Estimation of Flood Flow at Critical Point Aided by QGIS Software

Prof. Dr. Eng. **Henrique PIZZO**[1,2,*], M.Sc. Eng. **Vinícius GALIL**[3], Prof. Dr. Eng. **Celso RIBEIRO**[3], Asst. Prof. Dr. Eng. **Safa IBRAHIM**[4]

[1] Estácio University of Juiz de Fora, State of Minas Gerais, Brazil

[2] Municipal Sanitation Company of Juiz de Fora, Brazil

[3] Federal University of Juiz de Fora, Brazil

[4] University of Zakho, Kurdistan Region, Iraq

Abstract: *The present work presents the determination of the peak flow in a region strongly subject to flooding. This is Severino Meireles street, part of the Independência Stream Hydrographic Basin, in the municipality of Juiz de Fora, Brazil. After a review of the literature on local floods, it is a question of estimating the hydrological flow of floods. The basins contributing to the study site had their characteristic magnitudes (areas, topographic elevations, lengths of watercourses, etc.) obtained from the use of the QGIS software. The hydraulic drainage capacity of the street gallery in question is also calculated, verifying the condition conducive to the occurrence of floods. Finally, suggestions for mitigating the problem are listed*.

Keywords: *Floods, QGIS, Severino Meireles street, drainage gallery, upstream watersheds*

1. Introduction

The amount of impermeable soil and alterations in natural drainage systems are increasing as a result of the fast growth of metropolitan areas. As a result of the difficulty of rainfall infiltration, there is a significant rise in surface discharges, favoring the occurrence of floods [1].

It is advantageous for the community if the urban area is designed in an integrated manner, that is, if all public works are planned in a consistent manner. When the drainage system is not included from the beginning of the urban planning formulation, it is extremely likely that when developed, it will be both expensive and inefficient. System planning must be carried out in accordance with well-defined standards, while constantly taking into consideration local, physical, economic, and social characteristics. The objective must be a realistic, technically and economically efficient drainage system project that maximizes advantages while reducing costs, is compatible with other sector plans, and meets the needs of the community [2].

Reference [3] reports that, according to the International Disaster Database, between 2006 and 2016 floods caused 61,730 deaths and US$375 billion in property damage worldwide. As stated in [4], flood impacts and resulting damage can be reduced through structural (physical interventions) and non-structural (management) approaches, and more effectively by combining both.

Based on [5], Brazilian urban drainage is considered outdated, since the concept of channelling prevails over that of reservation and infiltration, prioritizing rapid drainage rather than the controlled disposal of reserved volumes. It is reported in [6] that studies on urban floods have been undergoing important conceptual advances and urban drainage actions have been aligned with the concept of sustainable development, adding social and environmental aspects to the technical conception.

2. Studies on Floods in the City of Juiz de Fora

An interesting retrospective on floods in Juiz de Fora is presented, with historical approaches to sanitation and territorial planning [7].

Questions about recent floods in the Ipiranga Stream [8, 9, 10], in the São Pedro Stream [9] and in the Matirumbide Stream [11] are addressed.

Analyses of the Drainage Plan for the North Zone of Juiz de Fora (2011) point out that the flooding areas generated for the urban area of the North Region indicate the neighborhoods Igrejinha,

Benfica, Bairro Araújo, Barbosa Laje, Bairro Industrial, Bairro Cerâmica, Monte Castelo and Remonta as being those, respectively, at greater risk.
According to [12], the Independência Stream Hydrographic Basin is one of the 156 sub-basins that drain the urban area of the municipality. It has 7.11 km^2 and 82,977 inhabitants (2015 estimate). The stream has a length of 5.47 km, of which 4.73 km are channelled and covered, and it covers an area with a strong residential, educational, health and commercial character. However, it should be noted that the Independência Stream Watershed still lacks studies to eliminate, or at least minimize to acceptable levels, the issue of flooding.

3. Methodology

The central point of the present work is to estimate the flood flow of a critical point, located in the Independência Stream Hydrographic Basin, in the city of Juiz de Fora, state of Minas Gerais, Brazil, and consequent comparison with the capacity of the drainage equipment of this site, which is a storm sewer. This expedient is intended to deepen the studies for the elimination or, at least, the attenuation of those phenomena in the place.
From searches in newspapers, news, available and disseminated knowledge, and manuals, 03 points very subject to flooding in the Independência Stream Basin were chosen: Severino Meireles street, a small extension of Rio Branco avenue, immediately adjacent to the first, and the corner of Morais e Castro street and 21 de Abril street. It was decided to have Severino Meireles street as the object of this study because, among the three points, it is the one with the highest frequency of floods and consequent damages. The problems are caused by precipitation from upstream neighborhoods such as Alto dos Passos, Bom Pastor and Guaruá which, not being properly drained at the source, have their surplus forwarding to the location object of research.

3.1 Geoprocessing

Regarding the operations via geoprocessing of the contributing hydrographic sub-basins, the first stage of this work consisted of the delimitation of the Independência Stream Basin. So that this task could be carried out consistently, a freely distributed and widely known application in the field of georeferencing called QGIS, an acronym for Quantum Georeferenced Information System, was used. Once the software was installed, a Digital Elevation Model - DEM was acquired. For that, it was necessary to access data from the ALOS PALSAR satellite, which uses L-Band reading with repeated pass interferometry, through the Alaska Satellite Facility website.
Once the collections of scenes were obtained, we opted for one that had an FBD type beam and Hi-Res Terrain Corrected detailing. The next stage of the procedure was to delimit the study area and, for this, a shape-file (SHF) of the municipality of Juiz de Fora was used. This operation aimed the study from an optimized file, providing a faster processing.
For the third stage, an SHF file of the taxpayers of the Paraíba do Sul River Basin was necessary, acquired on the website of the Brazilian National Water Agency which, in this case, was cut using the SHF file of the municipality as a delimiter. This operation was important to facilitate the identification of the Independência Stream Basin along with its outlet, a task that would be more complex due to the vast expanse of the Paraíba do Sul River Basin.
In the next step, with the DEM already optimized, it was possible to obtain images of the constituent watersheds of the entire municipality, as well as their respective directions and drainage segments. It was also possible to identify all the thalwegs that contribute, continuously or occasionally, to Independência Stream Basin. Finally, tools from the Geographic Resources Analysis Support System (GRASS) of QGIS were used, where it was possible to refine the pixels of the drainage line and their subsequent vectorization in order to generate the distances from the interfluves to their sub-outfalls. Such images were allocated over the model Google Earth image so that the adjustment between the basin and streets could be demonstrated. The georeferencing application also allows the extraction of other products, such as altimetric lines, sub-basin areas and total basin area, altimetric profile, slope index, contribution index, soil type and vegetation.

3.2 Hydrology

The Independência Stream Watershed is represented in Figure 1, delimited in green. The stream flows to Paraibuna River. The yellow lines define the natural waterways, the orange polygon encompasses the study area, subject to flooding, and the area in red denotes Severino Meireles street.

Fig. 1. Independência Stream Basin

Figure 2 presents a partial and closer view, in relation to the area under study, of the Independência Stream Hydrographic Basin, now delimited in light blue, still with the water lines in yellow and Severino Meireles street in red.

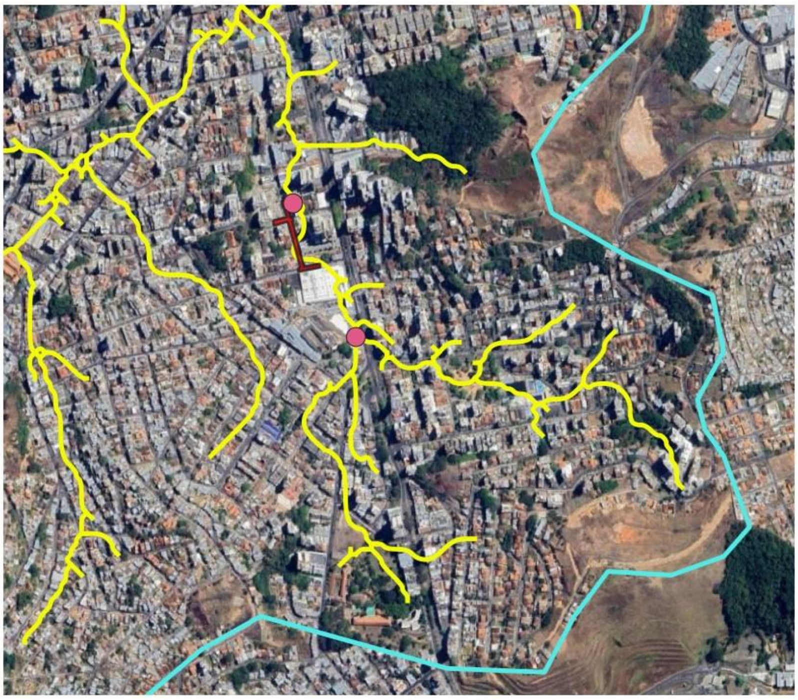

Fig. 2. Closer view of the study area

From the regions affluent to Severino Meireles street, in the same basin, three sub-basins were delimited (from that point on, simply called basins) and respective areas, through the previously exposed methodology. The main focus was given to basins 1 (burgundy) and 2 (brown), as they are the largest of the three basins. Basin 3 (blue) was considered to have integrated parameters from the others. The main watercourses whose length was materialized only partially through geoprocessing, had those complemented and extended to the watershed, through the monitoring of contour lines. The areas, length of the main watercourse, upstream terrain level and downstream terrain level (the latter common to the 2 basins) are, respectively, for basins 1 and 2, 518,162 m^2, 396,749 m^2, 1,399 m, 1,200 m, 825 m, 795 m, and 705 m (at the confluence point of both). Basin 3 has an area of 145,167 m^2. The scheme can be seen in Figure 3.

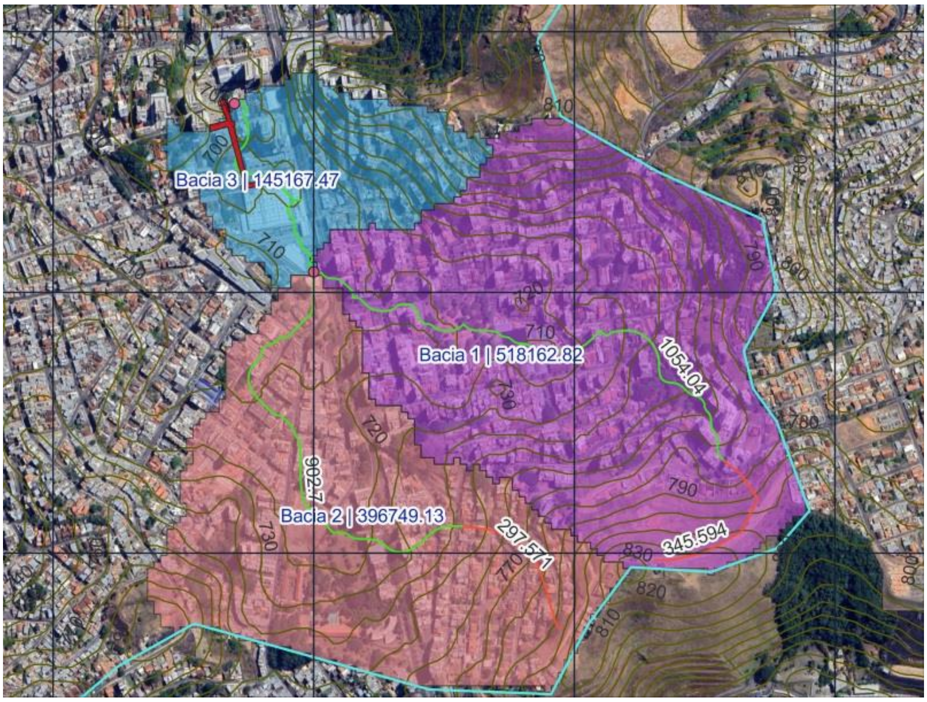

Fig. 3. Flood point upstream watersheds

The time of concentration is 10.7 minutes, determined by the average values adopted between those estimated by the formula of Shaake et al. (1) and those resulting from Kirpich formula (2) [13]. It is interesting to note that the time of concentration values referring to basins 1 and 2 were very close to each other when Shaake was used, as well as when Kirpich was used, although they differed when using one and the other formula. For this reason, it was believed that the average would have a better representativeness. The formulas are expressed in the following equations.

$$t_C = 0.0828\ L^{0.24} S^{-0.16} {A_{imp}}^{-0.26} \quad (1)$$

$$t_C = 0.0663\, L^{0.77} S^{-0.385} \quad (2)$$

Where t_C is the time of concentration (h), L is the length of the main watercourse of the basin (km), S is the average slope of the basin (level variation divided by the length of the main watercourse, m/m), and A_{imp} is a value between 0 and 1, which represents the percentage of impermeable area of the watershed.

A recurrence interval of 20 years was adopted, considering the type of situation studied in the present work. It should be added that, for the determination of peak flows, the Rational Method was adopted, emphasizing that it admits that the maximum flow occurs when the time of concentration of the basin is equal to the time of rain. And, thus, in the intensity-duration-frequency equation, such a consideration is admitted.

The value of rainfall intensity is 159.3 mm/h, determined by the intensity-duration-frequency equation for Juiz de Fora (3).

$$i = \frac{3{,}000\ T^{\,0.173}}{(t + 23.965)^{\,0.960}} \tag{3}$$

Where *i* is the rainfall intensity (mm/h), *T* is the recurrence interval (years), and *t* is the duration of rain (equivalent to the time of concentration, min).
The irregular rainfall distribution coefficient was calculated individually for each of the 03 basins, according to (4). A runoff coefficient of 0.75 was adopted, considering the upper limit value for residential areas with multiple conjoined units, as recommended by Ven Te Chow, in view of the situation presented.

$$C_d = A_{ac}^{\ -0.15} \tag{4}$$

Where C_d is the distribution coefficient (dimensionless), and A_{ac} is the accumulated area of each basin (ha).
The equation used to calculate the maximum flow was the Rational Formula, and is expressed in (5).

$$Q_{max} = 2.78\ C_e\, C_d\ i\ A \tag{5}$$

Where Q_{max} is the maximum flow (L/s), C_e is the runoff coefficient (dimensionless), *A* is the area of each basin (ha), and C_d and *i* are already defined.

3.3 Hydraulics

The rainwater drainage layer was obtained from the information system of the municipal sanitation company. This is expressed in Figure 4, where the drainage galleries are represented by blue lines, the Severino Meireles street gallery is surrounded by a yellow ellipse, and the level curves symbolized by red lines.

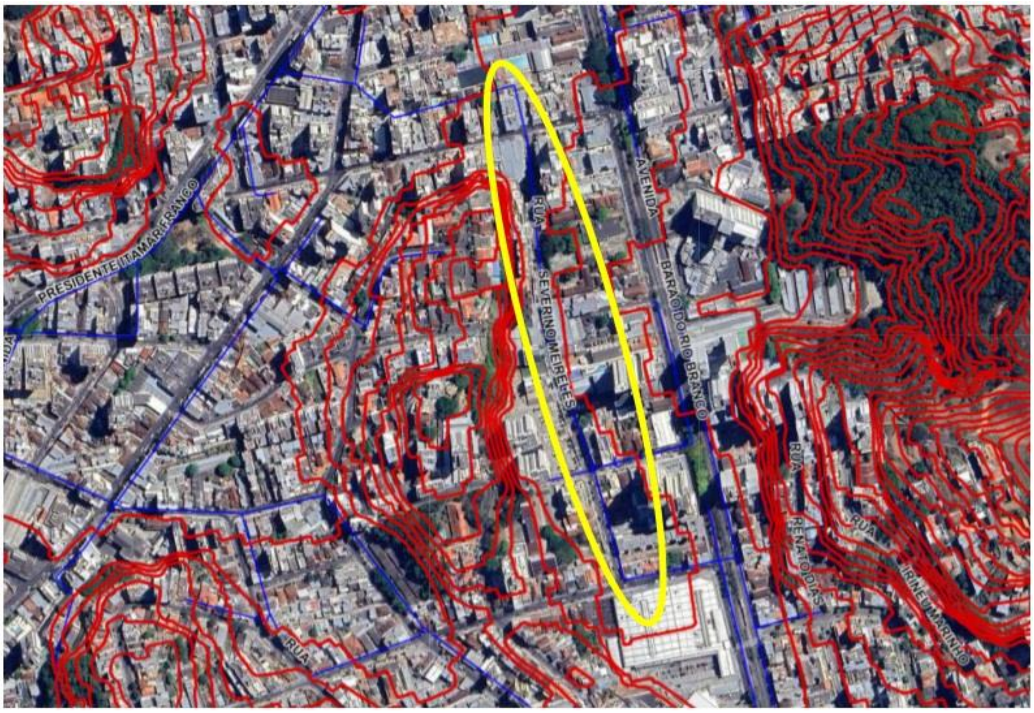

Fig. 4. Drainage gallery system

Based on a consultation with the Municipal Works Department, it was found that the gallery that drains Severino Meireles street is 2.0 meters wide by 3.0 meters high, and has a bottom slope of 0.46%. The estimated Manning coefficient is 0.018, equivalent to rough cement channels, bottom deposits, moss on the walls and tortuous layout.

The hydraulic flow capacity of the gallery was calculated by the Manning equation, described in (6). A clearance of 10% of the height was allowed, in order to contemplate small variations in the parameters adopted in relation to the field ones.

$$Q_{cap} = \frac{1}{n}\ A_m\ R_H{}^{2/3}\ I^{1/2} \qquad (6)$$

Where Q_{cap} is the hydraulic flow capacity, n is the Manning coefficient ($s/m^{1/3}$), A_m is the cross sectional area of flow (m^2), R_H is the hydraulic radius (A_m / wetted perimeter, m), and I is the hydraulic gradient (considered as the gallery bottom slope, m/m).

4. Results and Discussion

Despite the great uncertainties inherent to the process, whether related to field conditions, the equations used, and the arbitrated parameters, the values found, reported below, suggest a reasonable favorability for the flood conditions, in fact verified in practice, at that location.
The peak flow due to rainfall was calculated for each of the three basins, according to section 3.2 and (5), and then added together, in order to obtain the total flow that discharges into Severino Meireles street, totalizing 20.3 m^3/s.
As for the hydraulic flow capacity of the gallery, this was estimated at 16.5 m^3/s, in view of what was exposed in section 3.3 and the application of (6).
In order to increase the hydraulic flow capacity of the galleries, some measures must be considered. The initial verification would be to verify if the swallowing capacity of the culverts is sufficient for the affluent flow. Another step would be to verify whether the topographical conditions and whether the connections of the upstream pipes with the gallery in question allow the elevation of its bottom slope, even if a little, considering that it is very small.
Checking the hydraulic flow capacity of the pipes upstream of the gallery in question would also be an excellent attempt, also because it is known that there is an accumulation of water at a nearby point, upstream. It would also be recommended that employees enter the gallery, provided that all safety conditions are verified, in order to clear and clean it, thus helping to facilitate the flow of water.

5. Conclusions

Floods and overflows affect urban traffic and facilities, as well as the existence of waterborne illnesses and vector propagation. They also have repercussions for the environment, such as polluting and degrading urban water supplies. Flooding, in more extreme circumstances, results in significant consequences, including the loss of human life.
It is possible to suggest that the city of Juiz de Fora has urban dynamics that make it sensitive to problems like floods and spillovers, due to the region's substantial precipitation levels as well as the consequences of urbanization-related changes.
A study was presented to estimate the hydrological flows of the regions contributing to Severino Meireles street, heavily subject to flooding, part of the Independência Stream Hydrographic Basin, city of Juiz de Fora, Brazil. This flow was contrasted with the flow capacity of the local drainage gallery, confirming the favorable conditions for flooding. Some proposals for mitigating or eliminating such floods were previously discussed.
It is intended that this study be continued with the discretization of the areas upstream and consequent verification of available spaces for the installation of small reservoirs to dampen flows. Therefore, from the simulation of such reservoirs, whether in series or in parallel, it will be possible to estimate a new flow affluent to Rua Severino Meireles, eliminating the condition of flooding in that location.

Acknowledgments

The first author is grateful for the grant received from the Pesquisa Produtividade (Research Productivity) 2023 Estácio Juiz de Fora Program.

References

[1] Kessler, A., and M. H. Diskin. "The efficiency function of detention reservoirs in urban drainage systems." *Water Resources Research* 27, no. 3 (1991): 253–258. https://doi.org/10.1029/90WR02143.

[2] Fugita, O. *Urban drainage - design manual: Planning / Drenagem urbana - manual de projeto: Planejamento*. São Paulo: Cetesb, 1986.

[3] Zhu, F., P. A. Zhong, Y. Sun, and W. W. G. Yeh. "Real-time optimal flood control decision making and risk propagation under multiple uncertainties." *Water Resources Research* 53, no. 12 (2017): 635–654. https://doi.org/10.1002/2017WR021480.

[4] Shrestha, B. B., and A. Kawasaki. "Quantitative assessment of flood risk with evaluation of the effectiveness of dam operation for flood control: A case of the Bago River basin of Myanmar." *International Journal of Disaster Risk Reduction* 50, no. 4 (2020): 1–15. https://doi.org/10.1016/j.ijdrr.2020.101707.

[5] Souza, R. C. C. "Method for efficient sizing of flood containment reservoirs for the city of Curitiba-PR / Método para dimensionamento eficiente de reservatórios de contenção de cheias para a cidade de Curitiba-PR." M.Sc. thesis, Federal Technological University of Paraná, Curitiba, 2018. http://repositorio.utfpr.edu.br/jspui/handle/1/3105.

[6] Augusto, D. L. "Conception, modeling and detailing of a detention reservoir in a square, as an alternative for flood control in the Guerenguê River basin / Concepção, modelagem e detalhamento de um reservatório de detenção em praça, como alternativa para o controle de cheias na bacia do Rio Guerenguê." M.Sc. thesis, Federal University of Rio de Janeiro, Rio de Janeiro, 2008. https://minerva.ufrj.br/F/?func=direct&doc_number=000706264&local_base=UFR01.

[7] Machado, P. J. O., and S. B. Cunha. "Juiz de Fora: floods, sanitation and territorial organization / Juiz de Fora: inundações, saneamento e ordenamento territorial." *Revista Geográfica de América Central* 2, no. 47E (2011): 1–15. https://www.revistas.una.ac.cr/index.php/geografica/article/view/2455.

[8] Silva, R. S., and P. J. O. Machado. "Urban flooding: the case of the Ipiranga Stream watershed - Juiz de Fora/MG / Inundações urbanas: o caso da micro-bacia hidrográfica do Córrego Ipiranga - Juiz de Fora/MG." *Periódico Eletrônico Fórum Ambiental da Alta Paulista* 7, no. 2 (2011): 152–165. https://doi.org/10.17271/19800827722011110.

[9] Gerheim, D. K. M. "Overflows, flash floods and inundations in the urban area of Juiz de Fora: a look at the hydrographic basins of the São Pedro and Ipiranga Streams / Alagamentos, enxurradas e inundações na área urbana de Juiz de Fora: um olhar sobre as bacias hidrográficas dos Córregos São Pedro e Ipiranga." B.Sc. thesis, Federal University of Juiz de Fora, Juiz de Fora, 2016.

[10] Galil, V. M., H. S. Pizzo, W. G. Oliveira, and V. F. Calcaterra. "Methodology for determination of discharges in the Ipiranga Stream basin in Juiz de Fora / Metodologia para determinação de descargas na bacia hidrográfica do Córrego Ipiranga em Juiz de Fora." *Brazilian Journal of Development* 7, no. 2 (2021): 20728–20752. https://doi.org/10.34117/bjdv7n2-629.

[11] Amaral, C. M., I. B. S. Giarola, and J. O. Almeida Neto. "Identification of areas susceptible to flooding in the Matirumbide Stream watershed, Juiz de Fora-MG / Identificação das áreas suscetíveis à inundação na bacia hidrográfica do Córrego Matirumbide, Juiz de Fora-MG." In Os Desafios da Geografia Física na Fronteira do Conhecimento, edited by A. Perez Filho and R. R. Amorim, 4141–4149. Campinas: 2018. https://doi.org/10.20396/sbgfa.v1i2017.2567.

[12] Machado, P. J. O. "Urbanization and water quality of the Independência Stream, Juiz de Fora/MG / Urbanização e qualidade das águas do Córrego Independência, Juiz de Fora/MG." *Revista Equador* 5, no. 5 (2016): 20–35. https://doi.org/10.26694/equador.v5i5.4926.

[13] Silveira, A. L. L. "Performance of time of concentration formulas in urban and rural basins / Desempenho de fórmulas de tempo de concentração em bacias urbanas e rurais." *Revista Brasileira de Recursos Hídricos* 10, no. 1 (2005): 5–23. http://dx.doi.org/10.21168/rbrh.v10n1.p5-29.