UFSM

CIÊNCIA e NATURA

ISSN 2179-460X68751
OPEN ACCESS

Ci. e Nat., Santa Maria, v. 45, e16, 2023 • https://doi.org/10.5902/2179460X68751
Submitted: 04/12/2022 • Approved: 13/02/2023 • Published: 11/10/2023

Environment

Study of the hydrological impact of the growth of a residential neighborhood on urban drainage – A case study at the city of Macaé, Rio de Janeiro, Brazil

Estudo do Impacto hidrológico do crescimento de um bairro residencial na drenagem urbana – Estudo de caso na cidade de Macaé, Rio de Janeiro, Brasil

Laise Novellino Nunes de Souza[I], **Jader Lugon Junior**[I]

[I] Instituto Federal Fluminense, Rio de Janeiro, Brazil

ABSTRACT

This paper aimed to study the drainage system of a residential neighborhood through a case study. Thus, a sensitivity analysis of drainage was carried out considering the progress of the urbanization process in the Imboassica district, in the municipality of Macaé, Rio de Janeiro. It was possible to evaluate the model's response to different land use planning, represented with variations in the Manning coefficient and also in the Curve Number. The MOHID platform was used along with the OpenFlows FLOOD® software interface to elaborate scenarios with different soil characteristics, and distinct Digital Elevation Model (DEM) were adopted. In the first evaluation, three simulations (1, 2 and 3) were performed considering the natural topography of the terrain, using altimetry data obtained from the TOPODATA project of the National Institute for Space Research (INPE). Afterwards, the elevation quota represented in the Digital Elevation Model (DEM) was raised by 10 meters in the locations corresponding to the location of the houses and by 1 meter in the roads of the residential condominium, and then the three simulations (4, 5, and 6) were performed. The six simulations adopted the 10 years return period Rain Design. After that, another set of six simulations were performed, adopting the 50 years return period Rain Design. It was possible to observe that in the simulations considering the change in the elevations due to the presence to the houses and the road, the calculated value of the water depth increases in the drainage channels. The effect of the Curve Number changes was observed in the flood peak simulation, which is reduced due to the presence to greater vegetation. And finally, it was possible to observe the effect of the change in the Manning's Coefficient, whose increase caused a delay in runoff.

Keywords: Urban Drainage; MOHID; Open Flows; Curve Number; Manning's Coefficient

RESUMO

Este trabalho teve o objetivo de estudar o sistema de drenagem de um bairro residencial por meio de um estudo de caso. Assim, foi realizada uma análise da drenagem considerando o avanço do processo de urbanização no bairro Imboassica, no município de Macaé, Rio de Janeiro. Foi possível avaliar a resposta do modelo para diferentes condições de uso do solo, representados com variações no coeficiente de Manning e também de *Curve Number*. Foi utilizada a plataforma MOHID contando com a interface do software OpenFlows FLOOD® para elaborar cenários com diferentes características de solo, e adotou-se duas topografias distintas. Na primeira avaliação foram feitas três simulações (1, 2 e 3) considerando a topografia natural do terreno, utilizando-se dados de altimetria obtidas a partir do projeto TOPODATA do Instituto de Pesquisas Espaciais (INPE). A seguir, a cota de altitude representada no *Digital Elevation Model* (DEM) foi elevada em 10 metros nos locais correspondentes a localização das casas e 1 metro nas estradas do condomínio residencial e, então, foram refeitas as três simulações (4, 5, e 6). As seis simulações adotaram uma chuva de projeto de 10 anos de período de retorno. Por fim, mais seis simulações foram feitas tendo sido adotada uma chuva de 50 anos de período de retorno. Foi possível observar que nas simulações com a alteração nas elevações correspondentes às casas e à estrada, o valor calculado para a lâmina d'agua aumenta nos canais de drenagem. O efeito das alterações no *Curve Number* foi observado na simulação do pico de cheia, que é reduzido conforme uma área maior é considerada como coberta de vegetação na simulação. E finalmente, foi possível observar o efeito da mudança no Coeficiente de Manning, cujo aumento provocou um atraso do escoamento superficial.

Palavras-Chave: Drenagem Urbana; MOHID; OpenFlows; Curve Number; Coeficiente de Manning

1 INTRODUCTION

Management of the stormwater network is one of the most important aspects of developed cities due to changes in the permeability of the ground's surface and water percolation. Urban growth tends to increase impermeable surfaces due to the construction of roads and buildings. These impermeable areas, as a consequence, generate surface water accumulation, which causes urban flooding (Abd-Elhamid et al., 2020) which is among the most important factors that affect the design of storm water drainage systems. Changing the runoff coefficient will affect the design parameters of the drainage network, including outfall discharge, velocity, lag time and cost of construction. This study aims to assess the effect of changing the runoff coefficient due to urban growth on the design of a storm water drainage system. The hydrological models Hyfran, StormCAD and GIS are used to analyze different runoff coefficients. This study examines three zones in Dammam in the Kingdom of Saudi Arabia (KSA.Urbanization drastically alters the hydrological dynamics of coastal cities. The constructions create impermeable surfaces extended on permeable sandy soils, consequently, making it difficult to recharge aquifers with rain and increasing the retention of surface water (Garzo, Dadon & Castro, 2019).

Evapotranspiration, infiltration and water interception decreased after trees and other plants were deforested in the development process. Most of the rainwater is transported out of urban regions through the urban drainage system and finally discharged into rivers. Rivers tend to receive more water in the rainy season, resulting in frequent flooding. Nonetheless, due to the low water table recharge, it can be drier in the other periods of the year (Suripin et al., 2018).

The city of Macaé has suffered from the occurrence of flash floods, and therefore, it is considered an appropriate place to carry out studies aimed at mitigating urban floods (Tavares et al., 2018). The Imboassica neighborhood is a suitable place for the study of water runoff and infiltration, due to its current stage of development, in which it has not yet been fully urbanized and there is the possibility of applying different techniques to assist in flood containment measures. It is important to mention that the Macaé River Basin Committee included, in the Water Basin Plan, the need to invest in studies to increase knowledge and assess possible improvements to the existing drainage system. Such contribution of knowledge is applicable in actions to mitigate flooding as demanded in the revision of the Municipal Basic Sanitation Plan of Macaé, pages 66 and 68 (Saad, Cavalcante & Mendes, 2020).

The MOHID platform has been developed for oceanic and hydrological applications since 1985. It is possible to obtain computational modelling results for hydrodynamic and ocean transport simulations using MOHID WATER and for hydrological simulations on the watershed using MOHID LAND. The platform is available as an open and free programming code, being produced at MARETEC at the Superior Technical Institute of the University of Lisbon. One of the MOHID platform interfaces was developed by Bentley© and it is called OpenFlows FLOOD©.

The OpenFlows FLOOD© system is a commercial software that consists of an interface that allows: (i) to easily create a model using the MOHID platform codes; (ii) run the simulations and; (iii) visualize the results obtained. The MOHID platform has several computational resources to model hydrodynamics, hydrology, substance transport, considering the phenomena of interest to researchers, and with the possibility of adopting different formulations depending on the application. More specifically, dealing with the case of interest for this study, MOHID LAND can be used to simulate surface runoff and water infiltration into the soil (Junior, Costa & Rodrigues, 2016; Simionesei et al., 2016; Campos et al., 2017; Paiva et al., 2017; Garneau, Duchesne & St-Hilaire, 2019; Junior et al., 2019).

According to Trancoso et al. (2009), the use of simulation software, such as MOHID LAND, allows an integration between different hydrological processes, which will generate a prognosis of the system, and may help in selecting the best urban drainage technique.

2 OBJECTIVE

The general objective of this research is to study the urban drainage system of a residential neighborhood through a case study in the city of Macaé, Rio de Janeiro. Thus, a sensitivity analysis of the drainage was carried out considering the progress of the urbanization process in the Imboassica district. For this, the specific objectives are: Evaluate the model's response to different land use conditions, modifying the values adopted for the Manning Coefficient and the Curve Number in the model, evaluate the model's response considering two different Digital Elevation Model (DEM) and considering two Rain Design for 10 and 50 years return period.

3 MATERIAL AND METHODS

The MOHID platform was used with the OpenFlows FLOOD® software interface to elaborate scenarios with different soil characteristics, and two distinct topographies were adopted. In the first evaluation, three simulations (1, 2 and 3) were performed considering the natural topography of the terrain using altimetry data obtained from the TOPODATA project of the National Institute for Space Research (INPE). Next, the elevation quota represented in the Digital Elevation Model (DEM) was raised by 10 meters in the locations corresponding to the location of the houses and by one meter in the roads of the residential condominium, and then the three simulations (4, 5, and 6). The six simulations adopted 10 years periods of return Rain Design. Finally, six more simulations were performed, adopting a 50 years periods of return period Rain Design.

To study the transport of water in the drainage channels formed in the model according to the soil characteristics in the region of interest, different values of Manning Coefficient were adopted. The Manning Coefficient seeks to reflect the roughness of the channel and its interference with the water flow (ZHANG et al., 2019). The values used in this study were taken from Gribbin (2014) on pages 390, 391 and 392. In Table 1 are represented the values for the Manning Coefficient that are used in this study.

Table 1 – Values for the Manning roughness coefficient that used in the study

Manning's Roughness Coefficients [m^(-1/3)/s]	
Closed manholes └> (A) Polyvinyl Chloride (PVC)	0.007-0.011
Natural Channels (Watercourses) └> (A) Smaller watercourses └> Fairly regular section └> A little grass and herbs, little or no weeds	0.030-0.035
Natural Channels (Watercourses) └> (A) Smaller watercourses └> Fairly regular section └> Dense grass growth, depth of runoff significantly greater than grass height	0.030-0.050

Source: Gribbin (2014)

In order to model the surface runoff of the studied regions according to the soil, the formulation with the Curve Number was used. The Curve Number is a parameter used to describe the potential of surface runoff water, considering the losses that occur partly by the volume of water that infiltrates (percolating into the porous soil medium) and also partly by evapo-transpiration, being lost to the atmosphere by evaporation and transpiration of plants. The Curve Number therefore depends on the characteristics of the soil and its coverage (Fernandes, Costa & Studart, 2017).

The Curve Number is mainly about representing different hydrological conditions, being adjusted according to four different types of soil and different patterns of use and occupation. The quantification of this parameter is done through a series of pre-established values (Miguez, Veról & Rezende, 2016).

To understand the adopted soil groups, the values established in the book of Miguez, Veról and Rezende (2016) on page 55 were used, as shown below, in Table 2.

Table 2 – Table with soil types

Soil hydrological groups	
Group A	Sandy soils, with low total clay content (less than 8%), without rocks, without clayey layer and not even densified to a depth of 1.5m. The humus content is very low, not reaching 1%
Group B	Sandy soils that are less deep than those in group A and have a lower total clay content, but still less than 15%. In the case of purple earths, the limit can go up to 20% thanks to the greater porosity. The two humus contents can rise to 1.2% and 1.5% respectively. There can be no gravel or clay layers up to 1.5m, but a layer more densified than the surface layer is almost always present.
Group C	Muddy soils, with a clay content of 20% to 30%, but without impermeable clayey layers or containing gravel to a depth of 1.2m. In the case of purple earths, these two maximum limits can be 40% and 1.5m. At about 60cm in depth, a layer is more densified than in group B, but still far from the impermeability conditions
Group D	Clayey soils (30% to 40% of total clay) and with a densified layer approximately 50 cm deep or sandy soils such as B, but with an almost impermeable clayey layer or horizon of rolled pebbles

Source: Miguez, Verol and Rezende (2016)

In the value used for the vegetated area, considered as Forest or Wood, for the Curve Number, 50 was chosen instead of 55 due to the presence of a sandy clay soil in the region, but with good depth. The values used in this study were taken from Gribbin (2014), more specifically, on pages 448 and 449, presented in Table 3.

Table 3 – Part of the Table with values used for the Curve Number

Description of coverage	**Groups**			
Type of coverage and hydrological condition	A	B	C	D
Impervious areas: Paved; open ditches	83	89	92	93
Woodland: Woodland protected from grazing, and bush adequately cover the ground	30	55	70	77

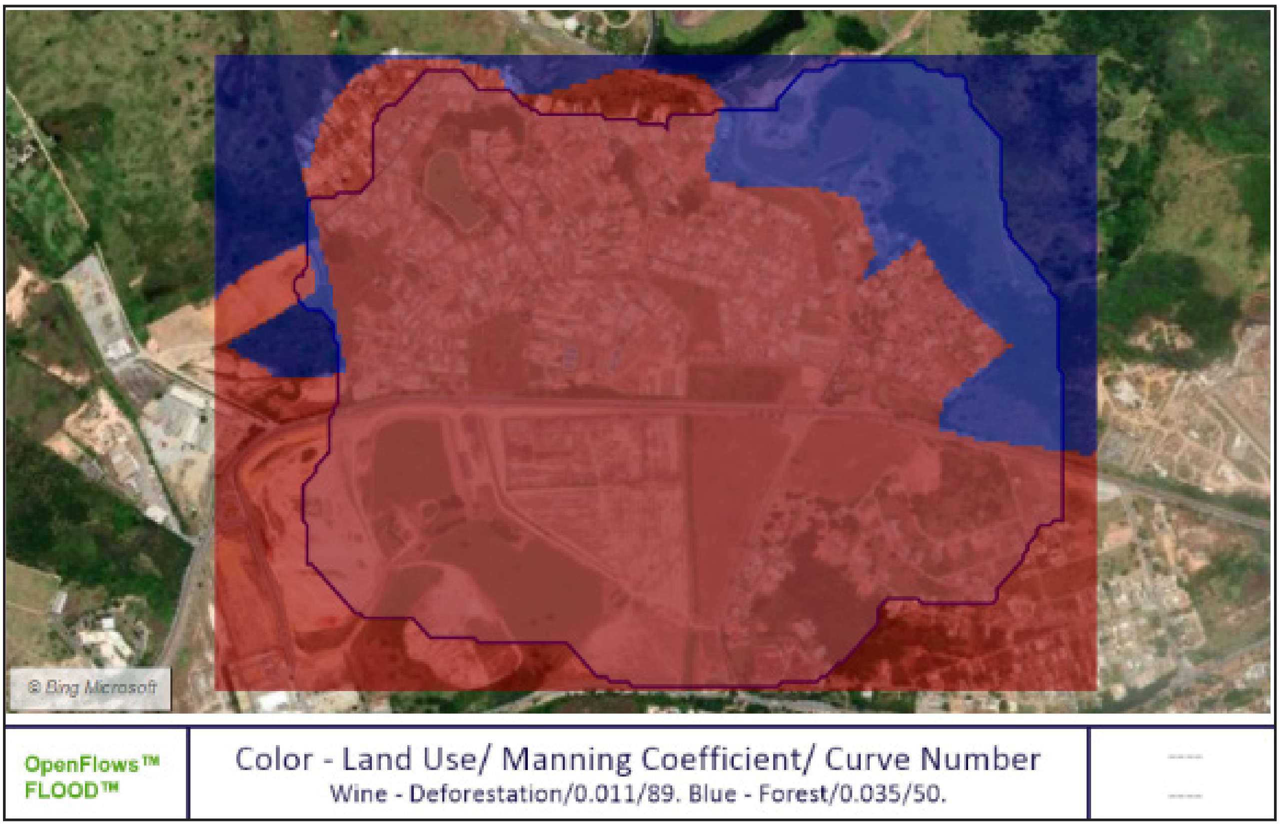
Source: Gribbin (2014)

In this article, three Manning's Coefficient variations and three Curve Number variations were adopted for the simulations: In simulations 1 and 4 it was considered that the region would be impermeable; in simulations 3 and 6, the entire region was considered as being vegetated; in simulations 2 and 5, the vegetated part and the urbanized part were considered.

To prepare the input files used in simulation 2 and 5, a land use map was produced in QGIS© software and it was imported into the OpenFlows FLOOD© hydrological program adopting the following Curve Number values: for vegetation of 50 and urbanization of 89, and the following Manning's values: for vegetation of 0.035 and urbanization of 0.011. Figure 1 represents the map with values in the legend for Curve Number and Manning's adopted in simulation 2 and 5 and the Drainage Basin simulated in the study region.

In the entire basin, the Rain Design of the city of Macaé adopted in this article considered a return period of 10 years and another one of 50 years.

Figure 1 – Map with the representation of Curve Number and Manning's Coefficient adopted in simulation 2 and 5 for urbanized area (deforestation) in wine and vegetated area (forest) in blue and Drainage Basin of Imboassica district, Macaé



Source: Elaborated by the authors (2021)

The definition of precipitation adopted in the model was established from the formulation of Intensity, Duration and Frequency (IDF) of Intense Rainfall (Miguez, Veról & Rezende, 2016):

$$I = \frac{a{T_r}^n}{(t+b)^m}, \quad (1)$$

where *a*, *b*, *m*, *n* are parameters that depend on the geographic space where precipitation is being analyzed;

t is the rain duration time in minutes (min);

T_r is the return time (years).

In this work, the maximum precipitation equation, developed from equation (1) for the city of Macaé, was adopted. (FESTI, 2007):

$$I = \frac{a{T_r}^n}{(t+b)^m}, \tag{2}$$

where $t = t_c$;

where I_{max} is the maximum precipitation (mm/hour).

To estimate the concentration time, considering the aspect of simplicity and good acceptance in the area of Civil Engineering, the formulation called California Culverts Practice was adopted (Miguez, Veról & Rezende, 2016)

$$t_c = 57 * \left(\frac{L^3}{H}\right)^{0,385} \tag{3}$$

t_c is the concentration time(min);

L is the length of the channel (km);

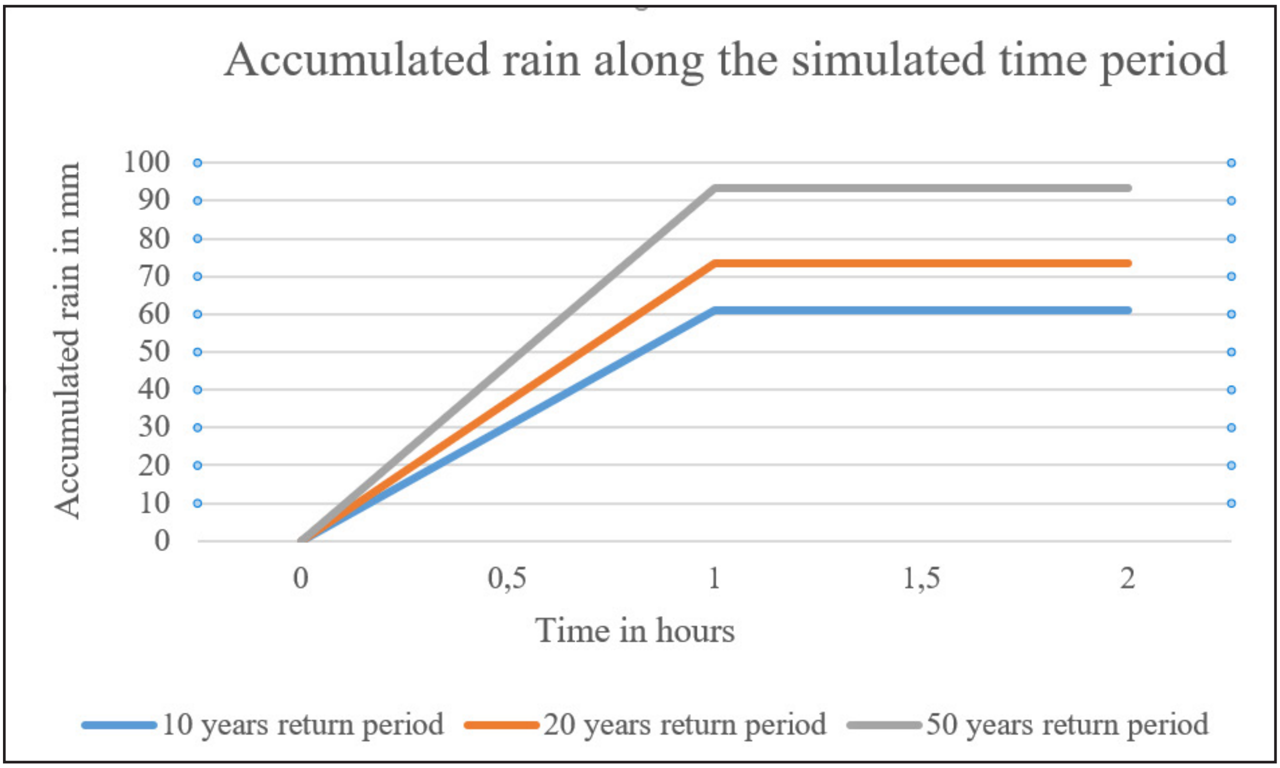
H it is the difference in level between the beginning point and end point of the considered channel (m).

It was adopted for calculation the unevenness of 1 meter and the length of the channel of 0.826344 km.

Using equations (1) to (3), it is possible to establish the evolution of precipitation intensity over time with a time series and use it in the simulation of urban drainage.

The estimated concentration time for the drainage basin using the California Culverts Practice formulation was 45 minutes, however, a rain of 1 hour was considered in this article. The simulation was done for a period of 2 hours, considering the rain period of one hour and a period of one hour without rain. The quantity of water accumulated in the basin during the 2 hours of simulated time for a rain designed of 10, 20 and 50 years return period is illustrated in Figure 2.

Figure 2 – Accumulated rain along the simulated time period



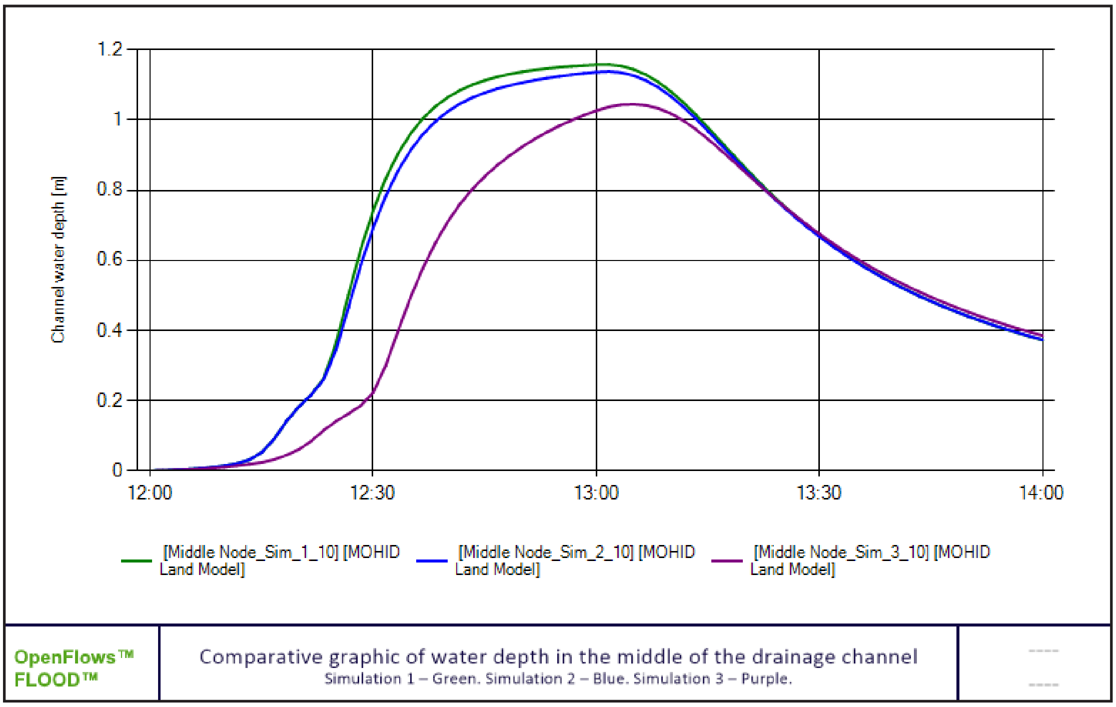
Source: Elaborated by the authors (2021)

4 RESULTS AND DISCUSSION

With the simulation results, it is possible to compare the water depth at points chosen as being of interest within the drainage channel. For the study in this work, two points were used, namely: the median region of the main channel and the final region of the main channel, which were considered more relevant.

Figures 3 and 4 illustrate the comparative graphs of simulation for a point located at an intermediate position of the channel and another at the end of the drainage channel, respectively, for 10 years return period. Simulation number 2 (represented in blue color) shows the results obtained considering the soil divided between urbanized and vegetated as shown in Figure 1, while simulation number 1 (represented in green color) considers that the soil is fully urbanized and simulation number 3 (represented in the color purple) considers that the soil is classified as vegetated.

Figure 3 – Comparison of results for simulations 1, 2 and 3 calculated for a 10 years return period considering a virtual monitoring station located at the middle of the channel

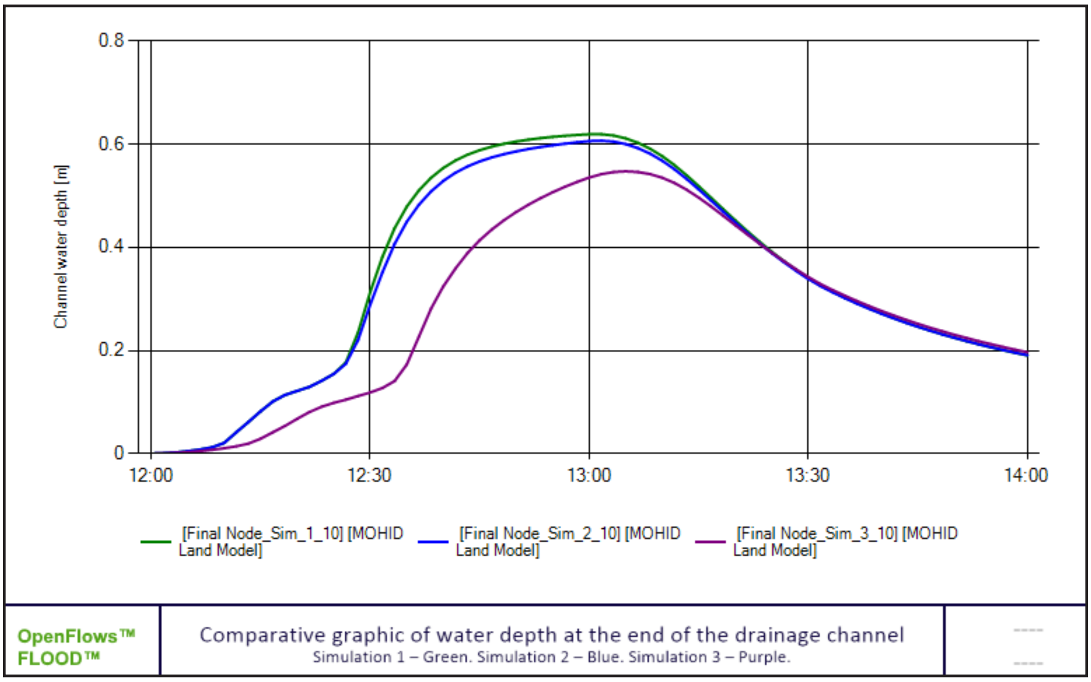


Source: Elaborated by the authors (2021)

Based on Figures 3 and 4, it can be observed that the drainage channel would have a more accentuated water depth as the urbanized area was more present, simulation 1 (green) denotes an impermeable region (corresponding to Curve Number 89), while simulation 3 (purple) denoted a fully vegetated region (corresponding to Curve Number 50).

The model was developed considering the altimetry data of the TOPODATA project from INPE, which correspond to the natural topography of the terrain measured by satellite and, therefore, do not consider changes in altitude generated by urbanization. Then, a modification was made to the terrain topography, raising the elevation of the cells representing roads by 1 meter and the elevation of the cells representing residences by 10 meters, and three news simulations were performed.

Figure 4 – Comparison of results for simulations 1, 2 and 3 calculated for a 10 years return period considering a virtual monitoring station located at the end of the channel

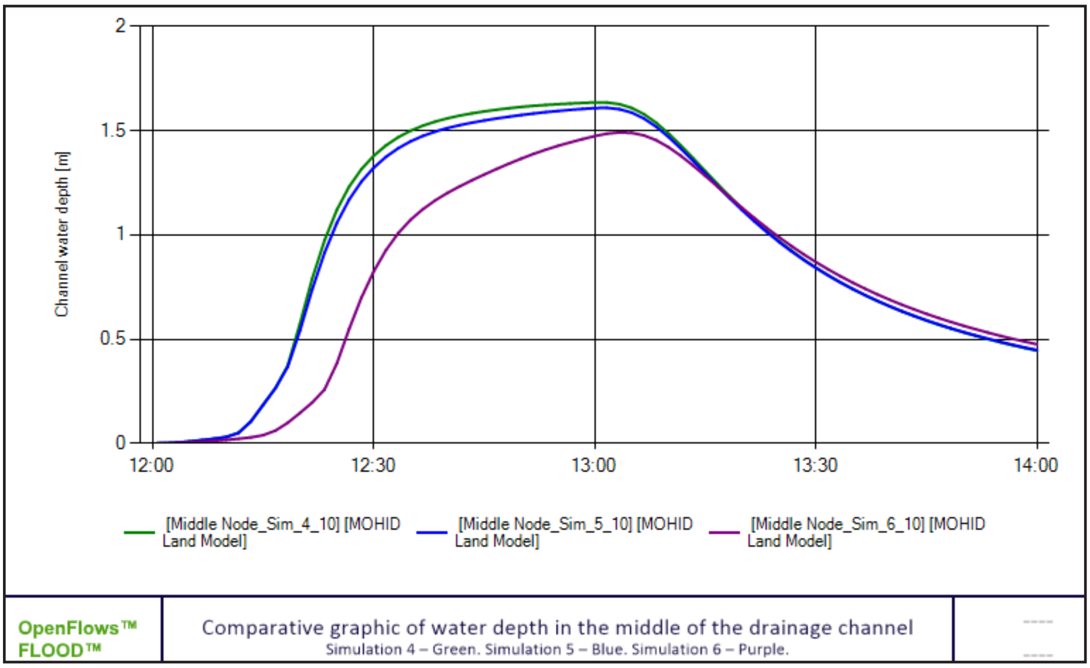


Source: Elaborated by the authors (2021)

With the simulation results, the results for the water depth at the same virtual monitoring stations at the drainage channel were studied. Figures 05 and 06 illustrate the comparative graphs considering the results obtained for the intermediate point of the channel and the end of the drainage channel, respectively. A Rain Design of return period of 10 years is considered. Simulation number 5 (represented in blue color) shows the results considering the soil divided between urbanized and vegetated as shown in Figure 1, while simulation number 4 (represented in green color) considers that the soil is fully urbanized and simulation number 3 (represented in purple color) considers that the soil is classified as vegetated.

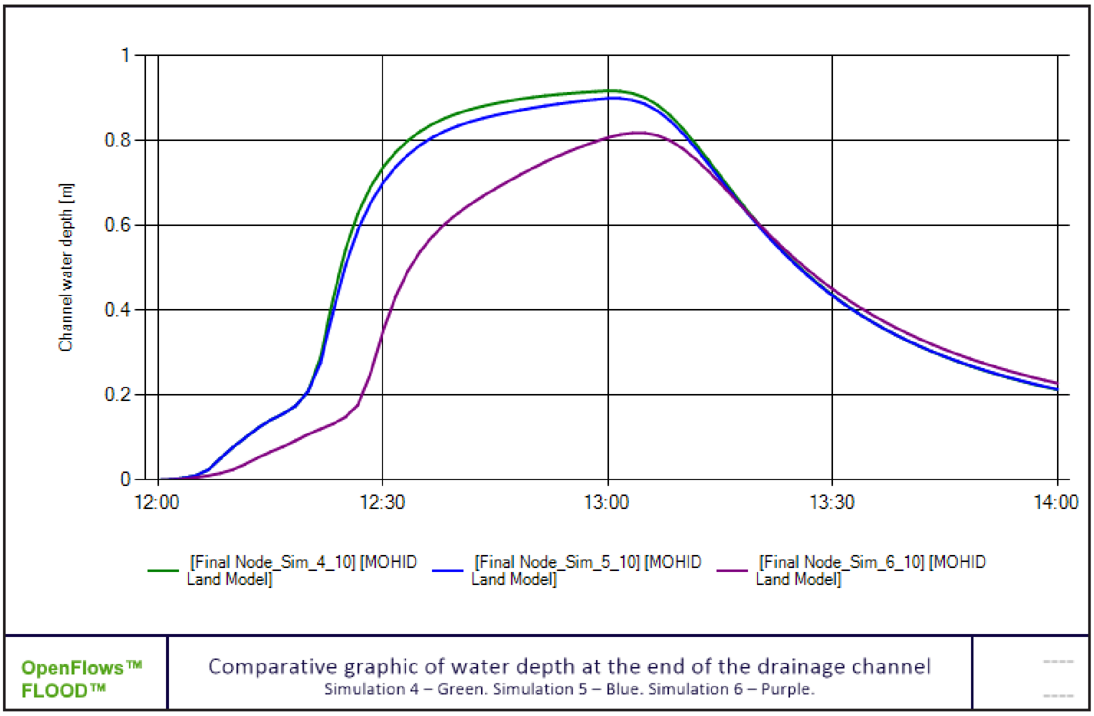
Using Figures 05 and 06 as a reference, it is possible to observe that the drainage channel had a greater water depth as the region becomes more urbanized, simulation 1 (green line) denotes an impermeable region (corresponding to Curve Number 89), while simulation 3 (purple line) denoted a fully vegetated region (corresponding to Curve Number 50).

Figure 5 – Comparison of results for simulations 4, 5 and 6 calculated for a 10 years return period considering a virtual monitoring station located at the middle of the channel



Source: Elaborated by the authors (2021)

Figure 6 – Comparison of results for simulations 4, 5 and 6 calculated for a 10 years return period considering a virtual monitoring station located at the end of the channel

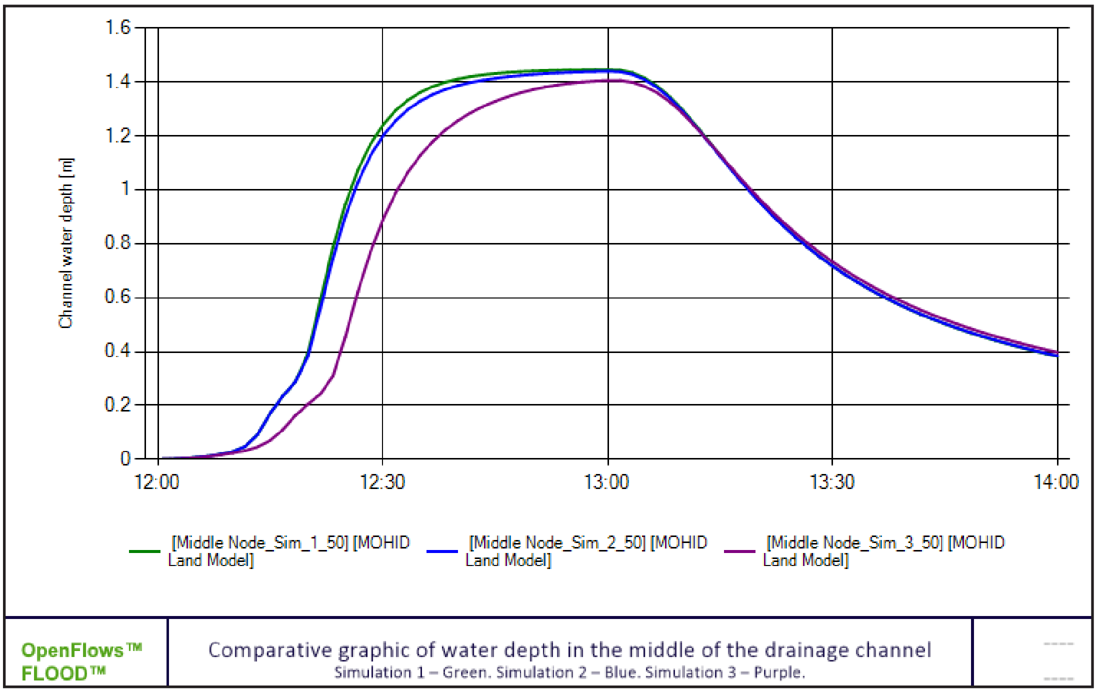


Source: Elaborated by the authors (2021)

Note that, when comparing the results represented in Figure 03 against Figure 05, and in Figure 04 against Figure 06, it is clear that the water depth has increased inside the drainage channel. This can be explained by the greater accumulation of water in the adjacent regions of the buildings and roads whose heights were considered, this increase in the amount of water is displaced to the channel due to topography and a decrease in the region available for infiltration.

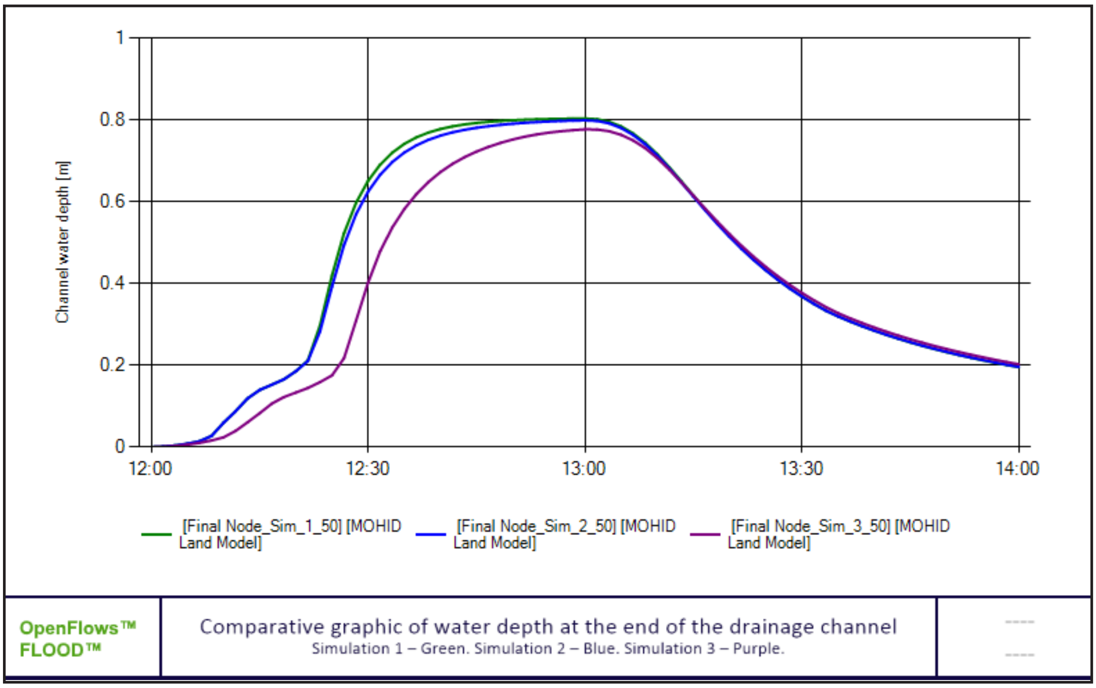
Figures 07 and 08 illustrate the comparative graphs of simulation 1 (green line), simulation 2 (blue line), simulation 3 (purple line), for a virtual monitoring station located at an intermediate position of the channel and another one at the end of the drainage channel, respectively, considering a Rain Design of 50 years return period. Simulation number 2 (blue line) represents the soil divided between urbanized and vegetated as shown in Figure 1, while simulation number 1 (green line) considers that the soil is fully urbanized and simulation number 3 (purple line) considers that the soil is vegetated.

Figure 7 – Comparison of results for simulations 1, 2 and 3 calculated for a 50 years return period considering a virtual monitoring station located at the middle of the channel



Source: Elaborated by the authors (2021)

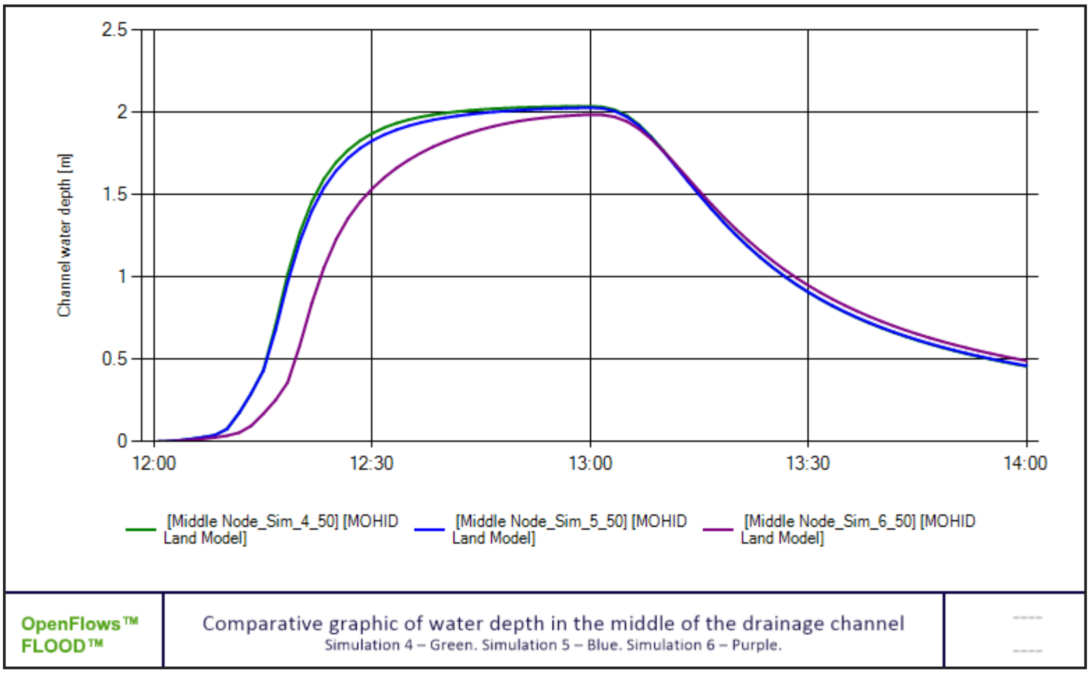
Figure 8 – Comparison of results for simulations 1, 2 and 3 calculated for a 50 years return period considering a virtual monitoring station located at the end of the channel



Source: Elaborated by the authors (2021)

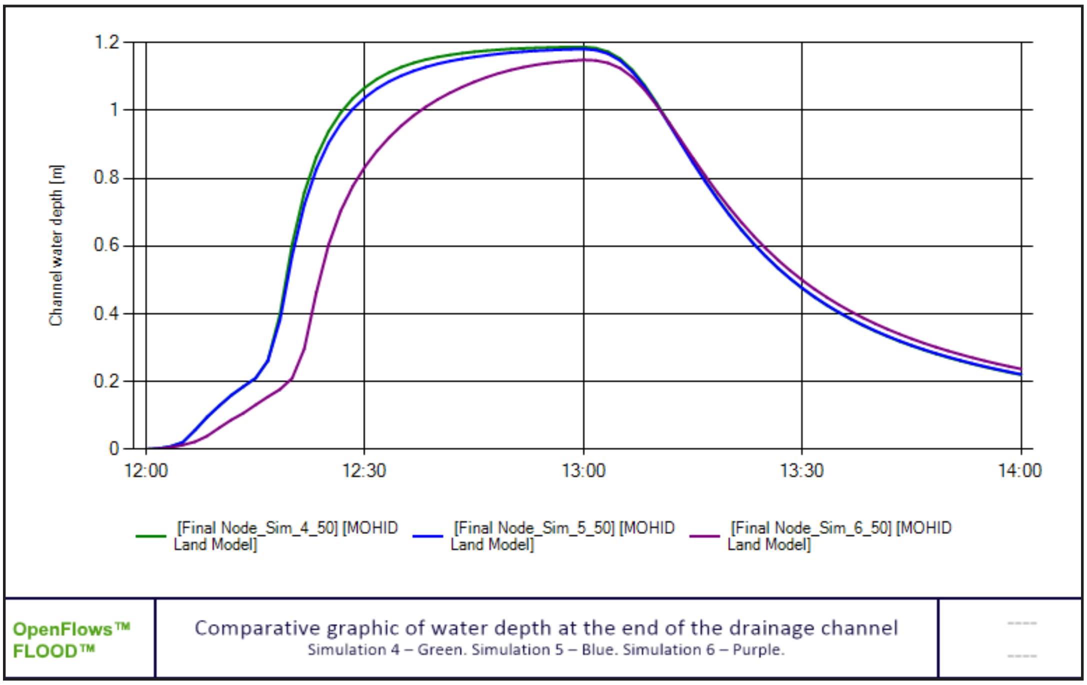
Figures 09 and 10 illustrate the comparative graphs of simulation 4 (green line), simulation 5 (blue line), simulation 6 (purple line), for the intermediate virtual monitoring station of the channel and at the end of the drainage channel, respectively, for a Rain Design of 50 years return. Simulation number 5 (represented in blue color) shows the results considering the soil divided between urbanized and vegetated as shown in Figure 1, while simulation number 4 (represented in green color) considers that the soil is fully urbanized and simulation number 3 (represented in purple color) considers that the soil is classified as vegetated.

Figure 09 – Comparison of results for simulations 4, 5 and 6 calculated for a 50 years return period considering a virtual monitoring station located at the middle of the channel



Source: Elaborated by the authors (2021)

Figure 10 – Comparison of results for simulations 4, 5 and 6 calculated for a 50 years return period considering a virtual monitoring station located at the end of the channel



Source: Elaborated by the authors (2021)

5 CONCLUSION

Through the analysis of the results, it was observed that in the simulations where there was greater elevation in the locations of the houses and the road in the condominium, the water depth increased in the drainage channels, such increase was attributed to the decrease in free space for water distribution in the model, and was considered more realistic. Regarding the simulations for a Rain Design for a return period of 10 and 50 years, it is concluded that the increase in the amount of rain results in an expected increase in the simulated water depth in the drainage channels.

It was observed that in the second hour of simulation, the water is not fully flowed throughout the channel. Which indicates that the time it takes for the water to travel through the channel (concentration time) is greater than the 45 minutes predicted using the California Culverts Practice formulation, this shows a possible inadequacy of the formulation adopted for the concentration time for this case study. A hypothesis for this inadequacy may be the lack of parameters that encompass the obstacles that the water has during its trajectory through the channel, as is the case of the Manning's Coefficient.

It was also possible to observe a very noticeable influence of infiltration due to the adopted Curve Number value, as the flood peak tends to decrease as more regions are considered vegetated in the simulation (from green to purple). In addition, due to the change in the Manning's Coefficient, there is a delay in surface runoff, that is, an increase in the delay for water to reach the main drainage channel, thus, simulations 3 and 6 even have a delay of a few minutes to observe a considerable amount of water in the channel.

The observations in this study were consistent with the technical expectations of aggravation of urban drainage problems caused by the urbanization process and the field observation. According to the literature, the drainage problems can be mitigated with the adoption of compensatory measures that retain part of the runoff observed in the model. The location of points with a greater depth of water makes it possible to assess which are the most affected points and which areas could be candidates for the adoption of compensatory techniques. In order to simulate the compensatory techniques, it is recommended to adopt as a reference the flooding generated by simulation 1, as this would represent the worst scenario, with the most impermeable region. In addition, simulation 2, which represents the behavior most similar to the real situation, as it presents part of the urbanized neighborhood and part still with vegetation.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support provided by FAPERJ, Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro, CNPq, Conselho Nacional de Pesquisa e Desenvolvimento Científico e Tecnológico, and CAPES, Coordenação de Aperfeiçoamento de Pessoal de Educação de Nível Superior.

REFERENCES

Abd-Elhamid, H. F., Zelenáková, M., Vranayová, Z. & Fathy, I. (2020). Evaluating the Impact of Urban Growth on the Design of Storm Water Drainage Systems. *Water*, 12(6), 1572. https://doi.org/10.3390/w12061572

Campos, L. F. De, Paiva, P. M., Rodrigues, P. P. G. W., Ferreira, M. I. P. & Lugon Junior, J. (2017). Disposal of Waste From Cementing Operation Offshore Oil and Gas Wells Building. *Ciência e Natura,* 39(2), 413–422. https://doi.org/10.5902/2179460X25821

Fernandes, R. De O., Costa, C. T. F. Da & Studart, T. M. De C. (2017). Análise de sensibilidade em hidrogramas de cheias máximas obtidos pelo método do SCS em uma bacia urbana. *Águas Subterrâneas,* v. 31(3), 243–254. https://doi.org/10.14295/ras.v31i3.28812

Festi, A. V. (2007). Coletânea das equações de chuva do Brasil. *Décimo sétimo Simpósio Brasileiro de Recursos Hídricos,* São Paulo. https://www.abrhidro.org.br/SGCv3/publicacao.php?PUB=3&ID=19&SUMARIO=267

Garneau, C., Duchesne, S. & St-Hilaire, A. (2019). Comparison of modelling approaches to estimate trapping efficiency of sedimentation basins on peatlands used for peat extraction. *Ecological Engineering*, 133, 60–68. https://doi.org/10.1016/j.ecoleng.2019.04.025

Garzo, P. A., Dadon, J. R. & Castro, L. N. (2019). Modelling environmental vulnerability of the Biosphere Reserve Parque Atlántico Mar Chiquito, Argentina, under agricultural and urban impacts. *Ocean & Coastal Management*, 170, 72–79. https://doi.org/10.1016/j.ocecoaman.2019.01.004

Gribbin, J. (2014). *Introdução À Hidráulica,* Hidrologia E Gestão De Águas Pluviais. Cengage Do Brasil.

Lugon Junior, J., Costa, V. T. R. & Rodrigues, P. P. G. W. (2016). Assessment of the impact of a small hydroelectric power plant over the water quality of the itabapoana river through a computational model. *Ciência e Natura*, 38(1), 95-105. https://doi.org/10.5902/2179460X31860

Lugon Junior, J., Tavares, L. P. Da S., Kalas, F. De A., Rodrigues, P. P. G. W. & Wasserman, J. C. A. (2019). Reservoir implantation for flood dampening in the Macaé River basin using the Mohid Land model. *Ciência e Natura*, 41, 29. https://doi.org/10.5902/2179460X18274

Miguez, M. G., Veról, A. P. & Rezende, O. M. (2016). *Drenagem urbana: do projeto tradicional à sustentabilidade.* Elsevier.

Paiva, P. M., Lugon Junior, J., Barreto, A. N., Silva, J. A. F. & Silva Neto, A. J. (2017). Comparing 3d and 2d computational modeling of an oil well blowout using MOHID platform - A case study in the Campos Basin. *Science of The Total Environment,* 595, 633–641. https://doi.org/10.1016/j.scitotenv.2017.04.007

Saad, A. M., Cavalcante, M. R. G. & Mendes, G. B. (2020). Revisão do plano municipal de saneamento básico de Macaé (rj). Produto 5 - Tomo III - *Drenagem e Manejo das Águas Pluviais Urbanas* (Programas, Projetos e Ações necessárias para atingir os objetivos e as metas do PMSB / Definição das Ações para Emergências e Contingências). Versão Preliminar. https://cbhmacae.eco.br/wp-content/uploads/2020/11/5.3-PMSB-Maca%E2%80%9A_Produto-5-TOMO-III_0920_R2.pdf

Simionesei, L., Ramos, T. B., Brito, D., Jauch, E., Leitão, P. C., Almeida, C. & Neves, R. (2016). Numerical Simulation of Soil Water Dynamics Under Stationary Sprinkler Irrigation With Mohid-Land: Soil water dynamics with MOHID-Land. *Irrigation and Drainage*, 65(1), 98–111. https://doi.org/10.1002/ird.1944

Suripin, S.; Sachro, S. S., Atmojo, P. S., Edhisono, S., Budieny, H. & Kurniani, D. (2018). Reducing Stormwater Runoff from Parking Lot with Permeable Pavement. *E3S Web of Conferences*, 73, 05016. https://doi.org/10.1051/e3sconf/20187305016

Tavares, L. P. Da S., Lugon Junior, J., Silva, J. A. F. Da, Wasserman, J. C. & Rodrigues, P. P. G. W. (2018) water management and urban flood mitigation: studies and proposals for the macaé river basin in brazil. *Journal of Urban and Environmental Engineering.* https://periodicos.ufpb.br/ojs2/index.php/juee/article/view/41313/22546

Trancoso, A. R., Braunschweig, F., Leitão, P. C., Obermann, M. & Neves, R. (2009). An advanced modelling tool for simulating complex river systems. *Science of The Total Environment,* 407(8), 3004–3016. https://doi.org/10.1016/j.scitotenv.2009.01.015

Zhang, H., Wang, Z., Xu, W. & Wang, H. (2019). *Determination of Emergent Vegetation Effects on Manning's Coefficient of Gradually Varied Flow*. IEEE Access, 7, 146778–146790. https://doi.org/10.1109/ACCESS.2019.2946917

Authorship contributions

1 – Laise Novellino Nunes de Souza

PhD student in water resources modeling from the Fluminense Federal Institute
https://orcid.org/0000-0002-9109-2101•E-mail: lalanovellino@hotmail.com
Contribution: Conceptualization; Methodology; Software; Validation; Formal Analysis; Investigation; Resources; Data Curation; Writing; First Writing; Data visualization

2 – Jader Lugon Junior

Master and PhD in computational modeling at the State University of Rio de Janeiro
https://orcid.org/0000-0001-8030-0713 • E-mail: jlugonjr@gmail.com
Contribution: Review and Editing; Supervision; Project Administration; Obtaining Financing

How to quote this article

Souza, L. N. N. de, & Lugon Junior, J. (2023). Study of the hydrological impact of the growth of a residential neighborhood on urban drainage – A case study at the city of Macaé, Rio de Janeiro, Brazil. *Ciência e Natura*, Santa Maria, 45, e16, . DOI 10.5902/2179460X68751. available in https://doi.org/10.5902/2179460X68751.