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Application of the SWMM model for the analysis of urban tunnel flooding in the city of Recife – PE

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ABSTRACT
Floods in urban centers have been recurrent, mainly in urban centers with disorderly growth and a deficient collection network. In this context, the city of Recife-PE is vulnerable to flooding in the event of moderate and heavy rainfall. Thus, the objective was to simulate the insertion of a detention reservoir in the Túnel da Abolição, located in a central area of Recife-PE, through a hydrological-hydraulic model, evaluating its effects in minimizing flooding inside the tunnel, from precipitation events that occurred in the city. For this purpose, data from the local micro-drainage system were obtained from the Recife City Hall and the parameters and variables necessary for the hydraulic-hydrological simulation were defined, such as: delimitation and characterization of the contribution areas, project rainfall and tide. Subsequently, calibration and validation of the model were carried out, which generated satisfactory results, with errors of less than 10%. However, the study site has an unfavorable flow condition, the drainage system concentrates the rainwater collected into the tunnel and the implementation of a detention reservoir, despite reducing volume and height at the control point, is not resolving. Because of this, a monitoring system was suggested as a proposal to anticipate possible pumping failures and avoid flooding.

KEY WORDS: Surface runoff. Hydrological modeling. Urban susceptibility.

1 INTRODUCTION

The new Report of the Intergovernmental Panel on Climate Change of the United Nations (IPCC, 2022), states that in a world scenario urban populations had an increase of more than 397 million people between 2015 and 2020, with more than 90% of this growth occurring in less developed regions. The World Resources Institute Brazil (WRI, 2015), published in its Manual of Urban Development Oriented to Sustainable Transport (DOTS) that the population of less developed regions was affected by being in areas far from large urban centers, the fact that the cities are not connected and do not have a quality public transport service to move to the centers of interest and the rest of the city.

Miyamoto (2010) and Berglund et al. (2020) correlate the increase of population density with the need to implement engineering equipment, such as tunnels, bridges and viaducts, and the use of intelligent infrastructures that allow for faster movement of people. According to Medeiros (2019), the proper functioning of a city depends on systems and infrastructures, such as the transport network, which allow the mobility of goods and people, promoting access to health, work, leisure, housing, among others, ensuring the vitality of the city itself.

In order to favor traffic in cities, it is imperative that Master Plans adopt quality urban infrastructure in their planning so that density generates positive impacts in urban areas and creates more prosperous and sustainable cities (WRI, 2015). For the Brazilian Institute of Geography and Statistics (IBGE, 2010) it is important to emphasize the importance of paving urban roads as an element of improvement for locomotion in cities.

For Mesquita and Lima Neto (2020) and Holanda and Soares (2019), who analyzed the impacts of soil sealing on the hydrology of an urban watershed, it was observed that urbanization without planning has a direct impact on hydrology, as the addition of sealing increases the amount and intensity of flooding and accentuates the volume of surface runoff, which may cause greater inconvenience to the local population and passers-by. Barros (2005), in turn, states that the gradual increase in the volume of surface runoff for the same precipitation index makes the designed drainage system obsolete, making it impossible for adequate drainage of rainwater.

In addition to increased soil sealing, factors such as rising global surface temperatures are directly linked to increased heavy rainfall in some locations and longer periods of drought in others. Thus, given the volume and frequency projections of these extreme precipitations, an increase in the occurrence of floods is expected. (Duarte et al., 2021; Verçosa, 2019).

Study conducted by Wanderley et al. (2018) on the daily precipitation of the city of Recife showed that all months of the year are favorable to the occurrence of extreme daily values, above 50 mm of precipitation, between March and August are more likely. Therefore, this reaffirms the susceptibility of the study area to extreme events of daily rainfall and the relevance of the subject before the planning of the drainage system of the city.

Flooding situations can cause interruptions or reduced performance in the modes of transport, and can interfere directly or indirectly in the behavior pattern of the population and in the distribution of inputs and services in a city, notably in metropolitan regions that are the most vulnerable, since they concentrate most of the collective and individual transport, and where the largest percentage of the population lives (IDTP, 2017).

The drainage solutions of the traditional system usually transfer the problem of flooding to the downstream areas, accelerating the flow of rainwater. Thus since the 1970s there has been a breakthrough in the search and employment of alternative solutions, among them the so-called "compensatory techniques" (Baptista et al., 2015). The use of compensatory techniques can be valid options to reduce flow and consequently flooding. (Kändler, et al., 2022; Zhu et al., 2019).

One way to evaluate the performance of these alternative solutions, before their implementation, is the use of hydrological and hydraulic models (Holanda et al., 2020; Monteiro et al., 2021). The use of hydraulic and hydrological models allows both the verification of the re-dimensioning of drainage systems and the simulation of the use of compensatory techniques, representing a fundamental tool in the management of water resources (Parisi et al., 2020).

One of the hydrological models that has been widely used lately for prognosis of the effects of waterproofing, caused mainly by urbanization, and for simulation of alternatives to reestablish more favorable environmental conditions is the Storm Water Management Model (SWMM). According to Lewis and Michelle (2022) the SWMM is a dynamic model of rainfall-runoff simulation used for single or long-term (continuous) event simulation of the quantity and quality of runoff mainly from urban areas.

In this context, the aim was to insert the existing drainage system of the urban tunnel of a coastal and flat city impacted by precipitation and tidal level, through the use of the hydrological and hydraulic SWMM, and evaluate the drainage behavior of the study site observing if the simulated results were consistent with the observed results and propose, from this model, a solution to minimize the effects of flooding.

2 METODOLOGY

2.1 Characterization of the study area

The City of Recife is located in the state of Pernambuco in the northeastern region of Brazil. It has an estimated population of 1,653,461 inhabitants and an area of 218.5 km², occupying the ninth place in the ranking of the most populous municipalities in the state. It is a

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coastal city geologically constituted by sedimentary rocks and with a relief composed of a plain surrounded by hills. It has a hot and humid tropical climate, with high rainfall during the rainy season from March to August and maximum rainfall of 391 mm in June. It presents a disorganized urbanization process, with the occupation of places unsuitable for habitation, such as floodable areas, hills and slopes, and has drainage system vulnerable to tidal oscillations (IBGE, 2021; Silva Júnior et al., 2020; Verçosa, 2019).

Currently the city has five urban tunnels that are extremely important for the mobility of the inhabitants in the city, so that the interruption of the use of some of these equipments affects mobility. The specific study area is the urban tunnel called the Túnel da Abolição, located at Real da Torre street and that passes under Benfica street (Figure 1). It, which is under the responsibility of the Department of Roads of Pernambuco (DER-PE), is 287 m long, 8.8 m high and is the most recently built, having its works completed in 2015.

Figure 1 - Formatting the margin

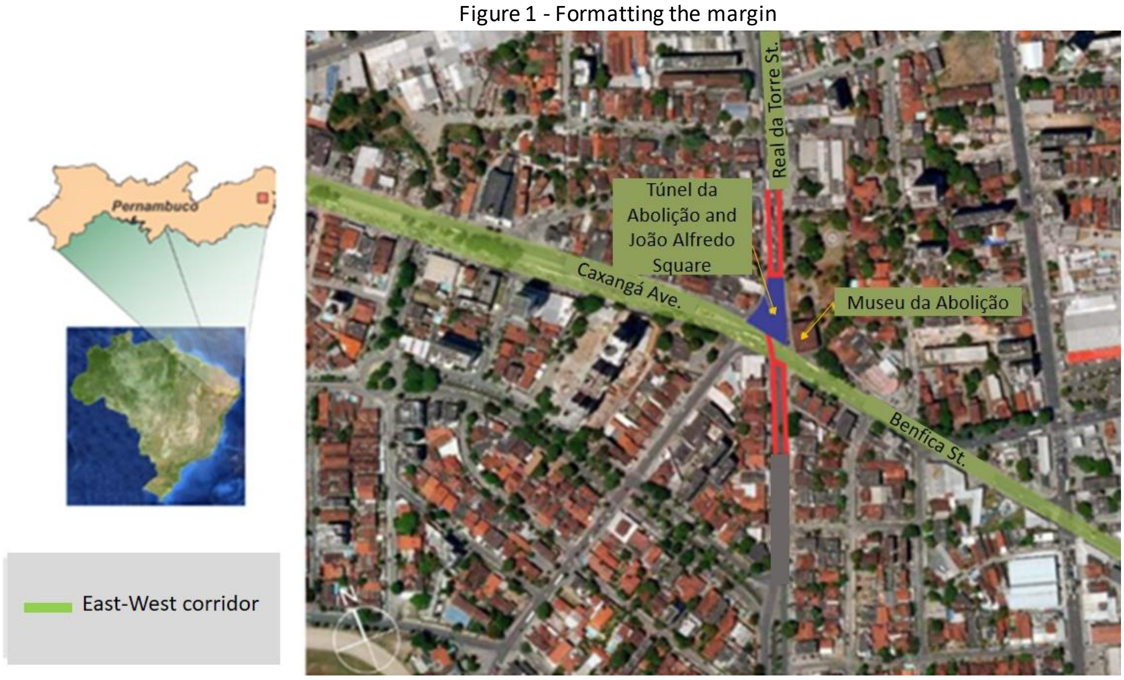

Figure 1 shows the location of the Túnel da Abolição and the East-West Corridor, with the Abolition Museum located next to the tunnel and João Alfredo Square just above it. The objective of the tunnel construction was to eliminate one of the most important intersections in the city, the East-West Corridor intersection with the 2nd Perimetral, in the direction from Torre to Afogados neighborhoods, optimizing one of the main retention points of the Caxangá Avenue/Benfica Street corridor, improving considerably the average speed of mixed traffic and the Caxangá Avenue transport corridor.

The tunnel differs from the others in that the retaining walls are made of 600 mm diameter secant piles. This technology was chosen because of the low level of vibrations emitted, since there are historical buildings in the surroundings, such as the Abolition Museum, which gives the tunnel its name and has an extensive external area with permeable soil. A square

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was set up in the upper and central part of the tunnel to integrate and humanize the surroundings of the Abolition Museum.

2.2 Modeling

The study region was divided into two contribution areas defined from the data available on the electronic platform - Portal of Geographic Information of the city of Recife (Recife City Hall - ESIG) which is under the responsibility of the Municipality of Maintenance and Urban Cleaning of Recife (EMLURB), in which you can extract the city plant in CAD environment and drainage information. The network has information regarding the location of the manholes and their elevations, as well as the dimensions and lengths of the galleries. Nevertheless, since some of these data were found to be missing, they were estimated and replicated by similarity. Other information about the Túnel da Abolição internal drainage project was extracted from its executive project (Government of the State of Pernambuco, 2012).

For the rainfall data, information from the National Center for Monitoring and Alerts of Natural Disasters (CEMADEN) rainfall station located in the Boa Vista district, 1.5 km from the tunnel, was used. For the information on the tide table, the data made available by the Directorate of Hydrography and Navigation of the Brazilian Navy (DHN). With the data, two rainfall events were used in the calibration and validation of the model. For this calibration the parameters were readjusted: 1) Manning's roughness coefficient for the conduits, 2) height of the sediment layer deposited in the conduits and 3) flooded area in the control node, to simulate the hydraulic capacity of the installed network closer to reality. After calibration, the model was validated using another rainfall event and then the possibility of adopting a detention basin in the study area to mitigate flooding was verified.

3 RESULTS

3.1 Precipitation and tide

The precipitation event that was used for calibration occurred on 06/13/2019, causing several inconveniences to the population of the City of Recife. In the 24 h period between June 13 and 14, CEMADEN recorded a total of 149.20 mm of precipitation over Recife, being the sixth largest accumulated rainfall value in 24 h for the month of June since 1961. This precipitation corresponds to 38% of the average rainfall expected for this month (391 mm). A second precipitation event was used in the analysis. This one occurred on 01/14/2022, with an accumulated volume of 91.16 mm, which also caused flooding in several parts of the city and also in the Túnel da Abolição. Figures 2 and 3 show the relation of precipitation and tide by hour intervals, in the respective events.

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Figure 2 - Relation precipitation x tide on the precipitation day of 06/13/2019

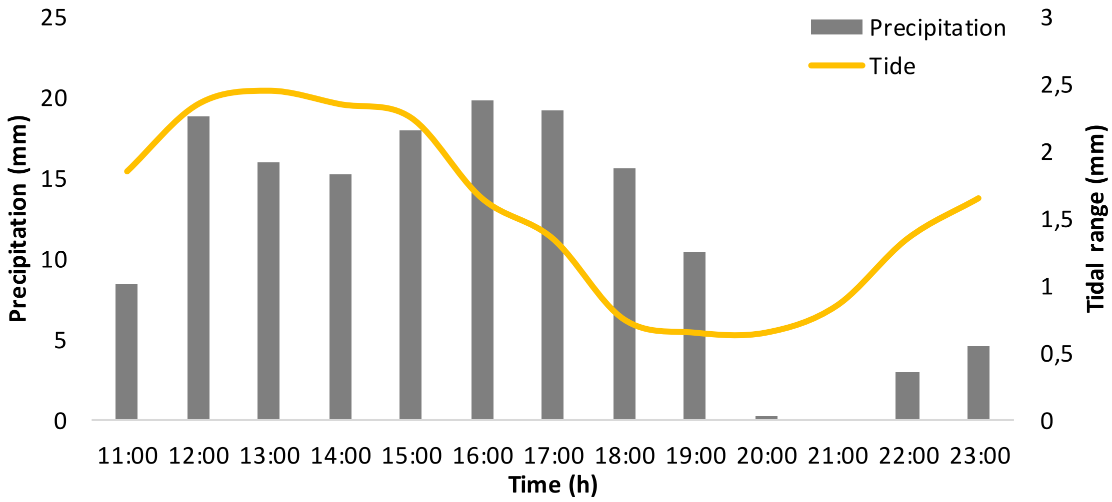
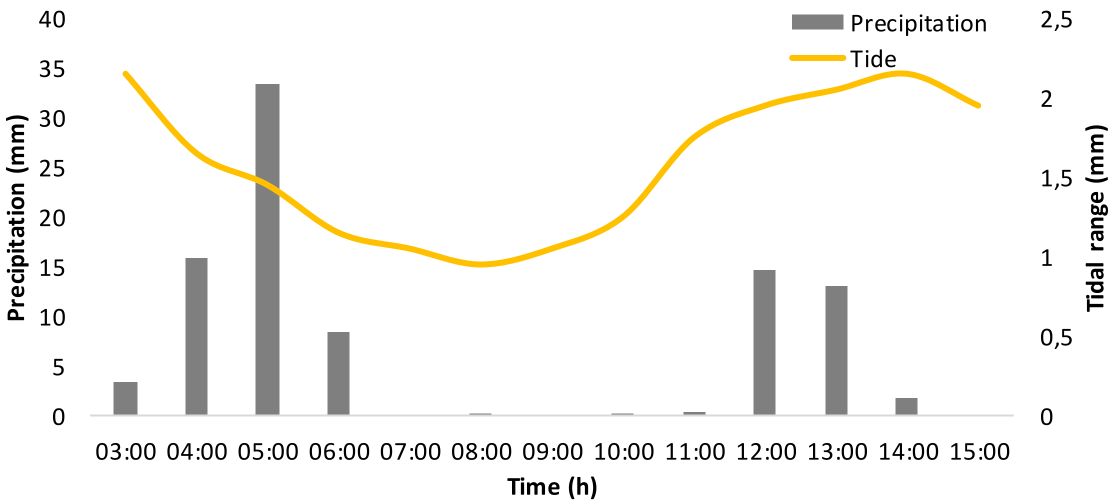


Figure 3 - Relation precipitation x tide on the precipitation day of 01/14/2022



As shown in Figure 2, referring to the event of 06/13/2019, there was a period of eight hours of uninterrupted precipitation, totaling 142 mm, and in the middle of this period, the tide reached a maximum height of 2.50 m. For the event of 01/14/2022, Figure 3 shows that there was a higher rainfall concentration than between three and six hours, and a total of 61.05 mm was measured. In the hour of greatest precipitation the tide was with height of 1.50 m, and despite the interval without rainfall between 7 and 11 h, the precipitation returned around 12 h, coinciding with the rise of the tide.

3.2 Existing Drainage Network

Figure 4 shows the image of the Túnel da Abolição (A) and the drainage network layout of the study site (B), respectively.

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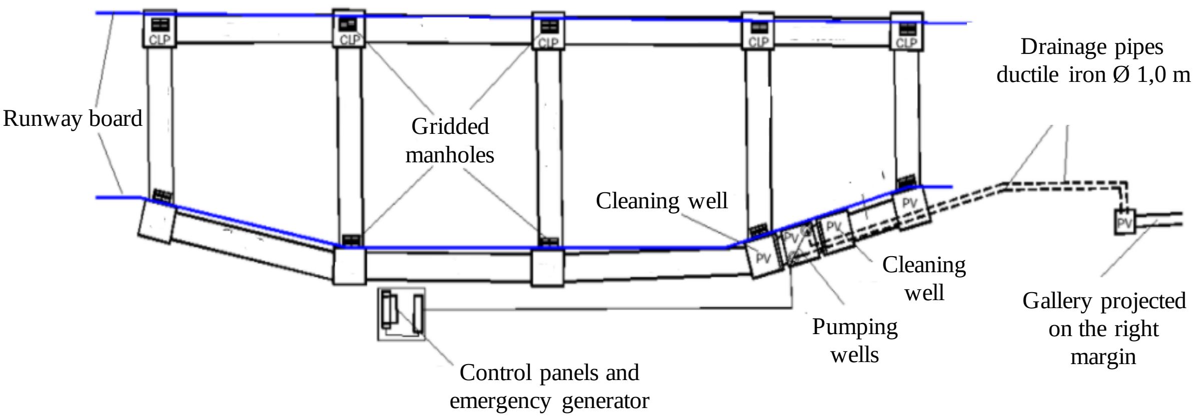
Figure 4 - A) Image of the Túnel da Abolição and B) its drainage network layout

The Túnel da Abolição, Figure 4A, presents a much lower level, when compared to the level of the adjacent streets, Figure 4B. The highlighted layout represents the main trunk sewer, which has 600 mm of diameter and starts at the Real da Torre Street and continues until its outlet in the existing channel at the João Ivo da Silva Street, receiving the contribution of the sewer system coming from the Hercílio Cunha Street.

Because the tunnel is located at a lower elevation, it was necessary to adopt a pumping system to redirect the accumulated water, represented in Figure 5, in horizontal projection.

Figure 5 - Drainage Scheme of the Túnel da Abolição Reservoir



At the lowest point of the runway a drainage system was built with a double function of conduction and storage of accumulated water, through concrete pipes with a constant diameter equal to 1.5 m and a storage capacity of 265 m³. Currently there are two six hp pumps and another reserve pump of four hp. However, due to constant theft of wiring and other intrinsic to the power supply network, the operation of the pumps ends up not being effective, and in the occurrence of rainfall, the system does not work satisfactorily in draining the water, resulting in flooding of the tunnel.

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In addition, the plaza at the top and center of the tunnel, which consists of seven raised beds with grass that are interspersed with fenced areas for lighting and ventilation, also contributes to this situation, as illustrated in Figure 6.

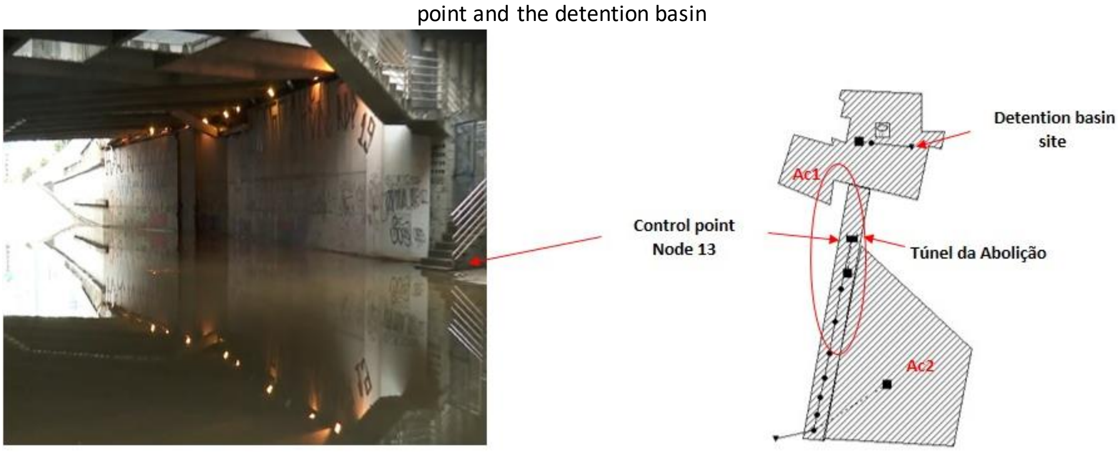
Figure 6 - Detail of the open areas for ventilation and illumination (A) and inside the tunnel during the rainy season (B).

In periods of precipitation, the beds accumulate water and direct it into the interior of the tunnel, which cascades through the gridded openings, making it difficult, at times of greater flow, for passersby to move around.

3.3 Application of the SWMM model

To simulate the current functioning of the drainage system the contribution areas and the drainage system were considered and entered into the SWMM software, Figure 7.

Figure 7 - Image of the tunnel interior, from 06/13/2019, and representation of the contribution areas, the control point and the detention basin



The insertion of the model in the SWMM software aims to represent the current functioning of the drainage system, considering the flooding at the Junction "Node 13" defined as a control point. In it the parameter for the maximum simulated flooding volume would be

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compatible with that observed and calculated on site during the rainfall events, without considering the existence of the pumps, since in both events they were out of operation.

This same procedure had also been adopted by other authors who studied flooding problems in Recife such as Silva (2018), who used hydrological-hydraulic modeling for flood mitigation in the surroundings of the Polytechnic School of Pernambuco; Oliveira (2017), who studied compensatory alternatives for urban drainage in a critical point of the city of Recife; Silva Júnior, Silva and Cabral (2014), who studied compensatory alternatives for flood control in urban areas with tidal influence in Recife; Silva Júnior (2015), who studied alternatives for flood control in Recife-PE; and Silva and Cabral (2014), who studied peak flow attenuation in a problem area, conducting a comparative study of detention reservoirs in lots, on streets and in a large area of the basin.

For both the calibration and the validation of the model, water heights were observed in photos and videos during the flooding that occurred during precipitation events, and from there the heights of this flooding at the control point were measured in loco.

On 06/13/2019, an event used for model calibration, it was obtained from the photographic records and the city plan in a CAD environment an approximate flooding area of 917 m². The maximum water depth height of 0.50 m at the control point was verified through photographic records and confirmed in loco. To define the volume of flooding, it was considered the equivalence between the delimited flooding area (917 m²) and the maximum water depth height observed (0.50 m) at the control point, replicating the water depth in the topographic design of the tunnel profile, whose product between these factors results, in estimative terms, in the flooded volume, which added to the volume of storage pipes (265 m³) resulted in an estimated total volume of 621 m³.

Table 1 below presents the main results obtained for the model calibration and validation.

Table 1 - Main results obtained for the model calibration and validation

		Calibration – event of 06/13/2019			Validation - event of 01/14/2022		
Aspects		Observed	Simulated	Relative Error (%)	Observed	Simulated	Relative Error (%)
Maximum Flooding Blade (m)		0.50	0.50	0.00%	0.45	0.49	8.89%
Maximum flooding volume (m³)		621	614	1.14%	585	540	-7.72%
Continuity Errors for:	Surface Runoff	-	-	0.00%	-	-	0.00%
	Flow propagation	-	-	1.01%	-	-	1.17%

As shown in Table 1, during calibration it was possible to reach a simulated flooding height of 0.50 m at the control point (Node 13) and a maximum volume of 614 m³, presented errors of 0% and 1.14% respectively for these parameters. At the end of the calibration step, a mean continuity error for surface flow of 0% and 1.01% was obtained for flow propagation. After the calibration, it was used the same modeling defined in the calibration, that is, without changing the physical parameters of the model, modifying only the precipitation series and the tide curve for the data measured for this day. Relative errors of 8.89% were obtained for flooding height, since the blade was 0.04 m higher than that observed and -7.72% for the maximum

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volume generated, since the volume of flooding was 45 m³ lower than that observed. In addition, they presented average continuity error for surface flow of 0% and 1.17% for flow propagation.

The previously cited works of Silva (2018), Oliveira (2017), Silva Júnior et al. (2017), Silva Júnior (2015) and Silva and Cabral (2014), adopted as admissible the limit of 10% for distortions. In view of this, it can be seen that the quality of the calibration and validation were satisfactory, with errors below the 10% limit both between height and volume of flooding, and for continuity (surface runoff and flow propagation).

3.4 Evaluation of the use of the compensatory technique

The Túnel da Abolição already presents in its design a control measure at the source, which is the adoption of storage conduits, whose function is to retain and conduct the captured water to a pumping well, from where the water is directed to its outflow. In this context, it was simulated the insertion of a detention basin beside the tunnel, on the museum site, as shown in Figure 7.

As the study area is situated next to a Museum, which has an extensive permeable outdoor area, the amphitheater site (a circular area surrounded by open-air steps), could function as a detention basin and part of the water collected in Contribution Area 1 (Ac1), which precedes the Tunnel, would be conveyed to this detention basin.

Table 2 below shows the comparative results for rainfall on 6/13/2019 with and without the implementation of the proposed detention basin.

Table 2 - Comparison between the results obtained for the 6/13/2019 rainfall events without and with the Detention Basin

Aspects		Without detention basin	With detention basin	Relative Difference (%)
Maximum Flooding Blade (m)		0.50	0.43	-14.00%
Maximum flooding volume (m³)		614	506	-17.66%
Duration of flooding (h)		10.79	9.90	-8.25%
Continuity Errors for:	Surface Runoff	0.00%	0.00%	-
	Flow propagation	1.01%	0.38%	-

As simulation results, presented in Table 2, it was observed that the maximum flooding blade and the maximum flooding volume decreased respectively by 14% and 17.66% for the rainfall event on 06/13/2019. In addition, there was a decrease in the flooding time of one hour in relation to the scenarios without and with the detention basin. However, even with the adoption of the detention basin, the simulations showed that the adoption of the compensatory technique would not be sufficient to solve the problem of flooding, considering that the height of the water depth at the control point would reach 0.43 m, sufficient height to cover the tire of a passenger car, indicating that the use of this measure is not the most appropriate to solve the problem.

Considering that the tunnel's profile is much lower than the level of the adjacent streets, it itself works as a reservoir and, even with a smaller volume, the accumulated water still has a high blade that makes its use unfeasible. Therefore, a pumping system with greater efficiency and effectiveness is necessary, with monitoring of the level of the reservoirs where the water is drained and remote control of the booster pumps in the tunnels so that they are activated when they reach high levels of accumulation. Furthermore, it is important to have a permanent monitoring system in case of pump failures, so that malfunctions are noticed in advance and can be resolved before potential flooding situations.

3.5 Financial Analysis

To complement the study, a financial analysis was performed by adjusting the value of the bid held in June 2020 (Government of the State of Pernambuco, 2020) for the implementation of a tunnel monitoring system in the city of Recife. The result achieved in the analysis totaled, in current values, R$ 314,133.63.
To implement this system, a panel is required to drive the drainage pumps by soft-Starter or inverters. The starting control of the pumps is performed by ultrasonic level transmitters and driven according to the level of the reservoirs through a programmable logic controller (PLC). The PLC comes with a GSM modem (Global Mobile Communications System) thus incorporating data from pumps and reservoir levels that are transmitted to a server. With this data reaching the customer it is possible to monitor the status of pumps, reservoir levels, alarm history and trends via graphical screens.

4 CONCLUSIONS

During the study of the site, it was found that it has an unfavorable flow condition, due to the underground drainage system concentrating all the rainwater collected into the tunnel, due to the design principles of the project. In addition, there is dependence on the pumping system for the flow of water, which is vulnerable and does not have a control system that informs in advance of possible failures. Demonstrating that the design of the designed drainage system and the lack of monitoring can be one of the causes of recurrent flooding in the studied area.

The scenarios simulated in SWMM were adherent to portray the existing drainage network of the study area, therefore, the quantitative analyses presented express the reality of the system. With the simulation of the implementation of a detention basin that would receive the volume of water captured from the contribution area Ac1, a reduction in the volume and height of flooding at the control point was verified, as well as a 10% reduction in the flooding time, although insufficient to solve the tunnel problem in such a way as to avoid its interdiction.

For effective resolution of the flooding problem, it is suggested the adoption of a real-time monitoring system to control the tunnel's pumping system. Even so, it is worth noting that such a system would still be sensitive to power outages, in addition to the fact that the city is a constant target of acts of vandalism and theft, which could also interrupt this monitoring.

It also reinforces the importance of the correct design of projects, where there is an interconnection between the disciplines of architecture, infrastructure and drainage. There are a number of legal instruments that guide the issue of rainwater. In addition, the use of hydraulic and hydrological models can make it possible to verify the design of drainage systems, including the simulation of using compensatory techniques.

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5 REFERENCES

BAPTISTA, M., NASCIMENTO, N.; BARRAUD, S. **Técnicas Compensatórias em Drenagem Urbana**. Porto Alegre: Editora ABRH, 2015.

BARROS, M. T. L. **Drenagem urbana**: bases conceituais e planejamento. Saneamento, saúde e ambiente: fundamentos para um desenvolvimento sustentável. Tradução. São Paulo: Universidade de São Paulo, Faculdade de Saúde Pública/Núcleo de Informações em Saúde Ambiental, 2005.

BERGLUND, E. Z.; MONROE, J. G.; AHMED, I.; NOGHABAEI, M.; DO, J.; PESANTEZ, J. E.; FASAEE, M. A. K.; BARDAKA, E. HAN, K.; PROESTOS, G. T.; LEVIS, J. Smart Infrastructure: A Vision for the Role of the Civil Engineering Profession in Smart Cities. **Journal of Infrastructure Systems**, v. 26, n. 2, p. 1-32, 2020.

DUARTE, T. L. S.; SANTOS, G. C.; CASTELHANO, F. J. Eventos de chuvas extremas associados aos riscos de inundações e de alagamentos em Aracaju, Sergipe. **GEOSABERES**: Revista de Estudos Geoeducacionais, v. 12, n. 1, p. 256-271, 2021

Diretoria de Hidrologia e Navegação. Ministério da Marinha, DHN-MB. Tábuas de Marés para 2022. Rio de Janeiro. 2022. Disponível em: https://www.marinha.mil.br/chm/dados-dosegnav-publicacoes/tabuas-das-mares. Acesso em: 01 fev. 2022.

Governo do Estado de Pernambuco. Corredor de Transporte Público Leste-Oeste. Projeto Executivo do Túnel da Abolição. Volume 1 - Memória Justificativa e Plano de Execução da Obra. Novembro. Recife 2012.

Governo do Estado de Pernambuco. Mapa de Obras 1 Trimestre. Recife, 2020. Disponível em: http://transparencia.recife.pe.gov.br/uploads/pdf/20210419-OF.158-21-MAPA_OBRAS 1TRIMESTRE_ 8d17d79088950ff2 d48d0f049f16a034.pdf. Acesso em: 10 fev. 2022.

HOLANDA, M. A. C. R.; SOARES, W. A. Analysis of the effect of impermeability of urban soils on the infiltration of rainwater in the city of Recife, PE. **Ambiente e Água**, v. 14, n. 4, p. 1-10, 2019.

HOLANDA, M. A. C. R.; OLIVEIRA, D. B. C.; SOARES, W. A.; SILVA, S. R. Analysis of the Viability of Implementing Sustainable Proposals to Reduce Tunnel Flooding in Recife, Pernambuco. **Revista Brasileira de Geografia Física**, v. 13, n. 4, p. 1904-1913, 2020.

IBGE. **Pesquisa Nacional de Saneamento Básico (PNSB) – 2008**. IBGE: Rio de Janeiro, 2010. 219p.

IBGE. Estimativa populacional 2021. Disponível em http://www.ibge.gov.br. Acesso em: 01 jun. 2022.

IDTP. INSTITUTO DE POLÍTICAS DE TRANSPORTE E DESENVOLVIMENTO. Estudo Técnico - Adaptação às Mudanças Climáticas na Mobilidade Urbana (2017). Disponível em https://antigo.mdr.gov.br/images/stories/ArquivosSEMOB/ArquivosPDF/Estudo_Técnico_-_Adaptação_às_mudanças_climáticas_na_Mobilidade_Urbana.pdf. Acesso em: 07 jan. 2022.

IPCC. Intergovernmental Panel on Climate Change. Climate Change 2022: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 2022.

KÄNDLER, N.; ANNUS, I.; VASSILJEV, A. Controlling peak runoff from plots by coupling street storage with distributed real time control. **Urban Water Journal**, v. 19, n. 1, p. 97-108, 2022.

LEWIS, A. R.; MICHELLE, A. S. Storm Water Management Model User's Manual Version 5.2 February 2022, 424p. Disponível em: https://www.epa.gov/system/files/documents/2022-04/swmm-users-manual-version-5.2.pdf. Acesso em: 07 jun. de 2022.

MEDEIROS, Camila Santos. **Vulnerabilidade dos Sistemas de Transporte em áreas de inundação**: uma mudança nos padrões de mobilidade e a busca pela adaptação às alterações climáticas. 2019. Dissertação (Mestrado em Urbanismo Sustentável e Ordenamento do Território). Faculdade de Ciências e Tecnologia, Universidade Nova Lisboa, Lisboa, Portugal, 2019.

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MESQUITA, J. B. F.; LIMA NETO, I. E. Impacto da impermeabilização na hidrologia de uma bacia urbana. *In*: ENCONTRO NACIONAL DE ÁGUAS URBANAS, XIII.,19 e 20 out. 2020, Porto Alegre, Rio Grande do Sul, Brasil. **Anais** [...]. Porto Alegre: Rio Grande do Sul, 2020.

MIYAMOTO, James Shoiti. **Grandes túneis urbanos**: uma proposta de gestão ambiental. 2010. Dissertação (Mestrado em Engenharia Ambiental). Universidade do Estado do Rio de Janeiro, Rio de Janeiro, 2010.

MONTEIRO, V. V.; Silva, S.; SANTOS, F. C. V.; SOUZA, A. C. SWMM – Modelo de aplicação de modelagem hidrológica para as cidades. In. Gestão da Produção em Foco. Belo Horizonte: Poisson, 2021, pp. 57-63.

OLIVEIRA, R. L. M. **Alternativas Compensatórias para drenagem Urbana em ponto crítico da cidade do Recife – PE**. 2017. Dissertação (Mestrado em Engenharia Civil). Escola Politécnica da Universidade de Pernambuco, 2017.

PARISI S. A.; SOARES, W. A.; FILHO, C. D. R. Análise da capacidade de infiltração para atenuação de alagamento em um ponto crítico na cidade do Recife Recife-PE. **Revista Águas Subterrâneas**, v. 34, n. 2, p. 236-249, 2020;

SILVA. Alisson Caetano. **Modelagem hidrológica-hidráulica para atenuação de alagamentos no entorno da Escola Politécnica de Pernambuco**. 2018. Dissertação (Mestrado em Engenharia Civil). Escola Politécnica da Universidade de Pernambuco, 2018.

SILVA JÚNIOR, M. A. B., SILVA, S. R.; CABRAL, J. J. S. P. Compensatory alternatives for flooding control in urban areas with tidal influence in Recife - PE. **Revista Brasileira de Recursos Hídricos,** v.22, n. 19, p. 1-12, 2017.

SILVA JÚNIOR, M. A. B. **Alternativas compensatórias para controle de alagamentos em localidade do Recife-PE**. 2015. Dissertação (Mestrado em Engenharia Civil). Escola Politécnica da Universidade de Pernambuco, 2015.

SILVA, P. O., CABRAL, J. J. S. P. Atenuação de picos de vazão em área problema: estudo comparativo de reservatórios de detenção em lote, em logradouros e em grande área da bacia. **Revista Brasileira de Recursos Hídricos**, v. 19, n. 2, p. 7-18, 2014.

VERÇOSA, L. F. M. **Modelagem Hidrológica e hidrodinâmica aplicada à avaliação da ocorrência de inundações na cidade do Recife, PE**. Dissertação (Mestrado em Engenharia Civil). Centro de Tecnologia e Geociências, Universidade Federal de Pernambuco, 2019.

WANDERLEY, L. S. A.; NÓBREGA, R. S.; MOREIRA, A. B.; DOS ANJOS, R. S.; ALMEIDA, C. A. P. As chuvas na cidade do Recife: uma climatologia de extremos. **Revista Brasileira de Climatologia**, v. 22, p. 149-164, 2018

WRI. World Resources Institute Brasil. Manual de Desenvolvimento Urbano Orientado ao Transporte Sustentável. Brasil, 2015. Disponível em: https://wricidades.org/sites/default/files/DOTS%20Cidades.pdf. Acesso em: 03 jan. 2022.

ZHU, Z.; CHEN, Z.; CHEN, X.; YU, G. An assessment of the hydrologic effectiveness of low impact development (LID) practices for managing runoff with different objectives. **Journal of Environmental Management**, v. 231, p. 504-514, 2019.