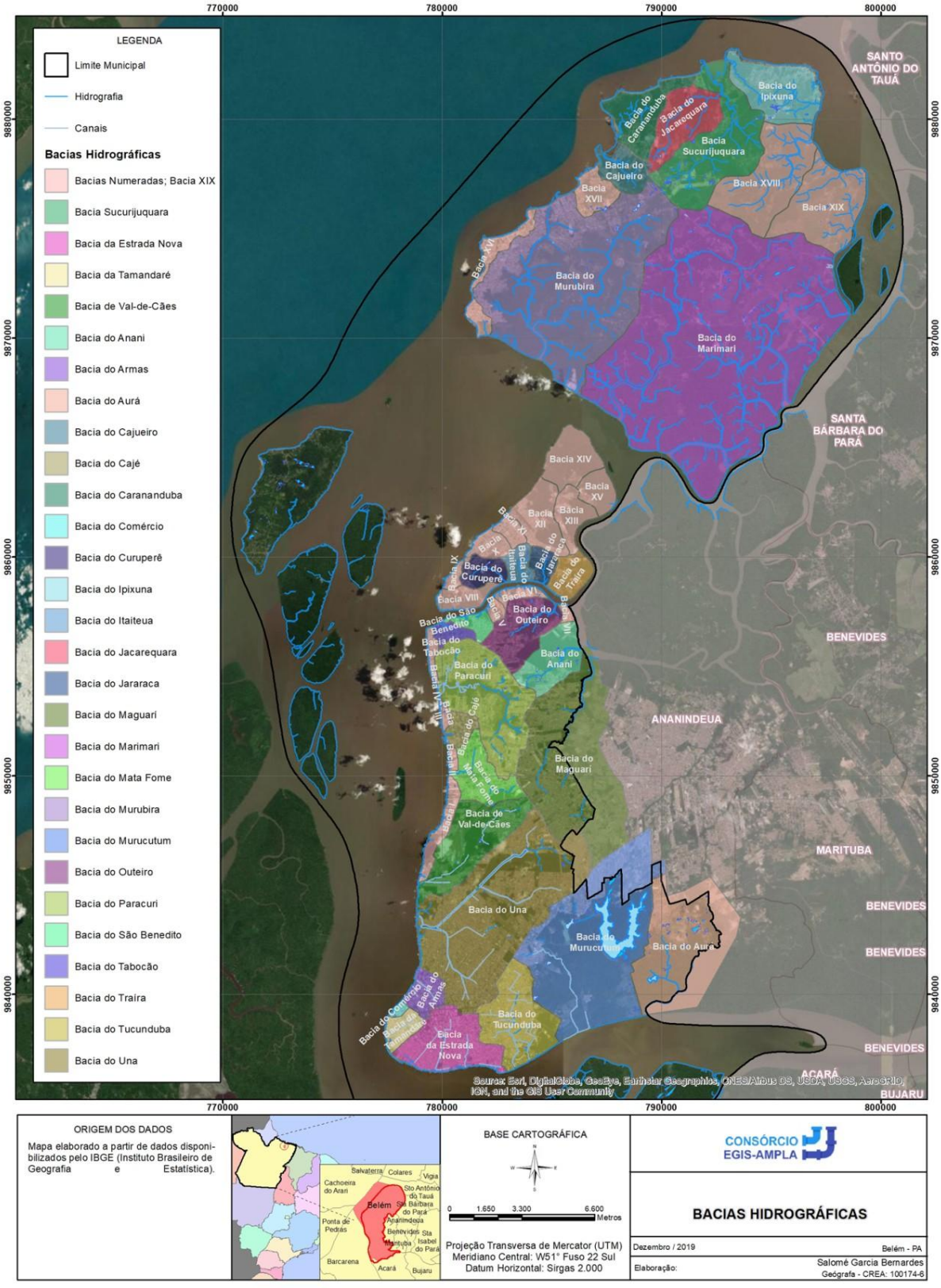
2 THEORETICAL FRAMEWORK

2.1 HYDROGRAPHIC BASINS OF BELÉM-PA

Figure 1 below presents the map of hydrographic basins of Belém-PA.

Figure 1

Map of basins in Belém/PA



Source: Belém (2020).

Figure 2 shows the map of hydrographic basins of the city of Belém-PA, including the Armas Basin.

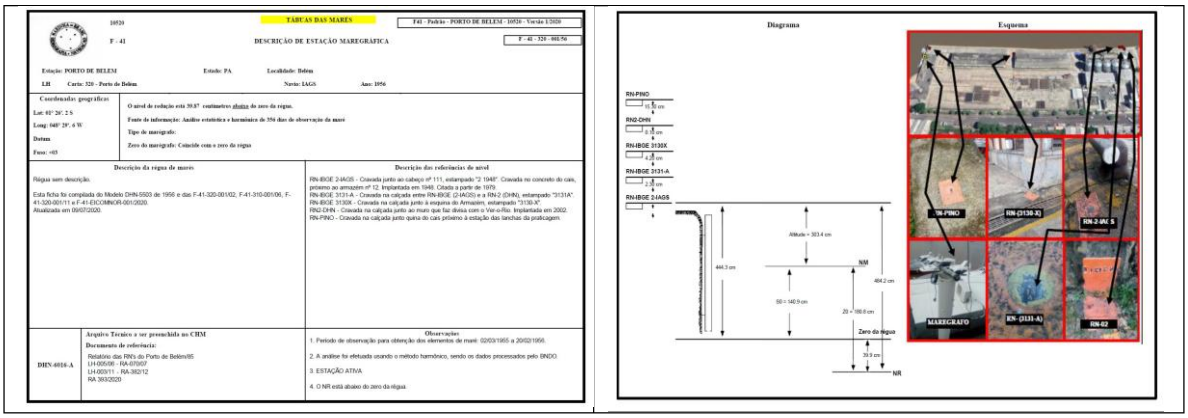
2.2 ALTIMETRY OF THE CHN AND IBGE

The Hydrography and Navigation Center of the Brazilian Navy collects and disseminates information from the Tide Gauge Station of the Port of Belém-PA, with the tide tables of this Port.

Figure 2 shows information regarding the Tide Gauge Station of the Port of Belém-PA.

Figure 2

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



Source: CHN (2025).

Figure 2 presents information from the Tide Gauge Station of the Port of Belém-PA, in which the measurement of the tide level is carried out by the reduction level methodology, and not by the Brazilian Altimetric Datum, of the IBGE.

2.3 BRAZILIAN ALTIMETRIC DATUM

According to IBGE (2009), the relationship between the Vertical Datum of the Brazilian Geodetic System (Imbituba and Santana) and the Reduction Levels and Hydrographic "Zeros" on the Brazilian Coast is obtained using the IBGE's Geodetic Database (BDG), which provides geodetic information to be used in engineering projects, mapping and scientific studies.

The most frequently requested information is the altitudes of the vertical stations (Level References, RRNN) of the Brazilian Geodetic System (SGB), for use in studies in which the unevenness or slope are important, such as in the implementation of urban drainage systems in coastal cities, which suffer tidal effect. The altitudes of the SGB originate from two particular values of the mean sea level (NMM), called Datum de Imbituba and Datum de Santana.

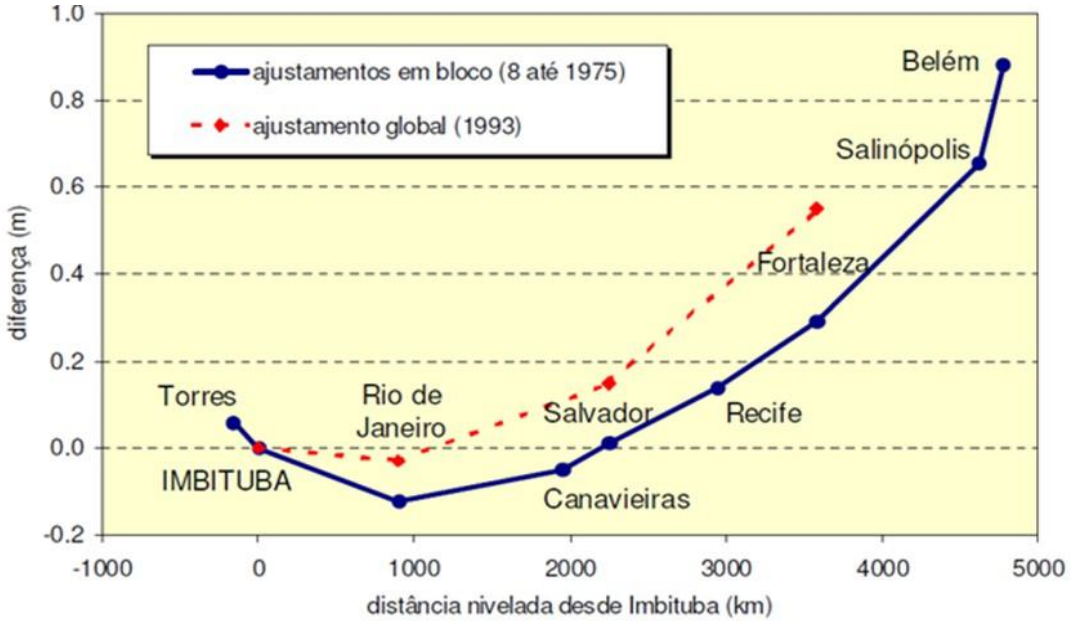
The first was defined from sea level observations of the Port of Imbituba (SC) between the years 1949 and 1957. To define the Datum of Santana (AP), observations made in 1957 and 1958 were used (Alencar, 1990; Femar, 2000; Light; Guimarães, 2003). The most

common source of information on tide levels on the Brazilian coast is the Tide Table (MT), published annually by the Brazilian Navy's Hydrography and Navigation Center (CHN) (CHN, 2025).

Figure 3 shows the differences between the altitudes of the RRNN of the IBGE Brazilian Altimetric Datum, referred to Imbituba, and their heights in relation to the local NMM.

Figure 3

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



Source: IBGE (2009); Alencar (1990).

Figure 3 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, 1990; Light; Guimarães, 2003).

Thus, the port of Belém has a tide gauge reading +0.8808m above the IBGE level (Alencar, 1990) for the terrain, and the positive sign indicates 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 SIMULATION USING SWMM

The free computer code *Storm Water Management Model* (SWMM), Urban Drainage Management Model (in Portuguese), is a hydrological-hydrodynamic computer modeling software, developed by the United States Environmental Protection Agency (USEPA) in 1971 (SWMM, 2012). For Garcia (2005) it is the most widely used application worldwide for urban

drainage simulation. It is a physical, distributed, discrete temporal simulation model, where a hydrographic basin is represented by a series of elements such as sub-basins, junctions, conduits, in order to enable the continuous simulation of hydrological-hydrodynamic events and processes (Beling, 2013).

This model 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 Armas Basin elaborated using the free software SWMM had the following methodological procedures:

I) Preparation of the tide curve and the precipitation time series; II) Identification and quantification of the components of the basin (sub-basins, nodes and conduits), with their physical characteristics (shape, type and use of soil, slope, sections, extensions, elevations, roughness), based on existing topographic surveys, geographical maps and other available maps; III) Feeding of the model prepared in the SWMM; IV) Execution and analysis of the results obtained.

3.1 LOCUS OF RESEARCH

The research had as its locus the Doca canal, in the city of Belém-PA. The images of the research site are presented below.

Figure 4 shows the Nova Doca Linear Park implanted in the Armas basin in Belém-PA.

Figure 4

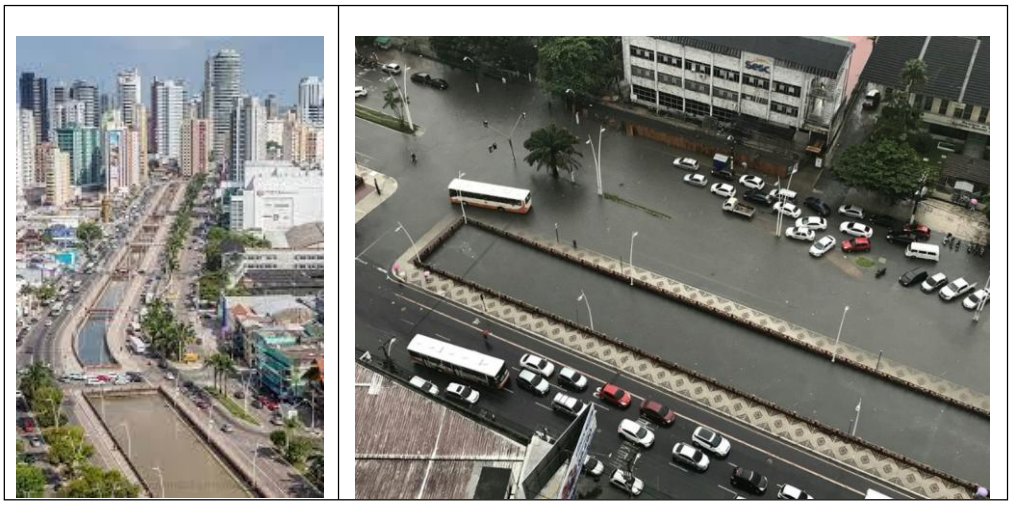
Nova Doca Linear Park implemented for COP30 in Belém-PA

Source: Government of the State of Pará (2025).

Figure 5 below shows an image of the Dock Channel with overflow and flooding due to high tide and heavy rain.

Figure 5

Overflow of the Dock Channel due to high tide and rain on 03/17/2022



Source: https://g1.globo.com/pa/para/noticia/vias-ficam-alagadas-e-canais-transbordam-apos-chuva- 1-hour-fort-in-belem.ghtml

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

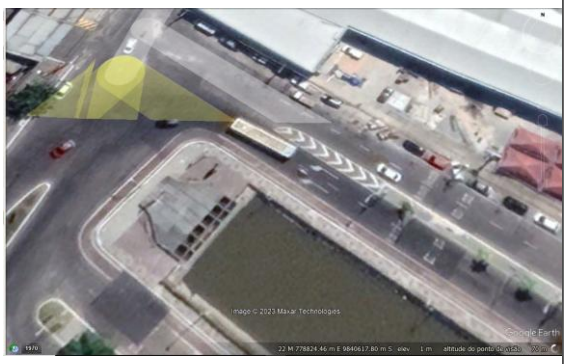
Figure 6 shows the floodgates of the Canal da Doca, on Av. Visconde de Souza

Franco, essential to its functionality.

Figure 6

Dock Channel Gates

Source: The authors



Source: Google (2025).

Figure 6 shows the floodgates of the Canal da Doca, in its outlet. The canal has sides covered in concrete, in a very urbanized urban area.

4 RESULTS AND DISCUSSIONS

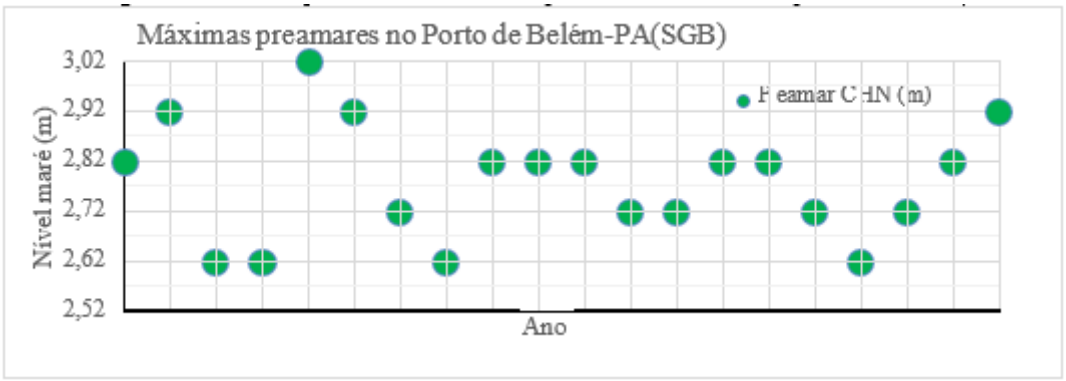
4.1 RESULTS

4.1.1 Tidal curve and precipitation time series

Figure 7 shows the levels of maximum preamares measured in the tide gauge of the Brazilian Navy (CHN) for the port of Belém-PA, transposed to the ground level according to the Brazilian Altimetric Datum of the IBGE.

Figure 7

High tides reported by the Brazilian Navy for Belém-PA



Source: The auhors.

Figure 4 shows the levels of the annual preamares maximums informed by the CHN and referenced to the IBGE's Brazilian Altimetric Datum. The maximum preamar, with an

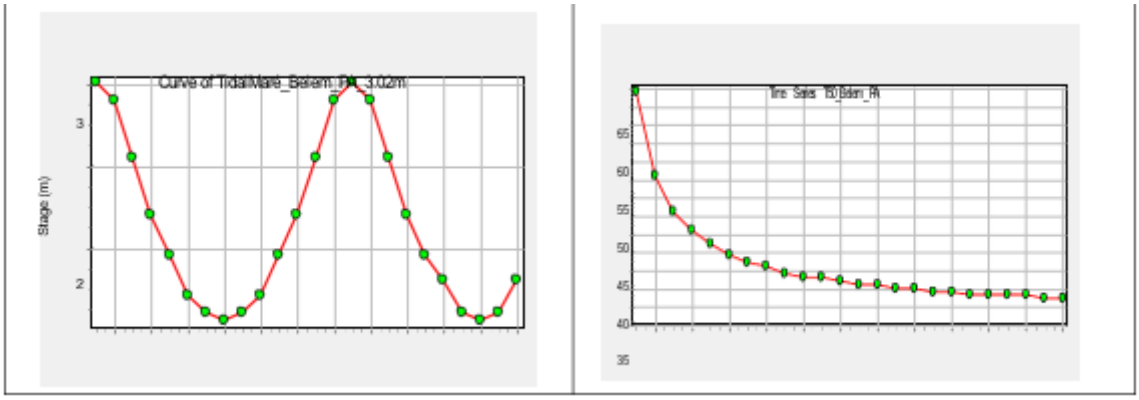
elevation of 3.02 m, occurred only in 2010. Based on the above, the maximum annual preamar with an elevation of 3.02m was adopted for this study. In this way, land with an elevation of more than 3.02m is not susceptible to tidal flooding.

Regarding the time series of rainfall of the 50-year return period for Belém-PA, used for the design of urban macro-drainage works, it was obtained based on Souza *et al*. (2012), with total rainfall of 172 mm and duration of 24 hours, using the methodology of hourly disaggregation of rainfall for the 24-hour event studied.

Figure 8 shows the tide curve with a 3.02m high tide and the rainfall time series, both used in the modeling.

Figure 8

Tidal curve and precipitation time series used in the simulation



Source: The auhors, based on data from CHN (2025).

Figure 8 shows the tide curve of a maximum tide of 3.02m and the rainfall time series with a return period of fifty years T50 used in the simulation.

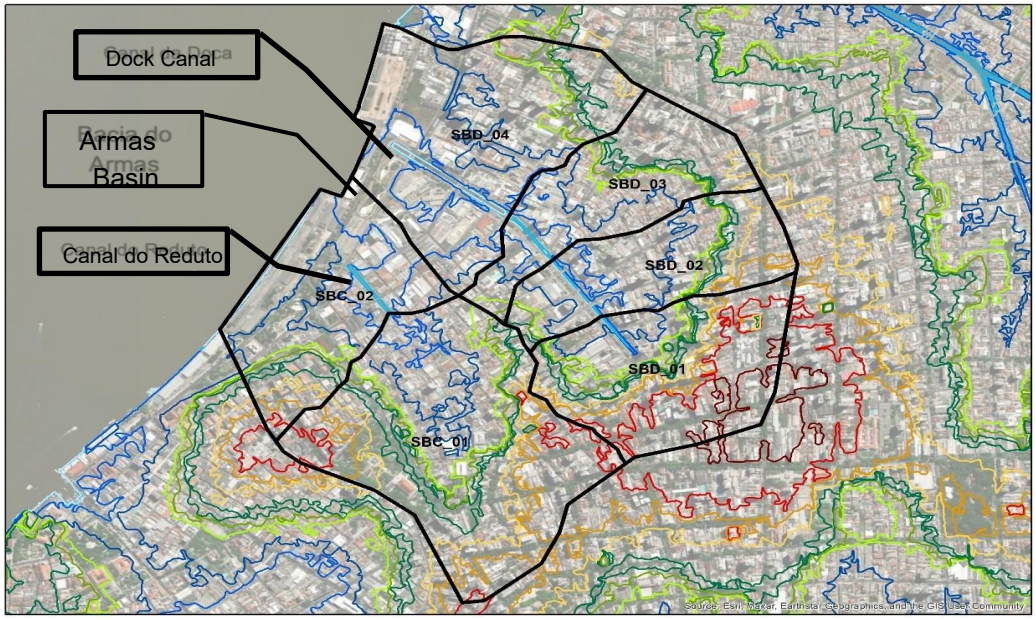
4.1.2 Armas Basin Information

The Armas basin has an area of 2.8km2 with great waterproofing, low altitude (0.8m), high rainfall, tidal influence and for these reasons it has frequent urban flooding. It includes two sub-basins, Doca (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 Canal da Doca, with a length of 1.1 km, is located at Av. Visconde de Souza Franco and Reduto, with a length of 0.3 km, is located at Av. General Magalhães. Both are lined in concrete and equipped with floodgates implanted in the 1960s (Belém, 2020).

Figure 9 shows the Armas Basin with its Doca and Reduto channels.

Figure 9

Armas Basin



Source: The auhors, using the free software QGIS (2025).

Figure 9 shows the Armas Basin, which includes the Doca sub-basin with its four sub-basins and the Reduto sub-basin with its two sub-basins.

Table 1 lists sub-basins, areas, channels and extensions of the Armas basin.

Table 1

Sub-basins and channels of the Armas basin

Sub-basin	Area (ha)	Exutory	Channel	Top width (m)	Span (m)	*n*
SBD_01	44.36	PD_01	Dock	10	189,10	0,013
SBD_02	33,14	PD_02	Dock	10	251,60	0,013
SBD_03	35,04	PD_09	Dock	10	180,00	0,013
SBD_04	62,42	PD_12	Dock	20	479,10	0,013
Sum	**174,96**				**1.099,80**	
SBC_01	73,00	PC_01	Redoubt	10		
SBC_02	40,21	PC_03	Redoubt	10	278,00	0,013
Sum	**113,21**					
SUM	**288,17**				**1.377,80**	

Source: The auhors.

Table 1 shows the Armas basin including the Doca and Reduto canals, which are interconnected by a pluvial gallery on Rua da Municipalidade.

4.1.3 Feeding of the model prepared in the SWMM

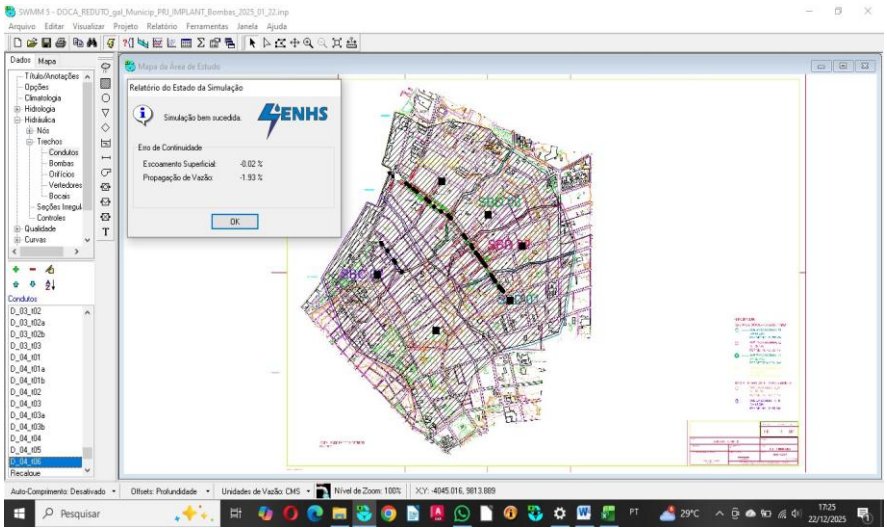
The collected information was inserted into the hydrological-hydrodynamic model of the Armas basin, enabling the execution of the simulation.

4.1.4 Implementation and analysis of the results obtained

Figure 10 below shows the result of the simulation of the Una basin under the effect of rainfall with a recurrence period of 50 years and a pre-tide of 3.02 m.

Figure 10

Result of simulation of the Armas basin in Belém-PA



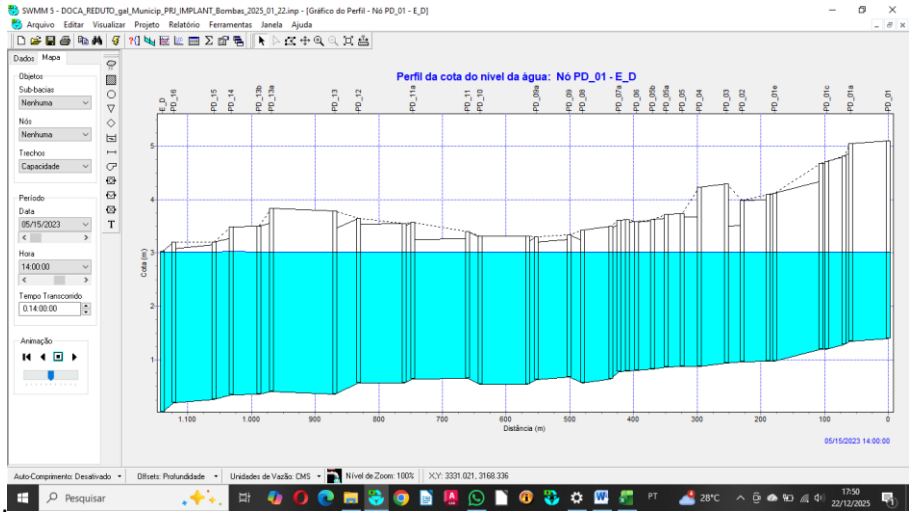
Source: The auhors.

Figure 10 shows the successful result of the simulation of the Armas basin with SWMM, with very small errors, of -0.10% for surface runoff and -1.93% for flow propagation.

Figure 11 shows the Dock Channel at the moment of maximum water depth.

Figure 11

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



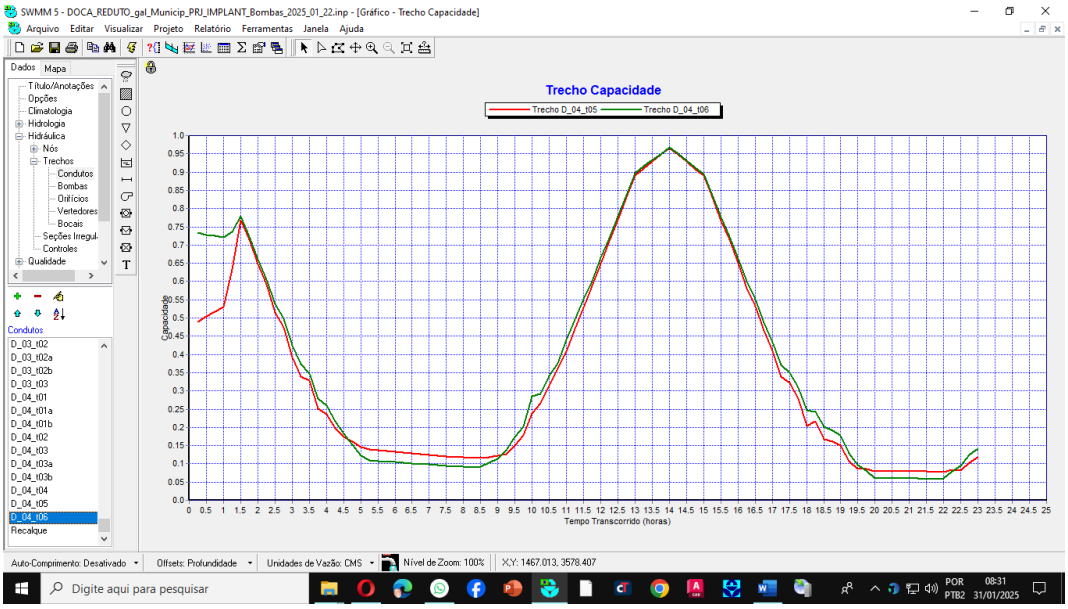
Source: The auhors.

Figure 11 shows that the land near the floodgates presents a risk of flooding.

The analysis of the flow with the aid of the computational model elaborated in the SWMM results in the fact that the most critical stretch for overflow and flooding is the final stretch of the Doca channel, as shown in Figure 12.

Figure 12

Time series of the capacity of the final stretch of the Doca canal

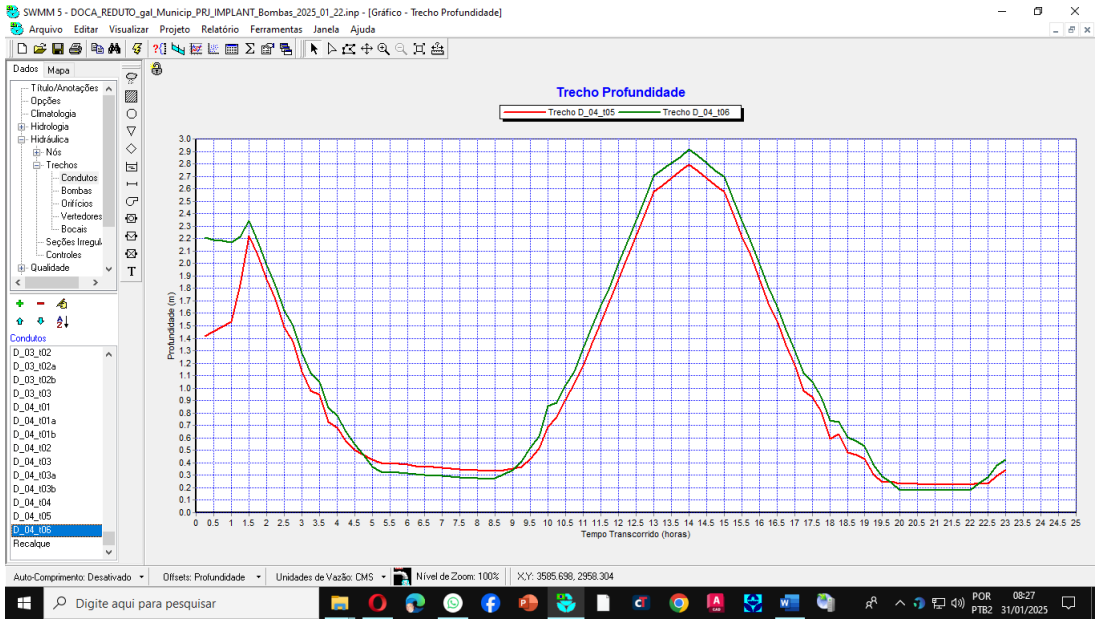


Source: The auhors.

Figure 13 shows that the moment of greatest occupied capacity of the channel, from 85% to 97%, occurs in the interval from 12:45 to 15:15 hours after the beginning of the event.

Figure 13

Time series of depths in the final stretch of the Doca channel



Source: The auhors.

Figure 14 shows the time series of the flow in the final stretch of the Doca channel.

Figure 14

Time series of the flow in the final stretch of the Doca channel

Source: The auhors.

Figure 14 shows that at the moment of maximum occupied capacity of the Dock channel, of 96%, the flow is 4 m3.s-1. As the usual value of 85% is exceeded, the use of booster electric pumps to prevent overflows and flooding is being studied. For this, we opted for the use of the free computational code *Environmental Protection Agency Network Evaluation Tool* (EPANET), also developed by USEPA, and suitable for the study of hydraulic

flows in pressurized conduits. In order to reduce the capacity used in these stretches to up to 85%, in this interval of higher risk of overflow, the insertion of four units of submersible electric pumps was studied, for settlement heights of 7.2mca and individual flows of 0.4m³/s. As an operating rule, they must be activated when the water depth in the section of the lift reaches 2.00m (85% of the capacity of the section) and turned off when it reaches 1.20m (51%), in order to reduce the capacity used in the channel to below 85%, preventing overflows.

Figure 15 shows the proposed location for the Rainwater Pumping Station of the Armas basin (EEAPA), at the confluence of Av. General Magalhães with Rua de Belém, at the end of the Reduto canal, which is connected to the Doca canal by the gallery of Rua Municipalidade.

Figure 15

Proposed location for EEAPA

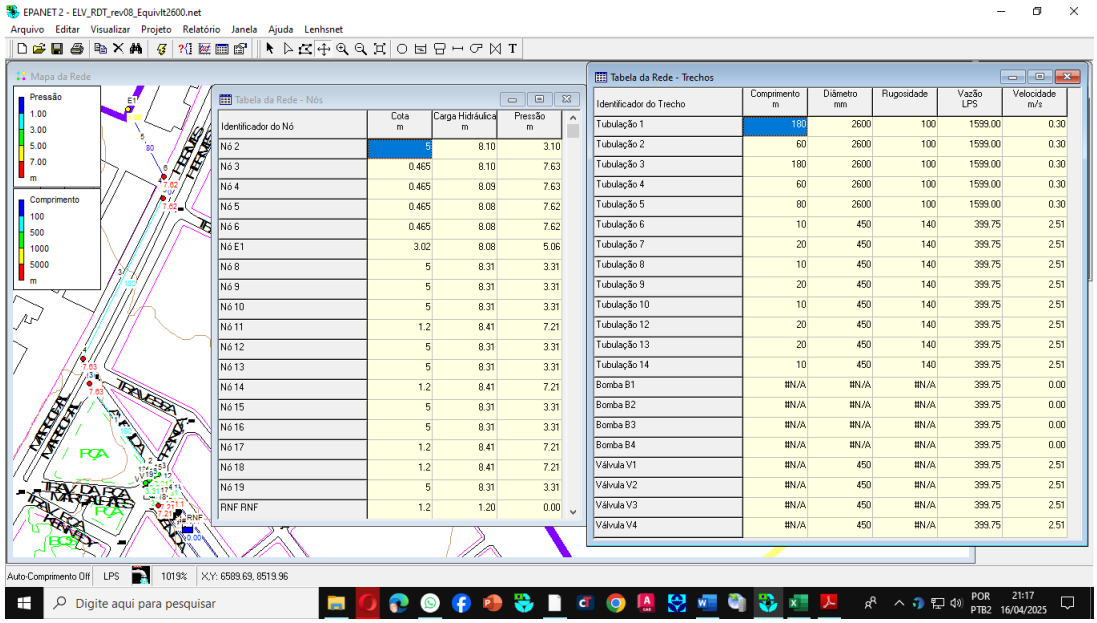
Source: Google Earth (2025).

Figure 15 shows the proposed location of the Armas Basin Rainwater Pumping Station (EEAPA), whose flow will be pumped to the Reduto discharge gallery, located after the floodgates of this channel.

Figure 16 shows the result of the EEAPA simulation in EPANET.

Figure 16

Result of the EEAPA simulation on EPANET



Source: The auhors.

Figure 16 shows the result of the EEAPA simulation in EPANET, considering the use of the drainage gallery of the Reduto channel for the flow of pumped water.

Figure 17 shows the discharge section of the Reduto gallery in Guajará Bay.

Figure 17

Reduto Gallery

Source: The auhors.

Figure 14 shows the image of the drainage gallery of the Reduto channel, in concrete,

with dimensions height 1.60m, width 3.40m and altimetric level of the bottom slab of 0.465m.

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.

5 CONCLUSION

The successful implementation of the Nova Doca Linear Park, in the Armas basin, in Belém-PA as an improvement of urban infrastructure before COP30, was based on the hydrological-hydrodynamic study prepared using a computational model in the SWMM described here.

The constraints of the urban flooding problem were the low elevation of the terrain, which is very waterproofed, the high level of the tides, which suggest the usefulness of the use of floodgates and finally the benefit of the use of electric pumps for rainwater settlement, to prevent overflows and flooding.

The study proved to be very useful, realistically simulating the hydraulic behavior of the basin when subjected to rainfall with a return period of 50 years, precipitation of 172 mm in 24 hours, concomitantly with the maximum known preamar, which occurred in 2010. An important conclusion was the indication of susceptibility to tidal flooding for land with elevation below 3.02m, with bas at the level of the maximum tide, which occurred in 2010,

The computational model resulted in reaching 97% of the capacity in the Dock channel, strongly suggesting the need to use electric pumps to prevent overflows, with the operational indication of maintaining the occupied capacity of the channel at a maximum of 85%.

The implementation of the Armas Rainwater Pumping Station (EEAPA) is an important equipment to prevent/combat overflows and flooding in the Dock Channel (and Reduto), acting at times of high water levels, together with the measures related to altimetric levels and operationalization of the floodgates. In this way, the Armas basin, as explained above, will be equipped with adequate mechanisms to prevent and combat overflows and flooding.

For the implementation of this EEAPA, with the objective of reducing the used capacity of the channel to below 85%, preventing overflows, the installation of four submersible electric pumps in parallel was studied using the EPANET software, and each unit can pump flow rates of 0.4m³/s to settlement heights of 7.2mca. The pumps must be activated when the water depth in the pumping station catchment reaches 2.00m and turned off when it reaches 1.20m,

by automation.

Thus, the computer simulation with SWMM and EPANET allowed to study an extremely relevant problem for the fight and prevention of flooding in Belém-PA and the formulation of appropriate engineering solutions.

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