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Artigo de Pesquisa

Prognóstico das alterações na topografia no impacto das inundações (Itajubá/MG – Brasil)

Prognosis of topography changes in the impact of floods (Itajubá/MG – Brazil)

Alexandre Germano Marciano[1], *Alexandre Augusto Barbosa*[1], *Alex Takeo Yasumura Lima Silva*[2], *Michelle Simões Reboita*[1] & *Ana Paula Moni Silva*[1]

[1]Federal University of Itajubá, Institute of Natural Resources, Itajubá, MG, Brazil. agermano@unifei.edu.br; barbosa@unifei.edu.br; reboita@unifei.edu.br; anamoni@unifei.edu.br.
[2]Federal University of Minas Gerais, Belo Horizonte, MG, Brazil. alex.takeo@uol.com.br.

Resumo: Com o aumento da urbanização, alguns tomadores de decisão acabam por realizar atitudes inadequadas que afetam o ambiente, por falta de conhecimento técnico ou interesse pessoal. No caso de áreas de inundação recorrente, a ocupação irregular pode causar uma série de problemas ambientais e econômicos. O Distrito Industrial do município de Itajubá-MG vem sofrendo ocupação acelerada e alterações morfométricas acentuadas. Visando prever o impacto dessas mudanças no uso e ocupação, este trabalho tem como objetivo traçar o diagnóstico das enchentes entre 2005 e 2021 e projetar um cenário futuro até o ano de 2030. Este artigo tem como objetivo avaliar os impactos causados pelas cheias. Foi utilizado o software HEC-RAS para simular as cinco propagações de cheias em seis cenários de ocupação. As simulações foram analisadas em oito locais de controle ao longo da área de estudo. Os resultados mostraram que, ao longo dos anos, em decorrência de uma ocupação crescente desta área, é prevista a ocorrência de represamentos de enchentes na região a montante dos aterros, mas devido à proporcionalidade da área, essas alturas de represamento são consideradas irrelevantes, não amplificando os danos causados pelas enchentes e, em alguns casos, levando à diminuição da área inundada no Distrito Industrial.
Palavras-chave: HEC-RAS, mapeamento de inundações, simulação bidimensional, inundação.

Abstract: With increasing urbanization, some decision-makers often take inappropriate actions that affect the environment due to a lack of technical knowledge or personal interests. In the case of areas with recurrent flooding, irregular occupation can cause a series of environmental and economic problems. The Industrial District of the municipality of Itajubá-MG has been experiencing accelerated occupation and noticeable morphometric changes. To predict the impact of these changes in land use and occupation, this study seeks to establish flood diagnosis between 2005 and 2021, and project a future scenario until the year 2030. This article intends to assess the impacts caused by floods. The HEC-RAS software was utilized to simulate five flood propagations under six different occupation scenarios. Simulations were analyzed at eight control sites

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throughout the study area. The results indicate that, over the years, as a result of increasing occupation in this area, flood damming is expected to occur in the region upstream of the landfills. However, due to the proportionality of the area, these damming heights are considered irrelevant, as they do not exacerbate the damage caused by floods. In some cases, they even lead to a reduction in the flooded area in the Industrial District.

Keywords: HEC-RAS, flood mapping, two-dimensional simulation, inundation.

1. Introduction

Flooding is a natural phenomenon that causes the most losses, and it is the most devastating, widespread, and frequent natural disaster in the world (Salman & Li, 2018). However, floods are not always harmful, as they are part of a natural cycle, bringing environmental and social benefits, especially in areas that have suffered from prolonged droughts and in ecosystems that need moisture (Ward *et al.*, 2021).

According to Andrade *et al.* (2012), anthropic actions can modify the watershed, influencing quantitatively and qualitatively in hydrological processes. The result of these modifications is only noticed when hydrological events of an extreme nature occur, and their consequences can be droughts, floods, production, and transport of sediments, in addition to the possibility of influencing water quality.

For Paz *et al.* (2010), knowing the hydrological behavior allows relating the flow regime with the ecological characteristics. This hydrological behavior can be represented through hydrological and hydraulic models. Models are physical or mathematical representations of reality, seeking to reproduce the procedures and behaviors of a system, with the aim of predicting responses (Marciano, 2019).

Hydrodynamic modeling is the mathematical representation of fluid motion, from the application of the principles of conservation of three quantities: energy, mass, and momentum. These quantities are not the only ones, but they are sufficient to mathematically represent the flow (Tucci, 1998; Silva, 2019). They use continuity and mass equations, known as Saint Venant equations, which can simulate two-dimensional non-permanent flow, as presented by Yu *et al.* (2021), Ezzine *et al.* (2020), Amarjouf *et al.* (2019), and Atallah *et al.* (2018).

These equations are solved in the HEC-RAS software, an open-access and widely accepted tool by professionals in the field of natural channel hydraulics. The HEC-RAS program was developed by the North American Army Corps of Engineering to simulate the flow in permanent and non-permanent regimes, the transport of sediments, and the water quality (USACE, 2021).

According to Brazilian Federal Law Nº 10,257 of July 10, 2001, every municipality that has a population of over fifty thousand people is required to establish an Urban Master Plan, and within it, there is a Public Policy division, where the flood prevention issues (Brazil, 2001). One of the flood prevention measures is urban zoning which can be used to map recurrent flood areas. The HEC-RAS software has tools to generate these maps safely, for example, the studies Tamiru & Dinka (2021), Ongdas *et al.* (2020), Basnet & Acharya (2019), and Ly *et al.* (2018).

According to Torres *et al.* (2020) and Cunha *et al.* (2019), the period from 2011 to 2017 is experiencing the most severe drought in recent decades in the southeast region of Brazil, contributing to the low frequency of flooding events. Santos *et al.* (2021), Ramiaramanana & Teller (2021), and Rogers *et al.* (2019), among other authors, show that when there were periods with low frequency of flooding, the population and the public authorities ignored the threat, increasing investments in areas susceptible to flooding.

Like most Brazilian cities that developed on the banks of rivers, the municipality of Itajubá lives with the problem of flooding. It has an estimated population of 97,334 inhabitants (IBGE, 2021) and five water courses cross its urban area: Sapucaí River, Piranguçu River, José Pereira Stream, Anhumas Stream, and Água Preta Stream. One of the main areas of development is the Industrial District, which is a geographic and sectoral concentration of companies, which are essential areas for the development of a city (Sengenberger & Pike, 1999). Part of the area of the Industrial District of Itajubá is within the areas subject to flooding, as described in studies by Moni (2006) and Marciano (2019).

Municipal law No. 3,352 of 2019 altered the Master Plan, which was created in 2003. One of the changes was the expansion of 160,000 m² in the Area of Economic Interest (AEI), which is primarily intended for the development of industries and production services (Itajubá, 2021). The expanded area is located in the Industrial District, which has ready infrastructure for: water, sewage, energy, and fast internet, making this area valued by investors. However, this area is located in the floodplains of the Piranguçu River, a place of recurrent flooding.

Marciano *et al.* (2018) presented a study within the Industrial District area to investigate the impact on flooding caused by the implementation of the airport. The HEC-RAS software was used to simulate the flow in two scenarios on the Piranguçu River, one with the implementation of the airport and the other without the implementation. Concluding that the airport will result in impacts on the flow of flooding, the most affected anthropic stretch is in the roundabout where some companies enter, and it would not be feasible to occupy the floodplain areas of the Piranguçu River without directed studies. Seeking to understand the dynamics of flooding in this location, this study aims to make a forecast of two-dimensional hydrodynamic analysis in the area already studied by Marciano *et al.*, (2018), in relation to the Master Plan for the Development of Itajubá (Itajubá, 2021). The study considered the urban growth rate of the study area, from the year 2005 to projections for the year 2030, to assess the impacts caused by floods.

2. Materials and methods

This section is divided into two parts: the first part presents the study area; and the second part shows the methodology used in the simulation and analysis, which is divided into four steps:

1. Occupancy scenarios – the creation of a digital elevation model (DEMs) of the scenarios;

2. Flood events – the creation of flood events cotagrams/hydrograms;

3. Hydrodynamic simulations – insertion of geometric and flow data in the HEC-RAS program, model simulation, and calibration;

4. Locations Analysis – verification of points in relation to floods and changes in scenarios

2.1 Study Area (Industrial District)

The study area is the Industrial District of the municipality of Itajubá located in the state of Minas Gerais (MG), Brazil. The Industrial District is located between the left banks of the Sapucaí Rivers and its tributary, the Piranguçu River, within the quadrilateral of geographic coordinates 22°25'17.0663"S, 45°28'35.4860"W and 22°26'51.0845"S, 45°29'48.7608"W (Fig. 1).

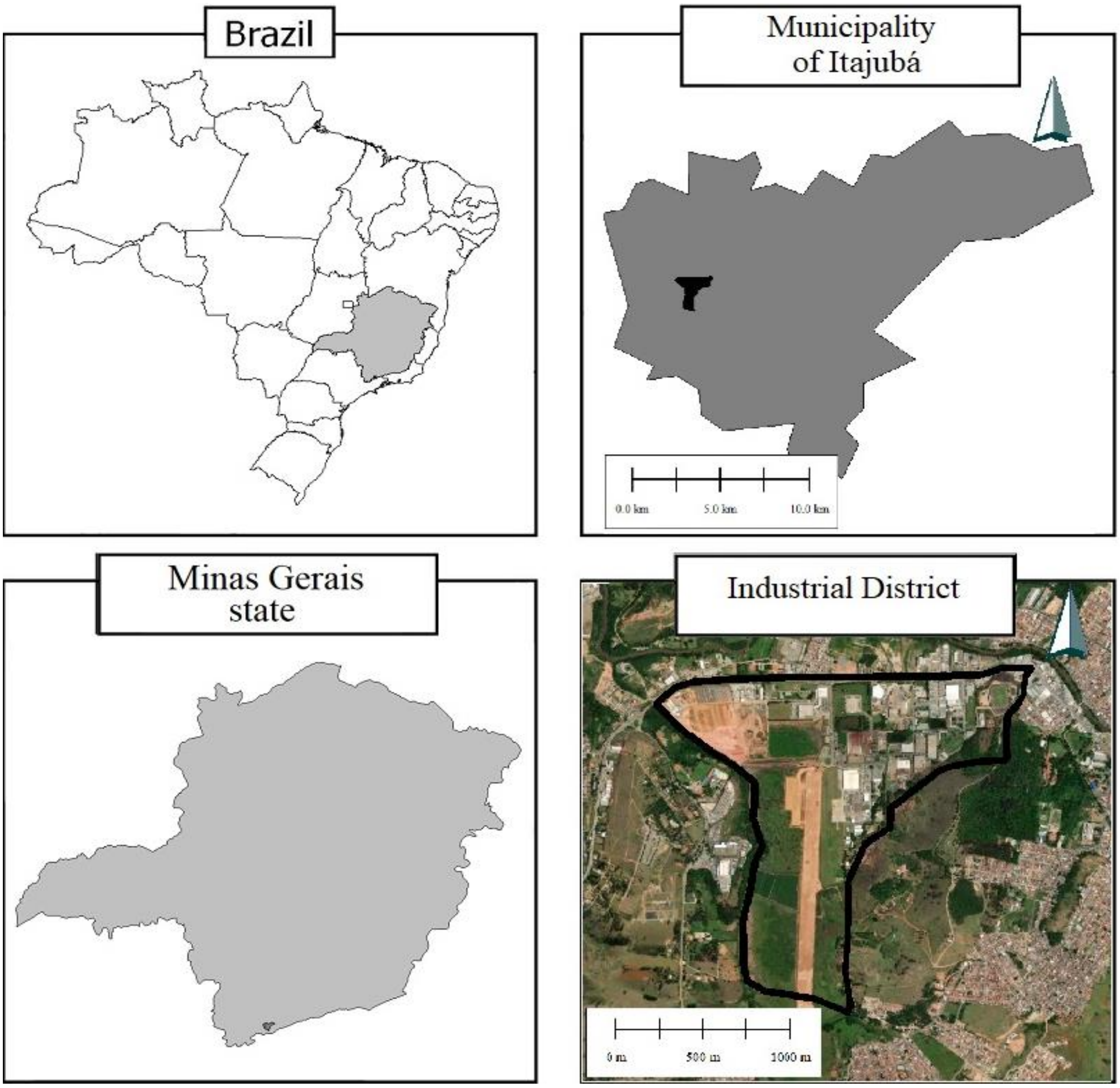

Figure 1. Map with the location of the Industrial District, in the municipality of Itajubá, state of Minas Gerais (MG), Brazil.

Figura 1. Mapa com a localização do Distrito Industrial, no município de Itajubá, estado de Minas Gerais (MG), Brasil.

The Sapucaí River basin has a drainage area of 982.36 km² and the Piranguçu River basin of 106.73 km². The Sapucaí River is strategic for the southern region of Minas Gerais, as its waters are used in public and industrial supply, irrigation, and the supply of the Furnas Hydroelectric Power Plant reservoir (Servidoni *et al.*, 2021; Vianna & Avelar, 2010). Both rivers originate in the Serra da Mantiqueira, at an altitude of approximately 1700 m, with a predominance of rounded top reliefs, concave-convex slopes, open alluvial plains, embedded valleys, and dendritic drainage (Sgarbi & Dardenne, 2002). The slopes vary from maximum extremes of 25% near the springs, until reaching average values in the rest of the plain stretch (Reis, 2014). The climate is tropical in altitude, with hot and humid summers and cold and dry winters, and average annual precipitation of 1,600 to 1,865 mm (Mello *et* *al.*, 2007; Sparovek *et al.*, 2007; Aquino *et al.*, 2012; Silva & Reboita, 2013), the rainy season being the months of October to March (Reboita *et al.*, 2010; 2017).

The study area is susceptible to flooding due to physiographic and morphometric characteristics, land use and occupation, and hydroclimatic trends in the region (Lorenzon *et al.*, 2014; Mendes *et al.*, 2019; Almeida *et al.*, 2017). According to Pinheiro (2005), Reis *et al.* (2016), Reboita *et al.* (2019), and Faria & Barbosa (2021) more than 74 flood events have been registered since 1821, with the largest magnitudes being in 1874, 1945, and 2000. On the other hand, the study area is valued by investors for having infrastructure and for being on the BR-459 highway.

2. Simulations and Analysis

The study area is the Industrial District of the municipality of Itajubá located in the state of Minas Gerais (MG), Brazil. The Industrial District is located between the left banks of the Sapucaí.

2.2.1. Step 1 – Occupation Scenarios (2005 to 2030)

The survey of the topography was carried out, from 2011 to 2019, in which more than 6000 points were collected, using the following equipment: Leica TS02 Total Station; and Leica CS09 GNSS Receiver. The collected points were processed in the Leica Geo Office 7.0 program and orthometrically corrected in the MapGeo 2015 program. These points were then imported into the Global Mapper V19 program, in an elevation grid format, creating Digital Elevation Models (DEMs) and saved in GeoTIFF (Georeferenced Tagged Image File Format) format.

From the images in Google Earth Pro 7.3, it was possible to characterize the growth of urbanization over the years with the changes that took place. However, 6 occupation scenarios were created (Fig. 2):

- Scenario 2005 - topography with area occupied in 2005, image dated 10/09/2005;
- Scenario 2013 - topography with area occupied in 2013, image dated 06/27/2013;
- Scenario 2015 - topography with area occupied in 2015, image dated 01/08/2015;
- Scenario 2017 - topography with area occupied in 2017, image dated 02/07/2017;
- Scenario 2019 - topography with the area occupied in 2019, but in the Area of Economic Interest of the Master Plan, the standard altitude of 840 m was used, the collection of points not being allowed, image dated 06/06/2019;
- Scenario2030 - used the scenario 2019, with the addition of 1 m of landfill in the Master Plan Economic Interest Area.

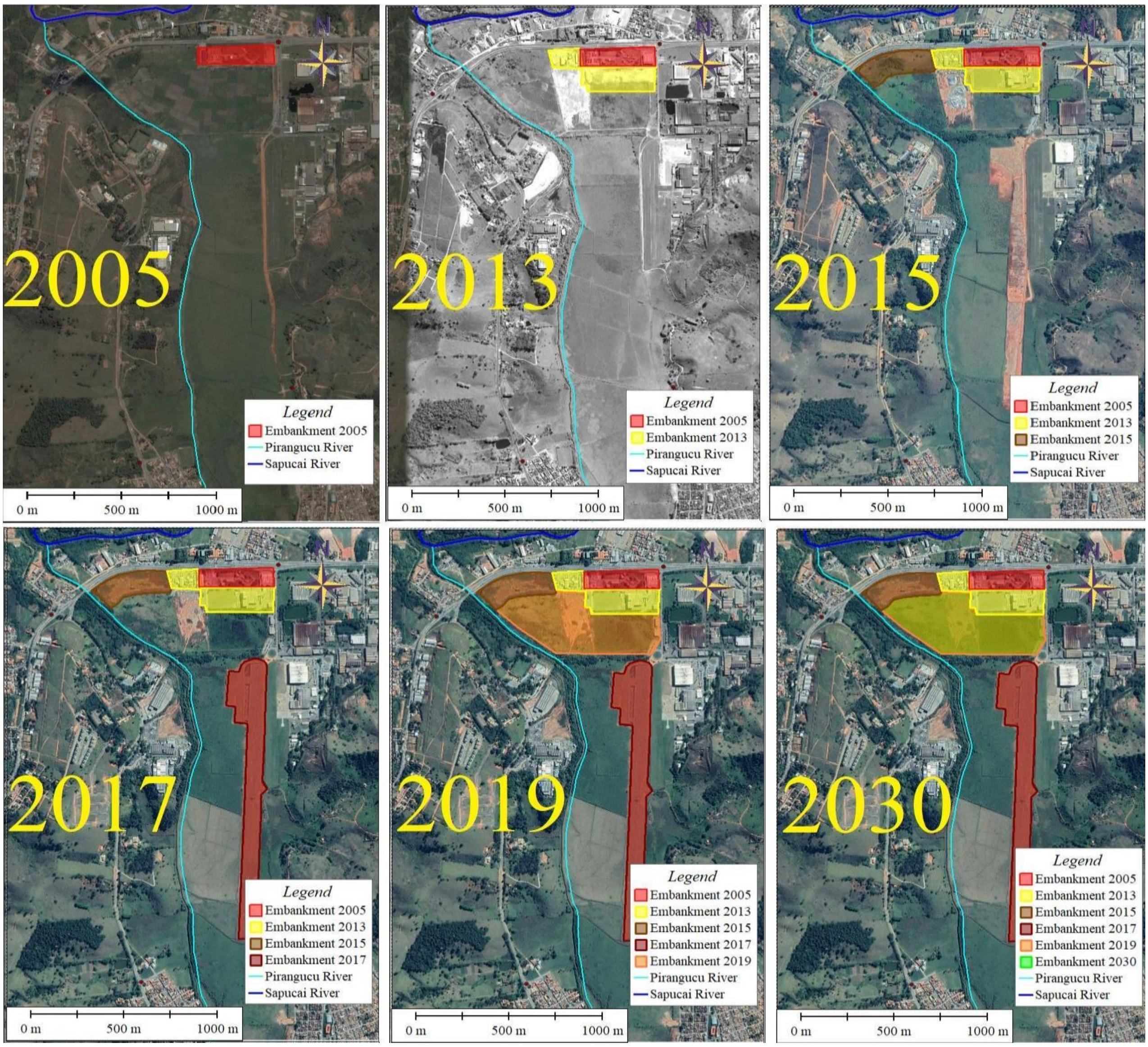

Figure 2. Scenarios of occupations in the years 2005, 2013, 2015, 2017, 2019, and 2030.

Figura 2. Cenários das ocupações nos anos de 2005, 2013, 2015, 2017, 2019 e 2030.

2.2.2. Step 2 – Flood Events

To characterize the floods that occurred, a survey of floods was made using cotagrams/hydrograms. These cotagrams/hydrograms were built with the support of the Water Information Laboratory (LIH) of the Federal University of Itajubá (UNIFEI), which is responsible for monitoring the main rivers in the upper basin of the Sapucaí River.

Five flood events were established for the construction of the cotagrams/hydrograms for the topobathymetric sections of the Piranguçu River and the Sapucaí River in the geographic coordinates presented in Table 1. These events have a duration of 240 hours and were defined as:

- **Event 1** – The event of greatest magnitude in 1874, according to studies by Moraes (2003) and Pinheiro (2005). Cotagrams of the event of the year 1874 in the Sapucaí River and the Piranguçu River;
- **Event 2** – Event of the year 2000 (Barbosa, 2000). Cotagrams of the 2000 event in the Sapucaí and Piranguçu rivers (Marciano, 2019);

- **Event 3** – 2000 event on the Sapucaí River. Cotagram of the 2000 event in the Sapucaí River (Marciano, 2019) and hydrograph with an average flow of 1.5 m³/s in the Piranguçu River;
- **Event 4** – Event of the year 2000 on the Piranguçu river. Cotagram of the 2000 event on the Piranguçu River (Marciano, 2019) and hydrograph with an average flow of 15 m³/s on the Sapucaí River;
- **Event 5** – 2013 event on the Pirangaçu river. Cotagram of the 2013 event in the Piranguçu River (Marciano *et al.*, 2018), and hydrograph with an average flow of 15 m³/s in the Sapucaí River.

Table 1. The geographic location of topobathymetric sections in the study area.

Tabela 1. Localização geográfica das seções topobatimétricos na área de estudo.

Topobatimetric Sections	**Coordinates**		
	Latitude	**Longitude**	**Height (m)**
Sapucaí River	22° 31' 11.6129" S	45° 29' 56.2733" W	834.48
Piranguçu River	22° 25' 18.5054" S	45° 29' 11.0080" W	852.07

2.2.3. Step 3 - Hydrodynamic simulation

The HEC-RAS 6.01 software was used to generate two-dimensional models that simulate the non-permanent runoff, from geometric data and runoff data (USACE, 2020). HEC-RAS is a complex modeling tool for shallow water, which includes a large number of applications for the 1D and 2D model, described by equations (1), (2), and (3) (USACE, 2020; Costabile *et al.*, 2020):

$$\frac{\partial h}{\partial t}+\frac{\partial p}{\partial x}+\frac{\partial q}{\partial x}=r \quad (1)$$

$$\frac{\partial u}{\partial t}+\frac{\partial}{\partial x}\left(\frac{p^2}{h}\right)+\frac{\partial}{\partial y}\left(\frac{qp}{h}\right)= -\frac{n^2pg\sqrt{p^2+q^2}}{h^2}-gh\frac{\partial H}{\partial x}+pf+\frac{\partial}{p\,\partial x}\,(h\tau_{xx})+\frac{\partial}{p\,\partial x}\,(h\tau_{xy}) \quad (2)$$

$$\frac{\partial u}{\partial t}+\frac{\partial}{\partial x}\left(\frac{pq}{h}\right)+\frac{\partial}{\partial y}\left(\frac{q^2}{h}\right)=-\frac{n^2pg\sqrt{p^2+q^2}}{h^2}-gh\frac{\partial H}{\partial x}+qf+\frac{\partial}{p\,\partial x}(h\tau_{xy})+\frac{\partial}{p\,\partial x}\,(h\tau_{yy}) \quad (3)$$

Where: $H(x,y,t)=z(x,y)+\ +h(x,y,\tau)$ is the surface elevation (m); z is the elevation of the cell in Cartesian coordinates x,y,t is the water depth (m); $p=hu$ and $q=hv$ are the specific flux in the x and y directions (m² s-1); u and v are the speeds at x and y; τ is the net rain (m); g is the acceleration of gravity (ms-2); n is the Manning roughness coefficient (s m-1/3); ρ is the density of water (kg m-3); τ_{xx}, τ_{yy} and τ_{xy} are the components of tensor stress and; f is the Coriolis parameter (s-1).

When the diffusive wave is selected, the inertial terms in Equations (2) and (3) are ignored. The above equations are solved with an implicit finite volume scheme.

The HEC-RAS software can calculate the fully dynamic 2D equation in shallow water based on joining an unstructured grid to a sub-grid based on high-resolution DEMs which can drastically affect model results as well as the performance (Costabile *et al.*, 2020; Shustikova *et al.*, 2019; Brunner 2016). Thus, Equation (1) is presented in full:

$$\frac{\Omega(H^{n+1}) - \Omega(H^{n})}{\Delta t} + \sum V_k . n_k . A_k(H) + R = 0 \tag{4}$$

Where: Ω is the three-dimensional volumetric space occupied by the fluid; R is the source term (net rainfall); V_k is the average velocity on face k with the normal vector n_k; $A_k(H)$ the average area on face k and the superscript n represents the time interval and Δt the integration time.

The integral form of Equation (4) is needed to calculate extra information (e.g. hydraulic radius, volume, cross-section data) at a pre-processing stage for each computational cell face (Quirogaa *et al.*, 2016; Aureli *et al.*, 2020). The sub-grid approach can be used to increase cell dimensions while preserving bathymetry details.

For the geometric data, we used the gutters and riverbanks inserted in GeoTIFF format (Step 1), and delimited the simulation flow with computational mesh polygons with spacing on the margins of 10 x 10 (m) and in the river channel of 5 x 5 (m).

For the flow data, we inserted the Manning roughness coefficient following the methodology of Chow (1959). And for certification, we measure flow using microwind flow meter equipment. The values used for the Manning coefficient were 0.12 for secondary gutters and 0.045 for the main gutter. We also inserted the cotagrams (step 2) and the average slope of the Sapucaí River stretch of 0.45 m/km.

2.2.4. Step 4 – Analysis locations

In order to assess the occupation of the area over the years, eight points were created within the study area, in order to make an overview of the floods. Table 2 shows the location of these points, and Figure 3 shows the layout of the study area. Points C, E, and F will be analyzed due to their locations. Point C is located in the expansion area of the Industrial District, point E is located at the main industries entrance roundabout, and point F is located near the airport runway (area that will not be grounded).

Table 2. Geographic location of topobatimetric sections in the study area.

Tabela 2. Localização geográfica das seções topobatimétricos na área de estudo.

Identification of Locations	Coordinates	
	Latitude	Longitude
A	22° 25' 23.7231" S	45° 29' 30.1677" W
B	22° 25' 27.3876" S	45° 29' 19.6086" W
C	22° 25' 32.4217" S	45° 29' 15.3744" W
D	22° 25' 36.5225" S	45° 29' 01.7138" W
E	22° 25' 39.3351" S	45° 28' 53.0274" W
F	22° 25' 46.8790" S	45° 29' 03.8757" W
G	22° 26' 11.4807" S	45° 29' 02.9268" W
H	22° 26' 45.6862" S	45° 28' 56.8392" W

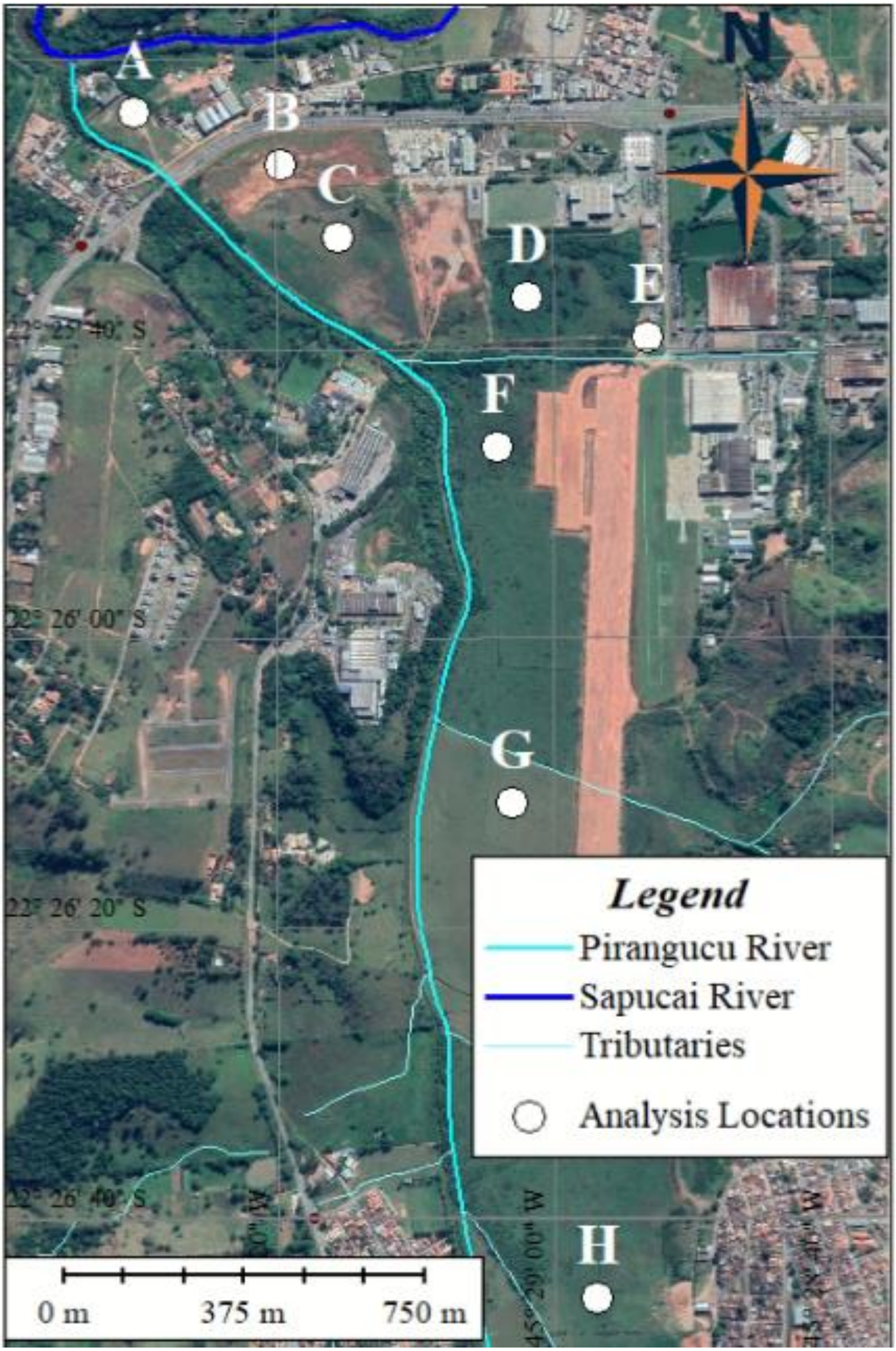

Figure 3. Analysis locations in the study area. Data source: Basemap ArcMap™ (2019).

Figura 3. Localizações das análises na área de estudo. Fonte de dados: Mapa Base ArcMap™ (2019).

3. Results and discussion

The results will be presented in four steps. The first stage consists of the digital terrain models, the second stage is the cotagrams / hydrographs constructed to represent the flood events, both of which are input data in the HEC-RAS software, the third and fourth stages are the results presented in maps and graphs, all followed by corresponding discussions.

3.1. Step 1 – Occupation Scenarios (2005 to 2030)

The topography for the six scenarios is shown in Figure 4. With the DEMs, it was possible to calculate the volume of the landfill in the respective years. Table 3 shows the amount of earth required for grounding. The largest volume of landfill was spent on the construction of the airport runway, therefore having a high financial cost, as it is located in a floodable area with soft soils (Carvalhais, 2017). The growth rate of the landfill increase was 927% compared to the 2005 scenario and 66% per year, disregarding the 2030 scenario, as it is a predicted scenario. These landfills are flood control measures, which aim to reduce the risks and damage caused by floods. It is evident that there is growing concern about the height of the landfill in the latter scenarios.

Table 3. Volume of landfills in occupation scenarios.

Tabela 3. Volume de aterros nos cenários de ocupação.

Occupation scenarios	Area (m²)	Volume (m³)	Average height (m)
Scenario 2005	41.200	13.873	0,33
Scenario 2013	71.100	71.868	1,01
Scenario 2015	50.500	102.102	2,02
Scenario 2017	175.700	491.486	2,80
Scenario 2019	206.200	466.523	2,26
Scenario 2030	370.000	370.000	0,99

3.2. Step 2 – Flood Events

For a better representation of the flood events, the simulation was standardized in 240 hours of duration. Figure 5 graphically shows the events:

- **Event 1** lasted 128 hours, the Sapucaí River reached a height of 5.45 m and the Piranguçu River 5.32 m above the average level, both rivers had a great performance in the event;
- **Event 2** lasted 120 hours, the Sapucaí River reached 4.52 m and the Piranguçu River 4.39 m above the average level, both rivers played a great role in the event;
- **Event 3** lasted 120 hours, the Sapucaí River reached 4.52 m above the average level and the Piranguçu River had an average flow of 1.5 m³/s, the Sapucaí river had greater participation in the event;
- **Event 4** lasted 105 hours, the Piranguçu river reached 4.39 m above the average level and the Sapucaí river had an average flow of 15 m³/s, the Piranguçu river had greater performance in the event and;

● **Event 5** was registered by the SME, lasted 12 hours, the Piranguçu river reached 3.20 m above the average level and the Sapucaí river had an average flow of 15 m³/s, the Piranguçu river had greater participation in the event.

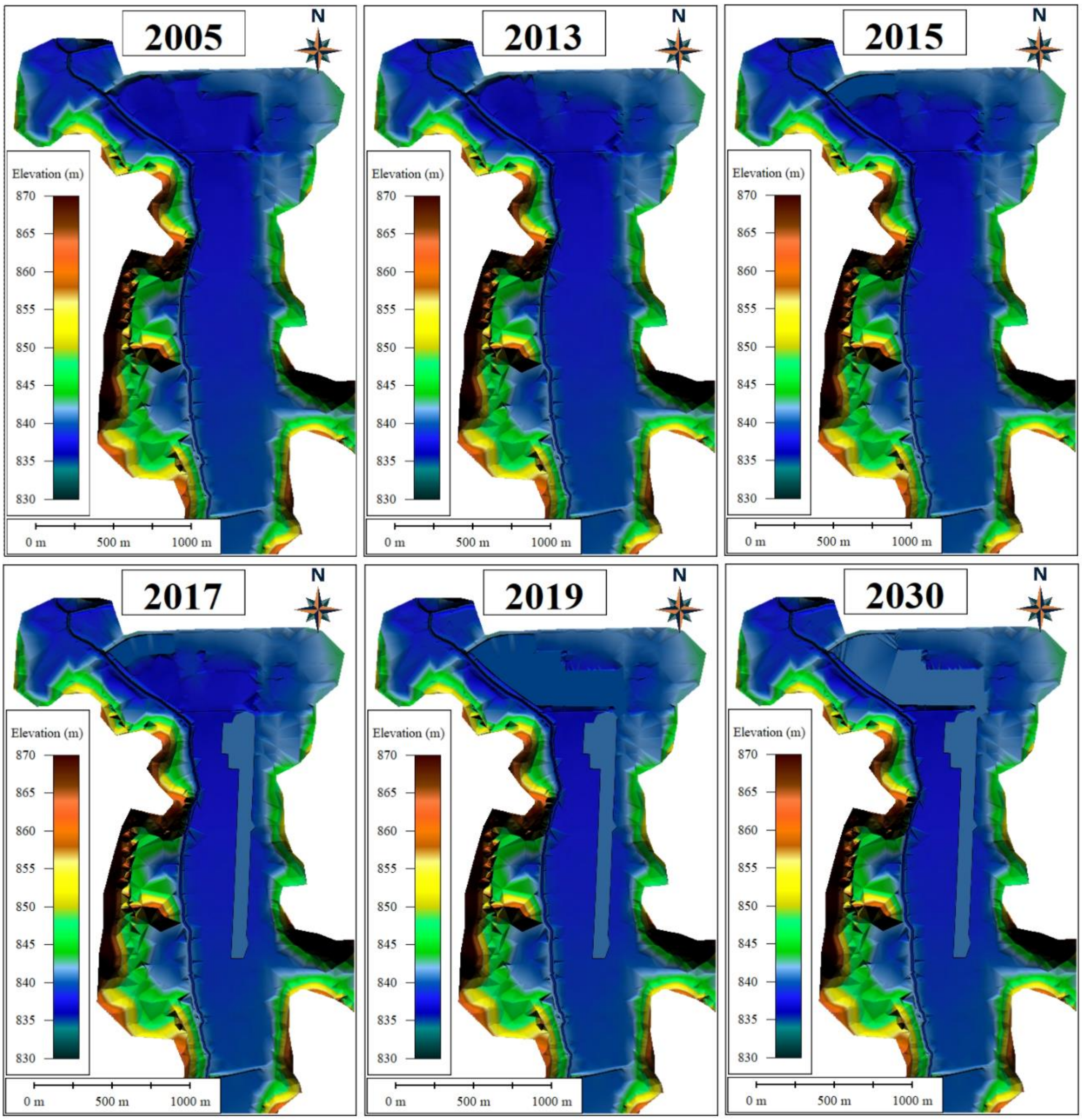

Figure 4. Scenarios of occupations (DEMs) in the years 2005, 2013, 2015, 2017, 2019, and 2030.

Figura 4. Cenários das ocupações (DEMs) nos anos de 2005, 2013, 2015, 2017, 2019 e 2030.

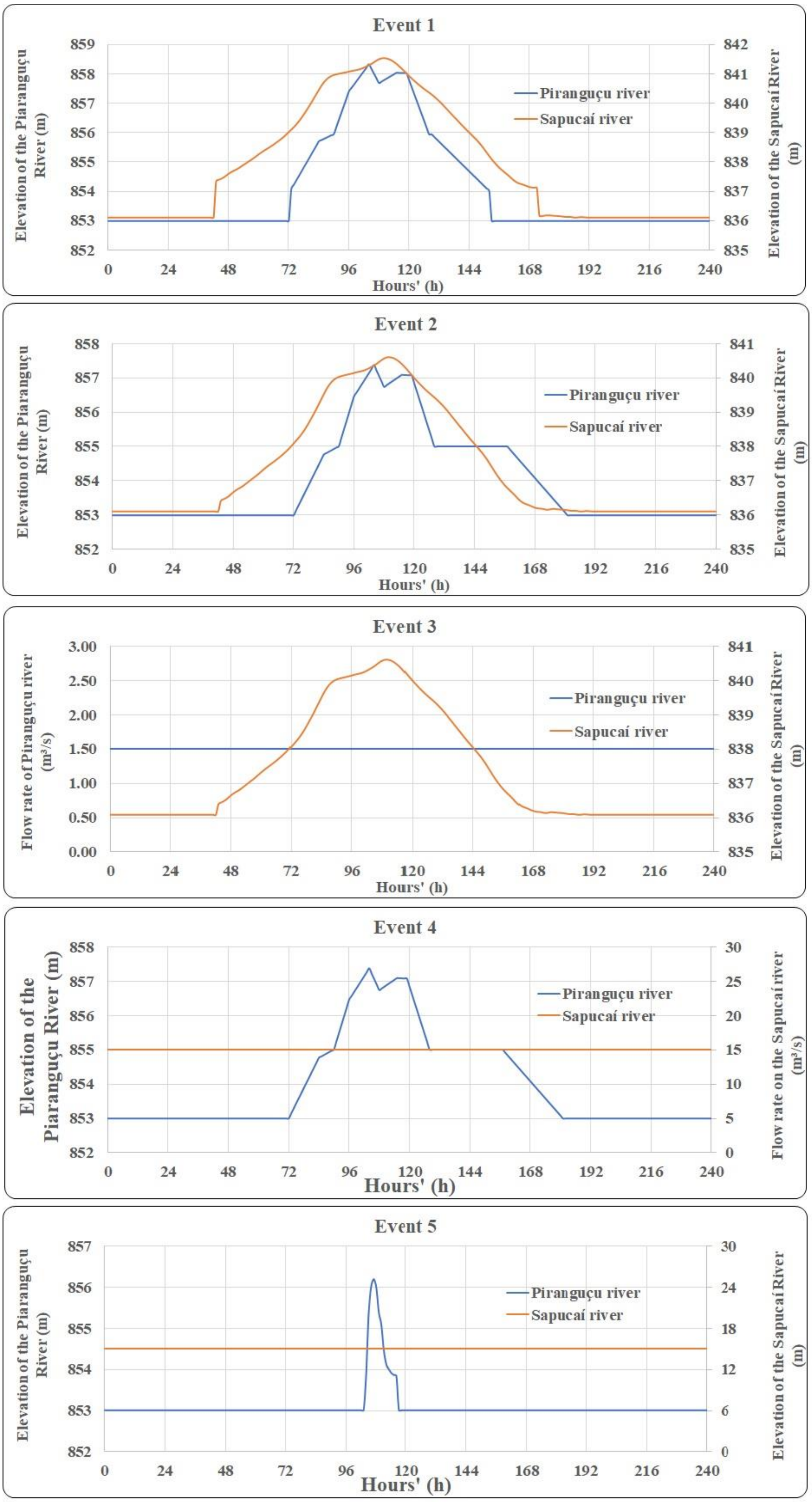

Figure 5. Cotagrams of the events of the Piranguçu and Sapucaí rivers.

Figura 5. Cotagramas dos eventos dos rios Piranguçu e Sapucaí.

3.3. Step 3 – Mapping of flooded area

With the results of the simulations, maps of the floodable areas were produced. Figures 6, 7, and 8 show the flooded areas and the occupied volumes in the study area.

- **Event 1** occupied the largest area and the largest volume filled by the flood, but according to Pinheiro (2005). In this 1874 event, there is no confirmation or photos, only reports from residents.

- **Event 2** the maps generated by the simulation of event 2 showed a greater floodable area and consequently a greater filled volume compared to events 3 and 4.

- **Event 3** showed that, in case of flooding of the Sapucaí River, its waters can enter the Piranguçu River, flooding its banks and damming the waters.

- **Event 4** had the flooded area and the volume filled by the flood greater than event 3, even with a lower flow, this is explained by the force of gravity, and the Sapucaí River had against the slope and flow of the Piranguçu River.

- **Event 5** is considered to be of low magnitude, as it did not have significant anthropogenic impacts, but it served to calibrate the simulations, as the SME recorded the event by the cotagram and the LIH collected the maximum altitude that the water level reached, making it possible to compare the result. The results found are very close to those found by Marciano *et al.* (2018).

In events 1 and 2, which are considered to be of great magnitude, the flooded areas increased and the flood volumes decreased in all scenarios. Events 3, 4 and 5 had the areas flooded and the flood volumes decreased over the occupation scenarios, but there was an increase in river flow as the landfills were occupied.

For the results of events 2, 3, and 4, the altitudes reached were confirmed according to the works of Barbosa (2000), Vianna (2000), Moraes (2003), Lima (2003), Pinheiro (2005), Moni (2006), Reis (2014), Barbosa *et al.* (2015), Martins *et al.* (2019), Marciano (2019), and Faria & Barbosa (2020), which proved to be coherent with regard to the flooded areas. In addition, these map results make it possible to scale the depth and calculate the flood volume of changing scenarios.

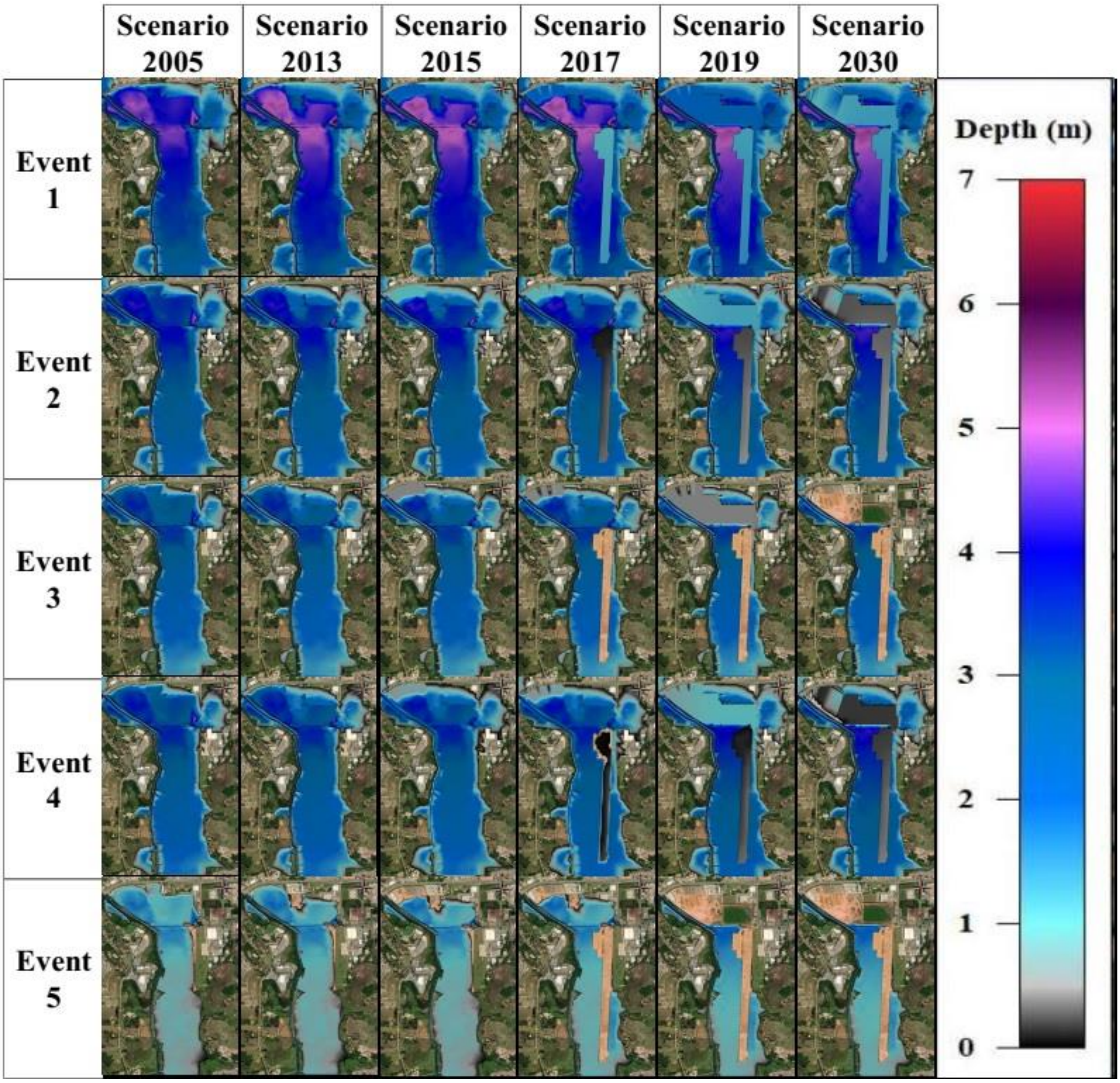

Figure 6. Flood maps from 2005 to 2030 in the study area. Data source: Basemap ArcMap™ (2019).

Figura 6. Mapas das cheias de 2005 a 2030 na área de estudo. Fonte de dados: Mapa Base ArcMap™ (2019).

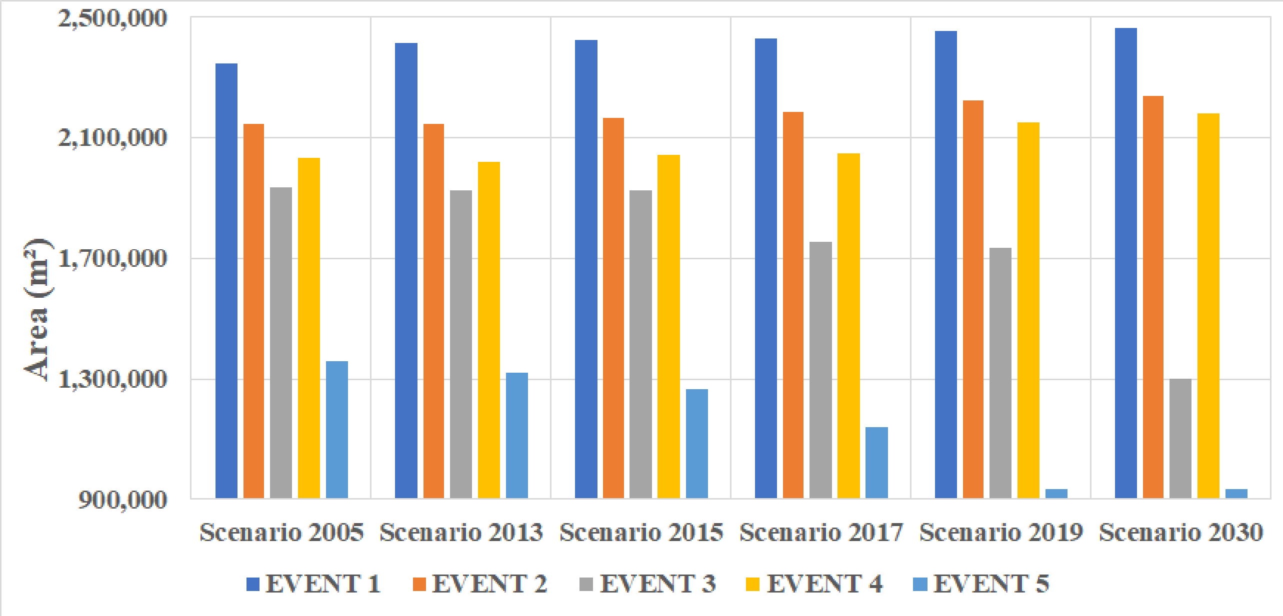

Figure 7. Flood area of simulated scenarios.

Figura 7. Área de inundação dos cenários simulados.

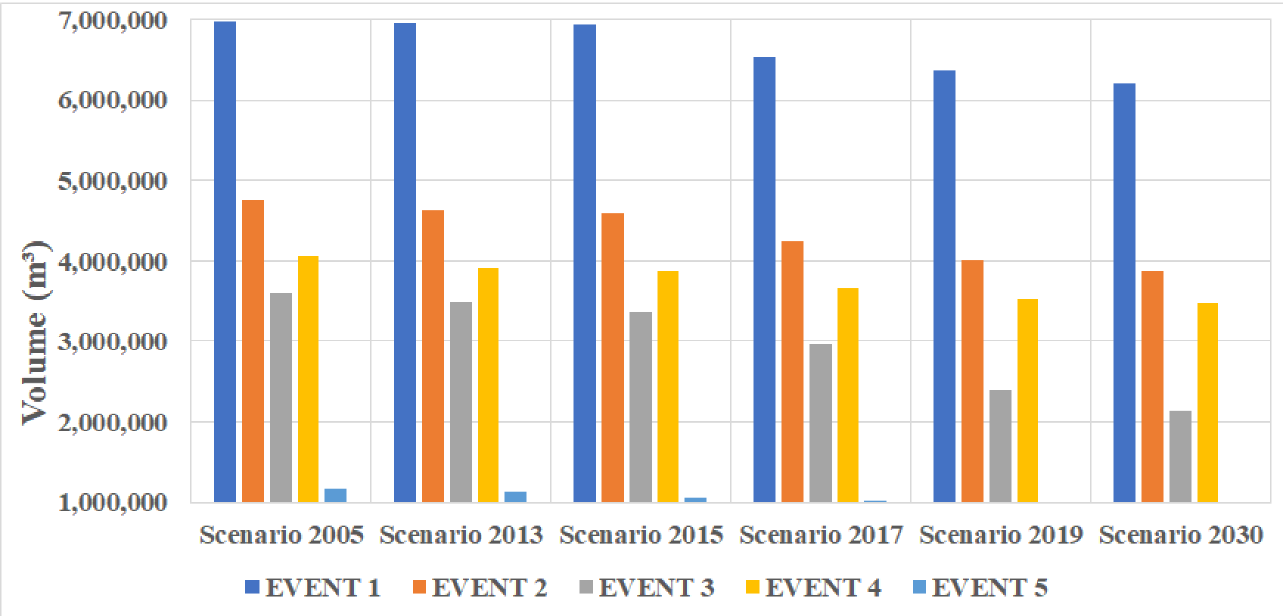

Figure 8. Flood volume of simulated scenarios.

Figura 8. Volume de inundação dos cenários simulados.

Point C is located in the area of economic interest of the municipality, which will undergo alterations to the facilities of industries. For this reason, it is noteworthy that the impact caused by the floods in 2005, 2013, 2015, and 2017 scenarios are minimal, compared to the 2019 and 2030 scenarios (predicting installed companies), even though the floods have reached a lower water level. In Figure 9, the variation in the water level reached by the floods from the 2005 scenario to the 2017 scenario was small, but in the 2019 and 2030 scenarios, there was an abrupt negative variation in the height of the water level.

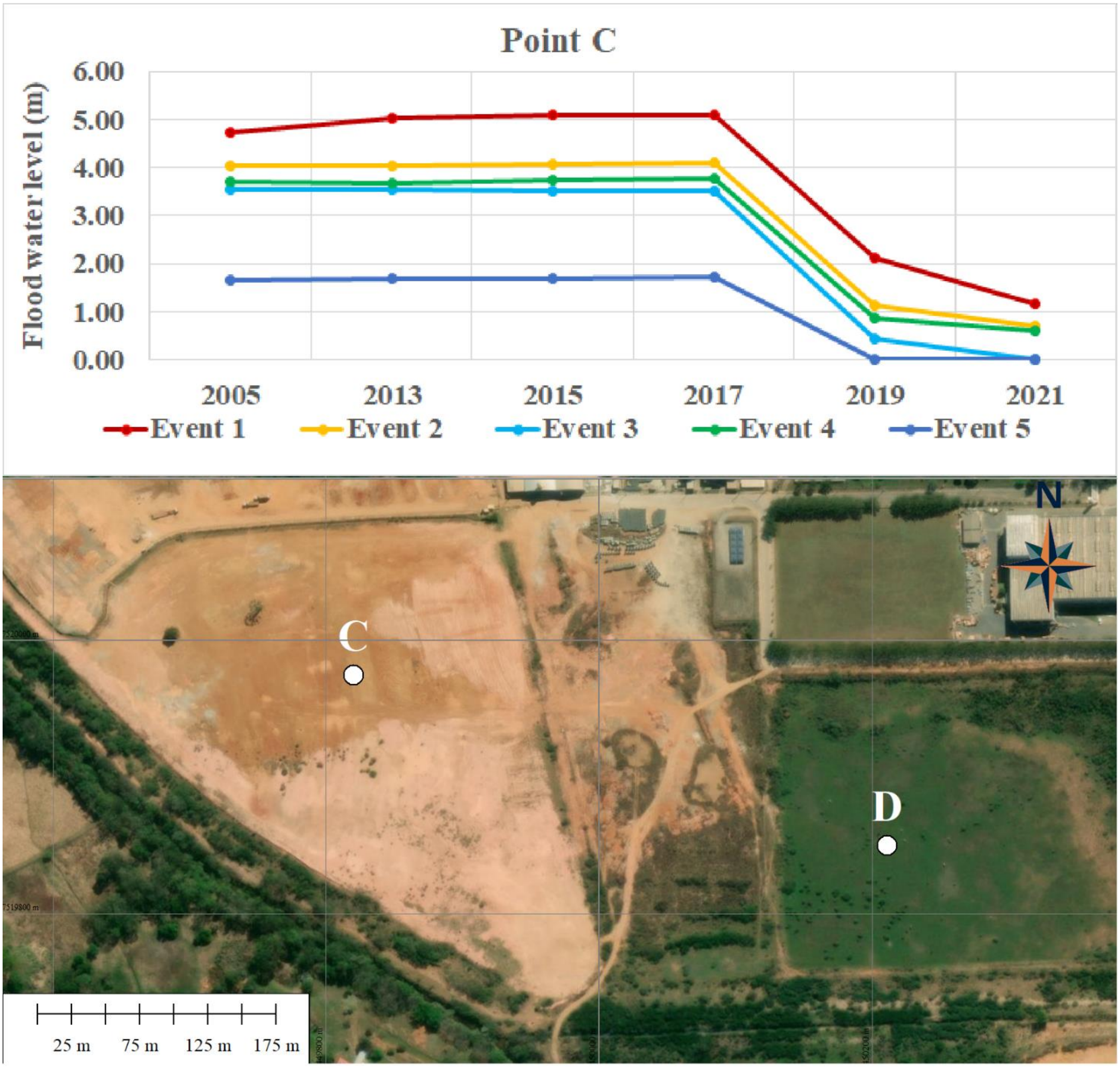

Figure 9. Graph of simulated floods and location of point C. Data source: Basemap ArcMap™ (2019).

Figura 9. Gráfico de cheias simuladas e localização do ponto C. Fonte de dados: Mapa Base ArcMap™ (2019).

Point E (Fig. 10) had the same trend as point C, with the floods being mitigated by the landfills. In an event of low magnitude there will be no flooding, the landfills will block the water.

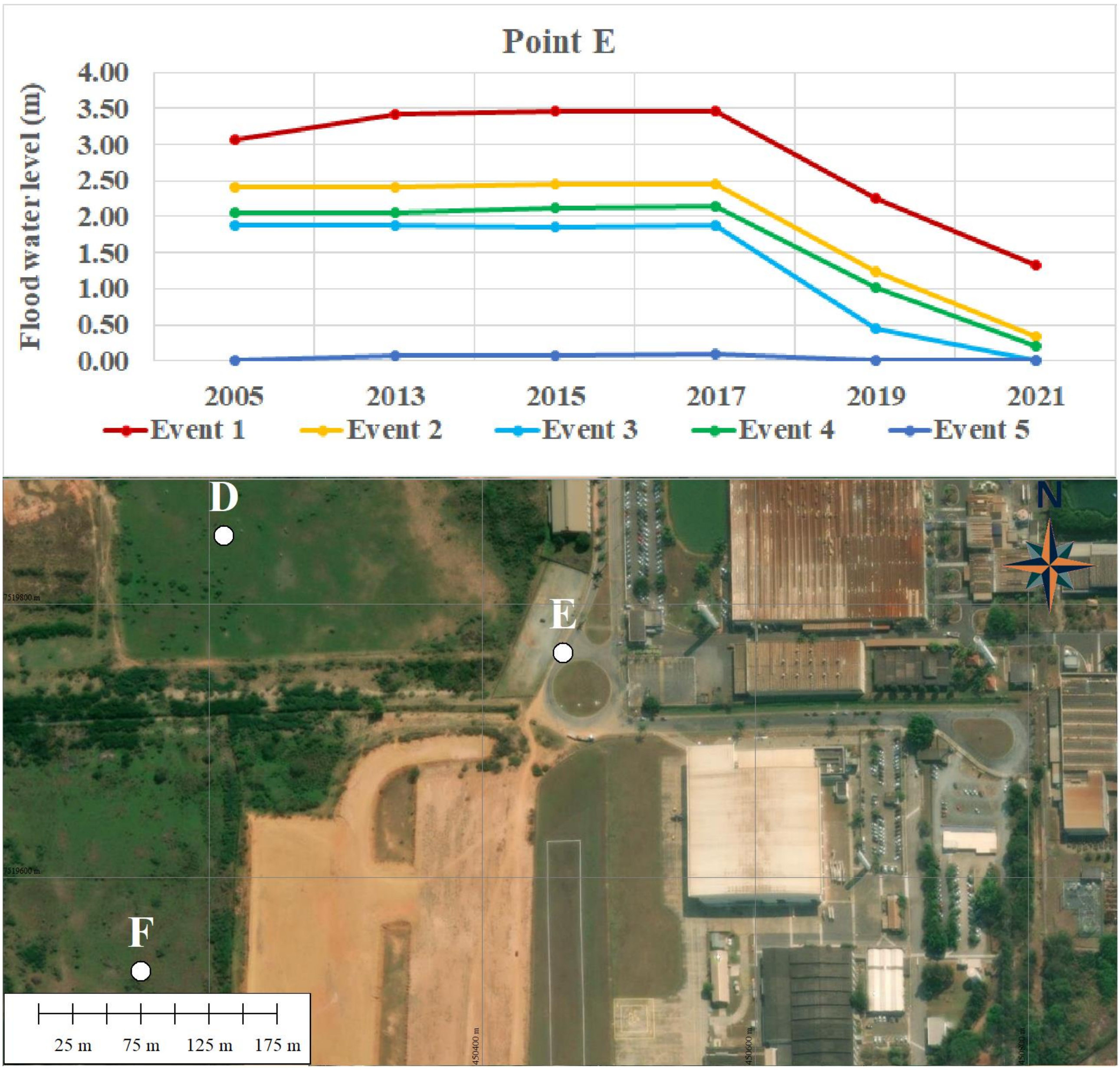

Figure 10. Graphic of simulated floods and the location of point E. Data source: Basemap ArcMap™ (2019).

Figura 10. Gráfico de cheias simuladas e localização do ponto E. Fonte de dados: Mapa Base ArcMap™ (2019).

Figure 11 shows point F which is on the left side of the airport landfill and upstream from the other landfills and the graph of the water levels reached by the floods. As landfills progress over time, water levels affected by flooding will increase in this area. The water that does not manage to surpass the barrier formed by the landfills will accumulate in this area, causing the water level and flow of the Piranguçu River to increase. However, the variation in the water level between the scenarios will be minimal, due to the size of the area upstream of point F that will be occupied by the flood.

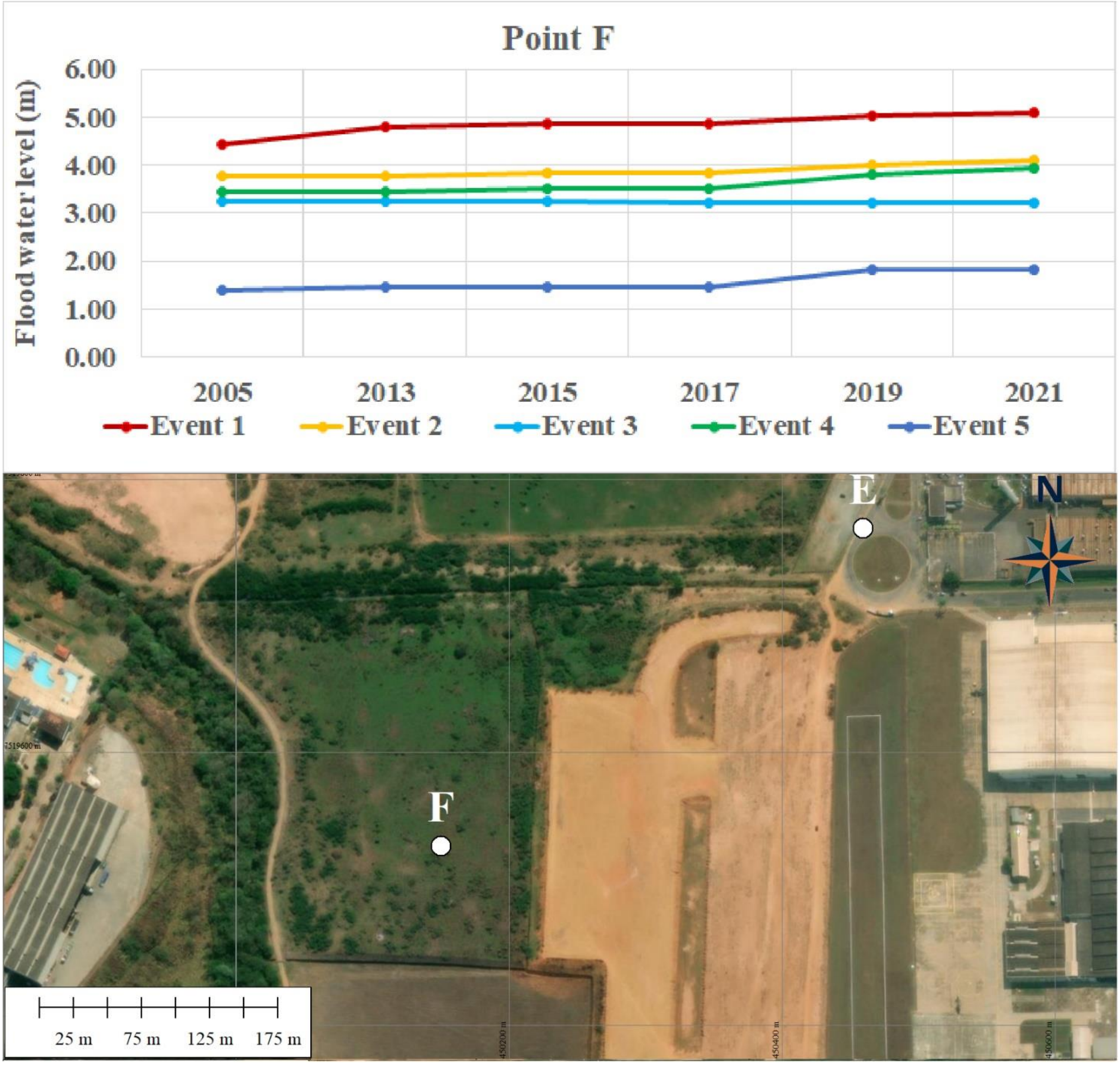

Figure 11. Graph of simulated floods and location of point F. Data source: Basemap ArcMap™ (2019).

Figura 11. Gráfico de cheias simuladas e localização do ponto F. Fonte de dados: Mapa Base ArcMap™ (2019).

With the analysis of the points, it was possible to compare with the study by Marciano *et al.* (2018), which confirmed that the airport built in 2017 (scenario 3) will impact the flow of a flood. However, this impact on the flow will be insufficient to cause damage to companies installed in 2021 in the Industrial District.

5. Conclusion

Topography and bathymetry data are costly and time-consuming to acquire and are responsible for most of the errors in the simulation. However, it is worth noting that the 2019 scenario has little topography data, as the fieldwork team was not authorized to collect data on-site. Also, the presence of hydraulic structures (bridges) that would increase the representativeness of the model was not inserted.

Despite the limited topographic and bathymetric data, it was possible to demonstrate that there is an increase in the urban growth rate in the study area, associated with the good infrastructure that exists there. However, it occupies a floodplain area, which is frequently flooded by the waters of the Piranguçu River. In this sense, a hydraulic/hydrological study is essential to understand the characteristics of the river and for investment by public and private companies.

With the changes in scenarios, it was found through simulations, that small and medium intensity flood events in the Piranguçu River will have the waters retained by the embankments of the 2019 and 2030 scenario. And in the occurrence of high-intensity flooding, the waters will suppress the embankments, flooding them. The landfill will bring investments from public and private companies, but when there is a high-intensity flood, the economic impacts will be incalculable compared to the 2005, 2013, and 2015 scenarios where these areas were used for grazing.

These results can support managers' decision-making by providing information for understanding several variables related to flooding, such as the area that will be flooded, duration and rate of water rise, and social vulnerability. It is emphasized that the goal is to analyze the behavior of the Industrial District area over time and flooding. Upstream and downstream areas may change with changing scenarios. For example, the confluence of the Piranguçu River with the Sapucaí River, which is not part of the study area, may have a significant increase in water level in floods.

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