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A Python implementation for the simplified dam-break flood modeling

Uma implementação em Python para a modelagem simplificada de manchas de inundação em rompimento de barragens

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ABSTRACT

Since 2010, the Brazilian government has required that dams that fall within the national dam policy must present a safety plan, which, among other topics, must address the definition of the hypotheses and possible disaster scenarios. To achieve it, the flood zone due to an eventual failure must be modeled for the Hazard Potential (Dano Potencial Associado – DPA) classification. The flood zone is the result of complex hydraulic phenomena that are difficult to characterize. Given the demand for DPA analysis and the data unavailability, the National Water Agency (Agência Nacional de Águas - ANA) proposed a simplified methodology for generating the flood zone. This paper proposes a Python implementation for this methodology with a user-friendly Graphical User Interface. Our implementation relies on free and open-source software. The results are similar to those produced by the original implementation and can be generated considerably in less time and with less user interaction.

Keywords: Flood zone; Dam failure; Python; Software; Hazard Potential.

RESUMO

Desde 2010, o governo brasileiro exige que as barragens que se enquadram na política nacional de barragens apresentem um plano de segurança que, entre outros tópicos, deve abordar a definição de hipóteses e possíveis cenários de desastre. Para isso, a mancha de inundação causada pelo possível rompimento deve ser modelada para a classificação da barragem quanto ao Dano Potencial Associado (DPA). A mancha de inundação é resultado de fenômenos hidráulicos complexos e difíceis de caracterizar. Diante da demanda por análises de DPA e da indisponibilidade de dados, a Agência Nacional de Águas (ANA) propôs uma metodologia simplificada para geração da zona de inundação. Este artigo propõe uma implementação em Python para esta metodologia com uma interface gráfica amigável ao usuário para a modelagem simplificada de manchas de inundação causadas pelo rompimento de barragens. Nossa implementação é baseada em software livre e de código aberto. Os resultados são similares aos produzidos pela implementação original e podem ser gerados consideravelmente em menor tempo e com menos interação do usuário.

Palavras-chave: Mancha de inundação; Rompimento de barragem; Python; Programa de computador; Dano Potencial Associado – DPA.

INTRODUCTION

Dams are important structures for society, whether they are built for irrigation, water supply, power generation, mining, among others purposes. In a dam failure event, reservoir's volume is released unexpectedly. This can cause considerable social, economic and environmental risks, and impacts.

In 2010 the Brazilian federal government enacted the Federal Law n° 12.334 (reformed through Federal Law n° 14.066/2020) (Brasil, 2010), which established the National Dam Safety Policy (Política Nacional de Segurança de Barragens - PNSB) and created the National Information System on Dam Safety (Sistema Nacional de Informações sobre Segurança de Barragens - SNISB). The law assigns to the public agency that authorized the construction of the dam is responsible for its supervision.

The dam classification systems according to the Article 7 of the above-mentioned law must be based on 1) Risk Category (Categoria de Risco - CRI), which considers its technical characteristics, state of conservation and compliance with the dam's safety plan, and on 2) Hazard Potential (Dano Potencial Associado - DPA), which is based on the potential loss of human life and the economic, social and environmental impacts arising from an eventual dam failure.

A dam falls under to the PNSB if it reaches at least one of the following criteria: a) height greater than or equal to 15m; b) volume greater than or equal to 3,000,000 m³; c) reservoir containing hazardous waste according to applicable technical standards and; d) medium or high DPA; e) high CRI, at discretion of the government agency responsible.

For the dams in general with medium or high potential for damage, or high-risk dams, the entrepreneur have a legal obligation to prepare the Emergency Action Plan (Plano de Ação de Emergência - PAE), a document included in the scope of the Dam Safety Plan (Plano de Segurança da Barragem - PSB) which is an instrument of the PNSB. This legal document imposes entrepreneurs to assess the adverse consequences in the event of a dam failure. It requires the modeling of induced floods and the mapping of the flood zone.

Although the production of the flood zone is the entrepreneur's responsibility, government agencies need to verify the results before authorizing the construction or granting its regulation. Furthermore, agencies often need to classify the risk of dams constructed before the enactment of the national dam safety policy.

The flood zone is the result of complex hydraulic phenomena that are difficult to characterize. The dam failure results in an instantaneous increase in flow in the downstream stretch of the river, originating a giant wave front that, as it propagates, causes a rise in the water level and flooding of the banks. The energy accumulated in the dam is released downstream in the form of a flood wave and has destructive effects until the total energy dissipation.

For the analysis of the flood wave propagation, there has been an increase in the number of researches and the development of hydraulic numerical models, such as the dynamic modeling through the HEC-RAS (2021). These methods aim to solve the complete Saint-Venant equations using numerical methods (Rossi et al., 2021). However, dynamic modeling requires a series

of technical data on the dam, on the topography and trained personnel for its application, which currently in Brazil, especially for the government agencies, are limiting factors (Petry et al., 2018; Carregosa, 2022).

Given to data unavailability and the shortage of trained personnel in government agencies, the National Water Agency (Agência Nacional de Águas - ANA) supported by the World Bank and in partnership with the National Civil Engineering Laboratory of Portugal (Laboratório Nacional de Engenharia Civil - LNEC) developed a simplified methodology for generating the flood zone (Melo, 2015; Petry et al., 2018). This method is based only on height, volume and location, and takes topographic data from Digital Elevation Model (DEM) from the Shuttle Radar Topography Mission (SRTM) with 30 meters of spatial resolution to replaces the numerical simulation of the hydrograph propagation along the downstream valley with empirical expressions.

The simplified dam-break flood modeling was proposed by Melo (2015) and modified later by ANA to better adapt to Brazilian dams' reality. Other authors proposed different simplified methods (Cunge, 1969; Wetmore & Fread, 1981; Rossi et al., 2021)

Although its results are approximations, it allows previous estimates about potential risk areas in the event of an accident. The zone generated in this way is for classification purposes and does not replace the dam failure study that must be carried out by the entrepreneur.

The determined flood polygon is superimposed on satellite images for analysis and classification into Hazard Potential categories. All features relevant to the national dam safety policy that are found within the zone, namely: homes, roads, industries, environmental conservation units, among others, generate a score. Thus, DPA is classified into three categories: Low, Medium or High according to the sum of the scores.

Although the methodology developed is simple and straightforward and has shown satisfactory results in several case studies (Ferla, 2018; Gonçalves, 2018; Fernandes et al., 2021) the current implementation, made available by Agência Nacional de Águas (2017c), has some disadvantages. It relies on Microsoft Excel and ESRI ArcGIS with Analyst and Spatial Analyst extensions, paid and closed-source software that is often not available to technicians from government agencies. The implementation is little automated and depends on plenty of interaction from a user with experience in GIS software. The national water agency estimates that the time taken to apply the methodology is about two hours, however, for novice users this time can extend. This is the time spent to generate results from the spreadsheets, scripts and GIS software. The DPA analysis should take as much time as necessary since it involves human lives and environment damage.

In recent years, Python has gained prominence among professionals from different areas for its versatility, ease of writing and reading and wide variety of available libraries that offer useful functionalities with high performance. For these reasons, a Python implementation for the simplified methodology for generating a flood zone due to a dam failure is proposed in this paper.

Our implementation, suited only for the DPA analysis purpose and should not be used for a complete dam break analysis, is based on free and open-source software, considerably decreases the number of steps, user interaction, the necessity of

previous experience in GIS software and time needed to apply the methodology compared to the original implementation. At the same time that it produces similar results.

LITERATURE REVIEW

The first step of the simplified dam-break flood modeling is the empirical calculation of the length of the river to be modeled. According to Petry et al. (2018), one of the main simplifications of the methodology is that the maximum water volume stored in the reservoir is the most relevant factor in determining the distance downstream to where the effects of the rupture wave are felt. Analyzing real cases of dam failures (The World Bank, 2014), a regression curve (Figure 1) was established, relating the stored volume with the maximum distance downstream of the potentially affected zone.

In order for this curve to be continuous, thus enabling the automation of the procedure, the minimum limit of 6.7 km was imposed, based on the fact that at this distance at least 50% of fatalities occur, and at most 100 km, a value considered sufficient for DPA classification. Minimum and maximum limits are shown in Figure 1 by the dashed lines.

The regression is defined by Equation 1. The equation is valid for volumes between 0 hm³ and 1000 hm³ (The World Bank, 2014).

$$L = 8.87 * 10^8 V^3 - 2.6 * 10^{-4} V^2 + 0.265V + 6.74 \quad (1)$$

Where:

L: length along the river that will be affected in the event of a rupture in km

V: dam volume in hm

If L < 5 then L = 5; if L > 100 then L = 100.

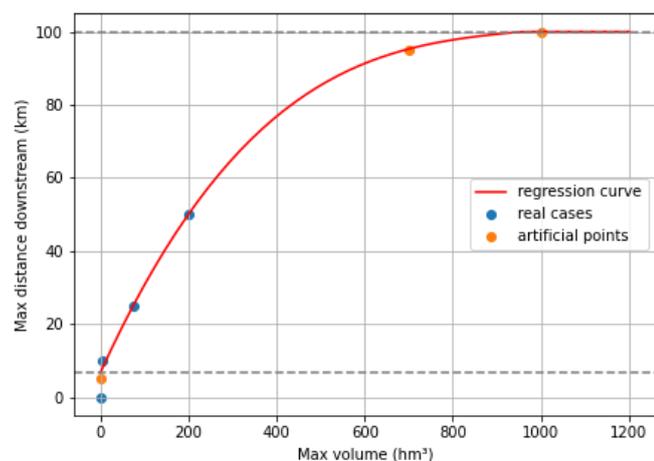


Figure 1. Relation between the maximum distance affected by the dam break and the maximum stored volume. Blue dots are real observed cases while orange dots are artificial added for a better fit of the regression curve. Grey dashed lines represent both minimum and maximum limits regarded as sufficient for DPA assessments. The red regression line is represented by Equation 1. Modified from The World Bank, 2014.

Both rupture and dampened flows calculations along downstream of the dam, are made using empirical equations available in the literature. For the maximum rupture flow in the dam, the equations of Froehlich (1995) and MMC - Mapping, Modeling and Consequences Production Center from the U.S. Army Corps of Engineers were adopted, depending on the relationship between height and volume of the dam.

For high volumes in relation to height, the methodology uses the MMC equation (Equation 2).

$$Q_{max} = 0.0039(V_{max}^{0.8122}) \quad (2)$$

Otherwise, the Froehlich equation (1995) (Equation 3) is used:

$$Q_{max} = 0.607(V_{max}^{0.295} H_{max}^{1.24}) \quad (3)$$

Where:

Q_{max} : dam failure flow in m³/s

V_{max} : dam volume in m³

H_{max} : dam height in m

For the dampened flow along the valley, two equations are used. In the case of dams with a volume greater than 6.2 hm³, the recommendations proposed by the United States Bureau of Reclamation - USBR are followed (Equation 4), in which the damping depends only on the distance “x” of the section from the dam.

$$Q_x = Q_{max} 10^{-0.01243x} \quad (4)$$

Where:

Q_{max} : dam failure flow in m³/s

x: distance from dam in m

Q_x : flow x meters distant from the dam in m³/s

For volumes below 6.2 hm³ the abacus proposed by The World Bank (2014) is adopted, in which the damping depends on the distance x and volume V_{max} of the reservoir. From the abacuses, Equation 5 was defined.

$$\frac{Q_x}{Q_{max}} = ae^{bx} \quad (5)$$

Where:

$$a = 0.002 \ln(V_{max}) + 0.9626$$

$$b = -0.20047(V_{max} + 25000)^{-0.5979}$$

Parameters a and b are obtained by multiparametric regression from the five curves shown in the Figure 2.

Up to this point in the methodology workflow, all estimates were based only on dam’s and its reservoir characteristics, especially height and volume, which allows estimating maximum flows along the modelled area.

In this step, it is expected to transform the flows obtained in the previous steps into heights of the flood wave in several cross sections along the river tracing. First, the user must manually trace dam’s river downstream talweg, up to the distance defined by Equation 1. This can be done in any GIS software.

Then, a smoothing of the talweg must be carried out, which has the main purpose of eliminating sharp curves in the original river tracing and thus minimizing the crossings between sections perpendicular to the channel. Intersecting sections can generate

undesirable geometric artifacts in the models. The perpendicular sections can be rotated in relation to its center to avoid intersections.

Agência Nacional de Águas (2017b) recommends tracing 21 sections perpendicular to the smoothed river trace. A 4000-meter length for the sections is appropriate for most case studies. Figure 3 shows the river tracing in red, a simplified tracing by 8 lines in blue and 21 non-intersecting sections with 4000 meters long each.

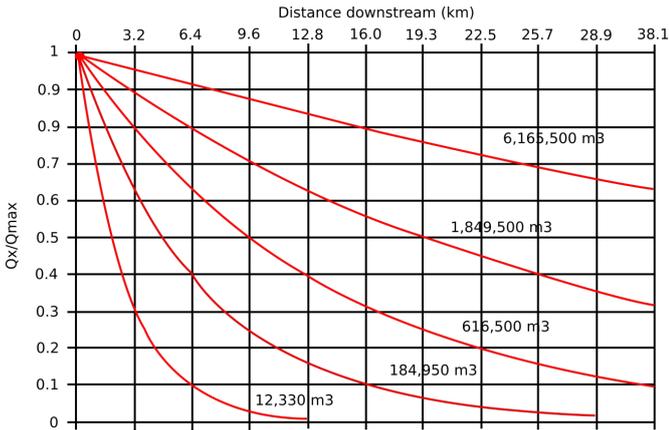


Figure 2. Damping of the maximum flow with the distance to the downstream for five different dam volumes. Modified from The World Bank, 2014.

The topographic profile of each cross section must be surveyed as accurately as possible. In general, the most available data for this survey is the SRTM. However, the DEM can be obtained by topographic survey with total station or drone.

Agência Nacional de Águas (2017b) recommendation is to discretize each cross section in 81 equidistant points and query its altitude from the SRTM file.

Having the topographic profile of each section, the hydraulic calculations can be done for each section by Equation 6.

$$\frac{Q_x}{\sqrt{J}} = K_s A R^{\frac{2}{3}} \quad (6)$$

Where:

Q_x : flow x meters distant from the dam in m^3/s

j : energy line slope

K_s : Manning-Strickler roughness coefficient ($K_s = 15 m^{1/3}s^{-1}$)

A : flow section area (m^2)

R : flow section hydraulic radius (m)

R is defined as the flow section area divided by the flow section perimeter.

Figure 3 shows in blue the talweg slope for a real-world example, which is the altitude of the central discretization point at each of the 21 sections. In orange, Figure 4 shows the mean slope and in green the energy line slope j , which takes into account the dam height.



Figure 3. River tracing in red, its simplification by 8 lines in blue and 21 non-intersecting sections in white.

Figure 5 shows, in the left-hand side, the topographic profile for section 4 from the Figure 4 example. 10 heights, from 0 to the dam height were traced in the profile and are shown by the green lines. For each height, the maximum flow is calculated using Equation 6. The right-hand side in Figure 6 shows the same heights in the y axis and the calculated flow in the x axis. From the 10 height/flow pairs a cubic polynomial regression curve can be fitted.

Since the maximum flow for each section can be calculated with Equations 4 and 5, the water height for each section can be retrieved from the regression curve, as shown by the red line.

The maximum water heights are calculated in this way for all 21 sections. Between the sections, in a region circumscribing the sections, the water heights are triangulated, generating a Triangular Irregular Network (TIN) representing the water surface. Finally,

the topography, obtained from the SRTM, is also triangulated. Thus, the intersection between both surfaces is the boundary of the flood zone.

Current implementation

The implementation proposed by Agência Nacional de Águas (2017) consists of the following steps:

1. Prepare the environment in ESRI ArcGIS using a Python script developed by ANA;
2. Input dam parameters into a massive hydraulic calculation Excel spreadsheet developed by LNEC which returns values that should be used in the next steps;

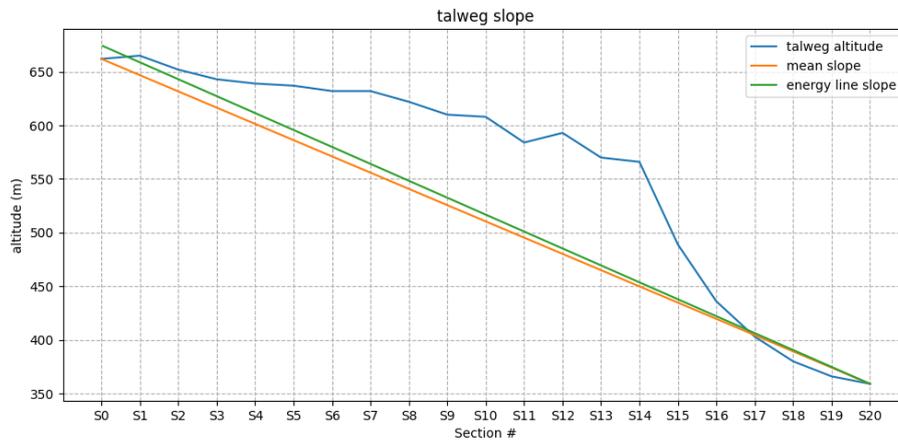


Figure 4. Schematic figure showing the river talweg, the mean slope and the energy line slope j.

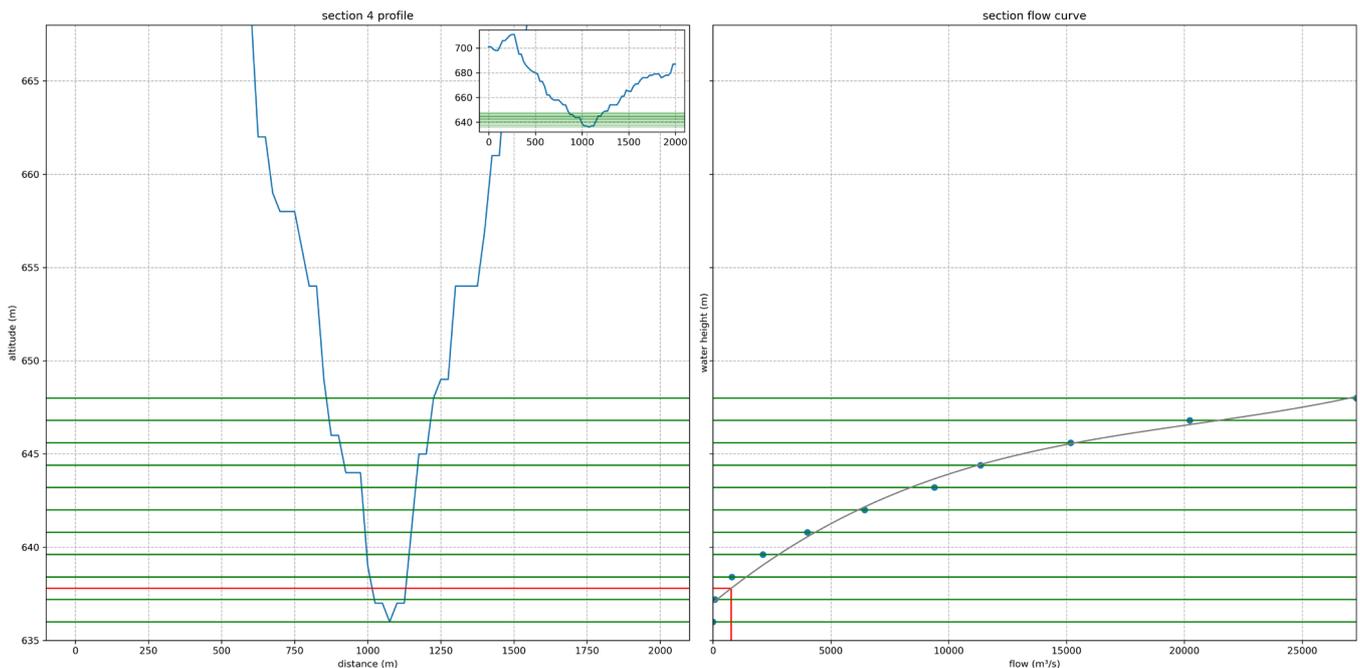


Figure 5. Schematic figure showing the topographic profile for a section in the left-hand side and 10 heights from 0 to the dam height as green lines. The right-hand side shows the same 10 heights in the y axis and the calculated flow in x axis. The red line shows the water height for this section retrieved from the regression curve.

The screenshot shows a software window titled "Mancha de inundação" with three tabs: "Passo 1", "Passo 2", and "Passo 3". The "Passo 1" tab is active. It contains the following fields and values:

Latitude	-30,0845
Longitude	-51,1126
Altura da barragem (m)	12,00
Volume armazenado (m ³)	3000000,00
Calcular	
Comprimento do rio (km)	7.53

Figure 6. First step (Passo 1). User must inform dam parameters such as coordinates (Latitude and Longitude), stored volume in m³ (Volume armazenado) and dam height (Altura da barragem).

3. Load the desired SRTM into ESRI ArcGIS and manually define the river trace with the length given by the hydraulic calculation spreadsheet;
4. Smooth the river tracing using a Python script developed by ANA;
5. Define 21 cross sections along the smoothed river path using ESRI ArcGIS;
6. Run a Python script developed by ANA which crops the SRTM by the river trace extension and sections; projects this SRTM in UTM; transforms the cross sections into a series of points; obtains the elevation of these points through the projected SRTM and generates an Excel spreadsheet;
7. Manually edit the Excel spreadsheet generated by the Python script; copy the data into another Excel spreadsheet and run a macro function to properly format the data;
8. Copy and paste the data from the previous step spreadsheet into the hydraulic calculation spreadsheet;
9. Copy and paste the results from the hydraulic calculation spreadsheet into the step 7 spreadsheet;
10. Run a Python script developed by ANA to generate the flood zone in ESRI ArcGIS based on the maximum elevation values of the simulated flood wave: subtracting point-by-point the SRTM values from the values of this surface. The flood zone in vector format can be exported for viewing in Google Earth.

Although numerous, the steps are straightforward, easy to understand and do not require the user to perform mathematical calculations manually. However, some experience with GIS software and data manipulation between different tables, which is error prone, is necessary.

MATERIALS AND METHODS

The Python implementation proposed in this paper aims to simplify the original implementation making it independent of paid and closed-source software, reducing user interaction and time needed for its application. Furthermore, there is no need for prior experience with GIS software. The source code, a portable version, and use instructions are available in the git repository: https://github.com/robertorolo/mancha_de_inundacao

The implementation offers a user-friendly Graphic User Interface (GUI) that divides the methodology application into three steps.

To exemplify the proposed workflow, the Lomba do Sabão dam will be used. It is located in the Brazilian city of Porto Alegre, in the state of Rio Grande do Sul. The dam stores 3,000,000 m³ of water and is 12 m high.

Step one

In the first tab (Passo 1) shown by Figure 6, the user must inform dam parameters such as coordinates (Latitude and Longitude in decimal degrees) of the dam's central point, stored volume in m³ (Volume armazenado) and dam height in meters (Altura da barragem).

Calculate (Calcular) button will return the river length (in kilometers) that should be traced. In this case 7.53 km. Considering that this is a didactic example, the tracing of the river will be made according to the length calculated by the software, even if there are still buildings beyond. In a real situation, the route should go as far as there are structures of interest.

The river length calculated by the methodology is a guess based on previous dam failure events. However, if there are structures of interest beyond the tracing, the modeler can extend the length to cover them.

Step two

In the second tab (Passo 2), the DEM must be loaded (Carregar SRTM), it can be downloaded in GEOTIFF format from the USGS EarthExplorer website or obtained from other sources. SRTM loading is done by the user because files can be large in sizes. The river tracing in KML format also should be loaded (Carregar traçado). User can inform the number of lines to simplify the original tracing (Número de retas para simplificação) and perpendicular sections length in meters (Comprimento da seção), although default values are appropriate for most cases.

Calculate (Calcular) button will plot, as shown by Figure 7, the SRTM, the original river tracing, the simplified river tracing and 21 equidistant perpendicular sections.

There may be sections that intersect. In this case, sections can be exported (Exportar seções) in shape file format and rotated, since the section midpoint location is not altered (Agência Nacional de Águas, 2017), in GIS software until it does not intercept anymore. Or that there are intercepts only at the ends of the sections. This is a very simple and quick procedure that can be performed in open source GIS software. Thus, the edited

shapefile can be imported (Importar seções) to the software. The new geometric configuration is shown when sections are imported as shown in Figure 8.

We propose an iterative algorithm which randomly rotates the sections until it do not intercept anymore that works as follows:

- [1] while sections intercepts or loop time is less than a predefined time limit;
- [2] for each section;
- [3] checks if this section intersects with the previous or subsequent section;
 - [3.1] if intercepts: rotate a random value between $-\alpha$, $+\alpha$ degrees until sections do not intersect. If not intercepts: do nothing;

Where alpha is an angular increment defined by the user.

The algorithm is available in the source code; however, it is not implemented in the GUI to make the application as simple and easy to use as possible.

Once the user is happy with sections geometry he or she can proceed to the last step.

Step three

Step three is where all the hydraulic calculations are made without user interaction. The Calculate (Calcular) button will start the calculations, once it is finished, a three-dimensional interactive model is shown (Figure 9) for checking. If results are unexpected,

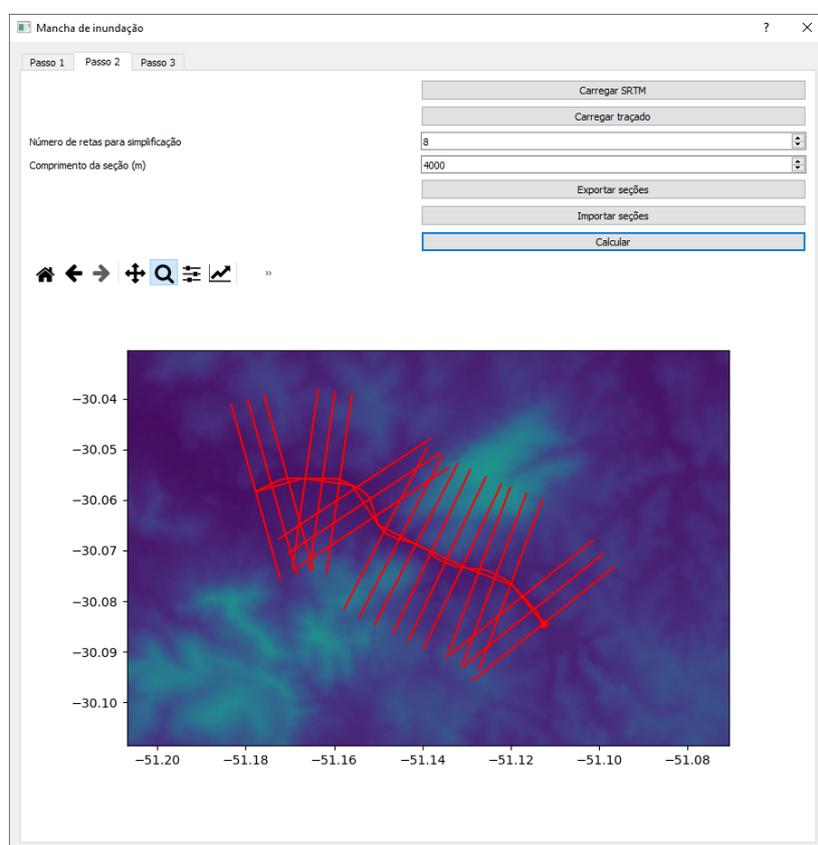


Figure 7. Second step (Passo 2). SRTM and river tracing must be loaded. The sections geometry can be adjusted. Darker colors indicate lower altitudes and vice-versa.

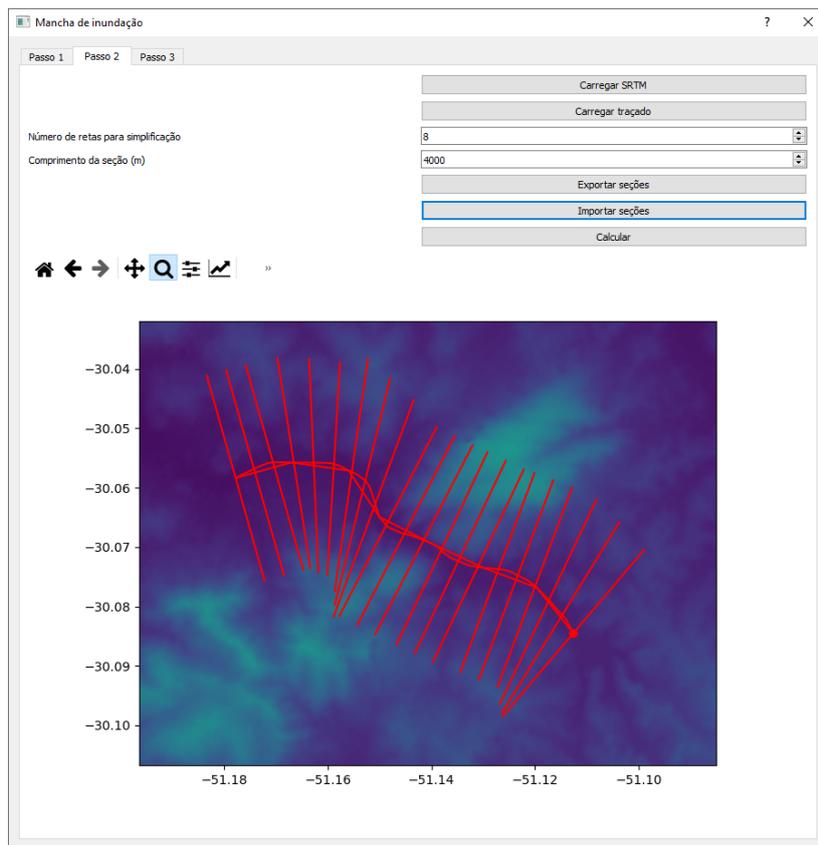


Figure 8. Non intersecting sections re-imported to the software.

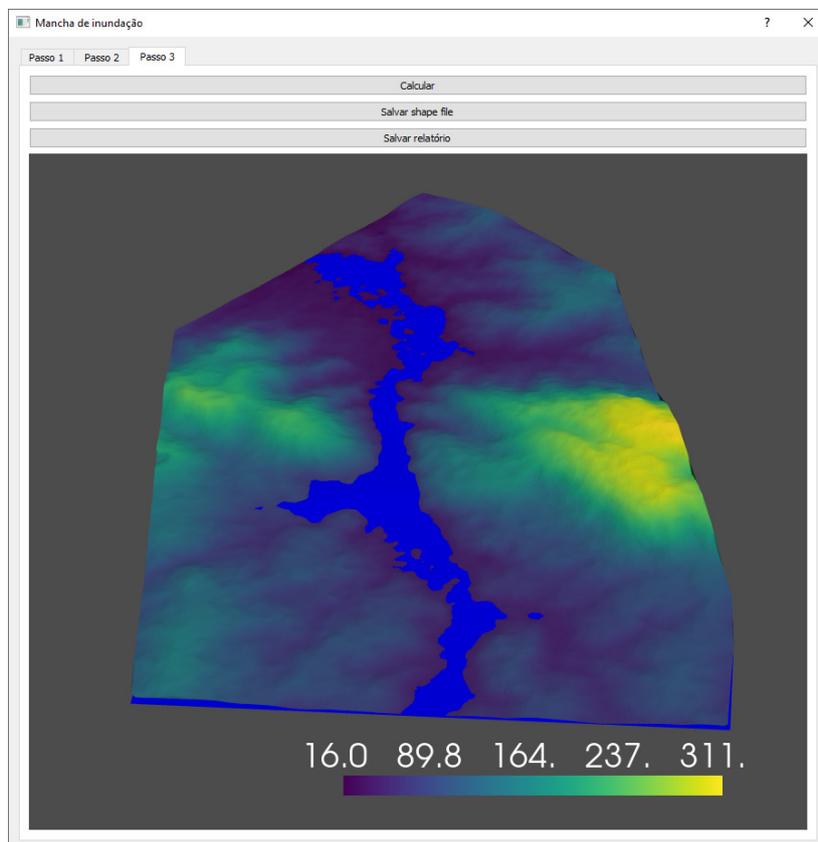


Figure 9. Step 3 (Passo 3). All the hydraulic calculations are made here.

the user can go back to steps 1 and 2 and edit the parameters or load new files.

A shapefile with the flood zone can be saved (Salvar shapefile) and imported in GIS softwares, such as Google Earth, as shown in Figure 10. A CSV format report can be saved (Salvar relatório). Table 1 shows the report for the Lomba do Sabão dam.

Tschiedel et al. (2017) compared different dimensional approaches for the dam break simulations for the Lomba do Sabão dam. The results obtained by the authors were compared with those generated by the proposed implementation. Figure 11 shows, on the left-hand side the results obtained by Tschiedel et al. (2017) and on the right-hand side the results generated by the proposed implementation. At least from a visual point of view the results are quite similar with some natural differences given the difference in the digital terrain model used and in the parameters. For the purpose of DPA classification both flood zones will produce similar results. In this example, the route of the river extended to where there were structures of interest.

RESULTS AND DISCUSSIONS

Our implementation is divided into two files: `mancha_de_inundacao.py` which carries all the Python functions and `pyqt5_gui.py` which encompasses the functions into the GUI. The functions module can be imported in a Jupyter Notebook or a Python script to generate flood zones in batch, reading the parameters from a CSV file for example.

The GUI is easy to use and the hydraulics calculations are quite fast. Lasting no more than a minute. A technician from a government agency without prior experience will not take more than 10 to 30 minutes to generate a flood zone following the tutorial.

The implementation relies on a few Python libraries and its dependencies (geopandas, rasterio, matplotlib, pyqt5, pyvista and pyvistaqt) most of them are mainstream, which reduces the chances of errors resulting from updates. Nonetheless, a portable version, which requires no installations, is distributed.

The shapes generated by the software are in raw state. If necessary, a refine modelling can be made with simple GIS

Table 1. Report for Lomba do Sabão dam.

Section	Distance	Flow	Water height
0	0	1076.773122	3.56132954
1	374.4456859	1065.294822	3.472504455
2	748.8913719	1053.93888	3.92247759
3	1123.337058	1042.703991	2.957598235
4	1497.782744	1031.588865	2.354482682
5	1872.22843	1020.592225	2.919320181
6	2246.674116	1009.712809	2.403575101
7	2621.119802	998.9493656	4.040441899
8	2995.565488	988.3006597	3.888178877
9	3370.011174	977.7654681	4.751854725
10	3744.456859	967.3425806	3.319825013
11	4118.902545	957.0308001	3.676459895
12	4493.348231	946.8289422	3.377006776
13	4867.793917	936.7358351	2.564987992
14	5242.239603	926.7503197	1.710769708
15	5616.685289	916.8712488	2.675013074
16	5991.130975	907.0974879	2.441047071
17	6365.576661	897.4279144	2.688948285
18	6740.022347	887.8614177	2.548835614
19	7114.468033	878.3968989	3.812776886
20	7488.913719	869.0332709	3.26742232

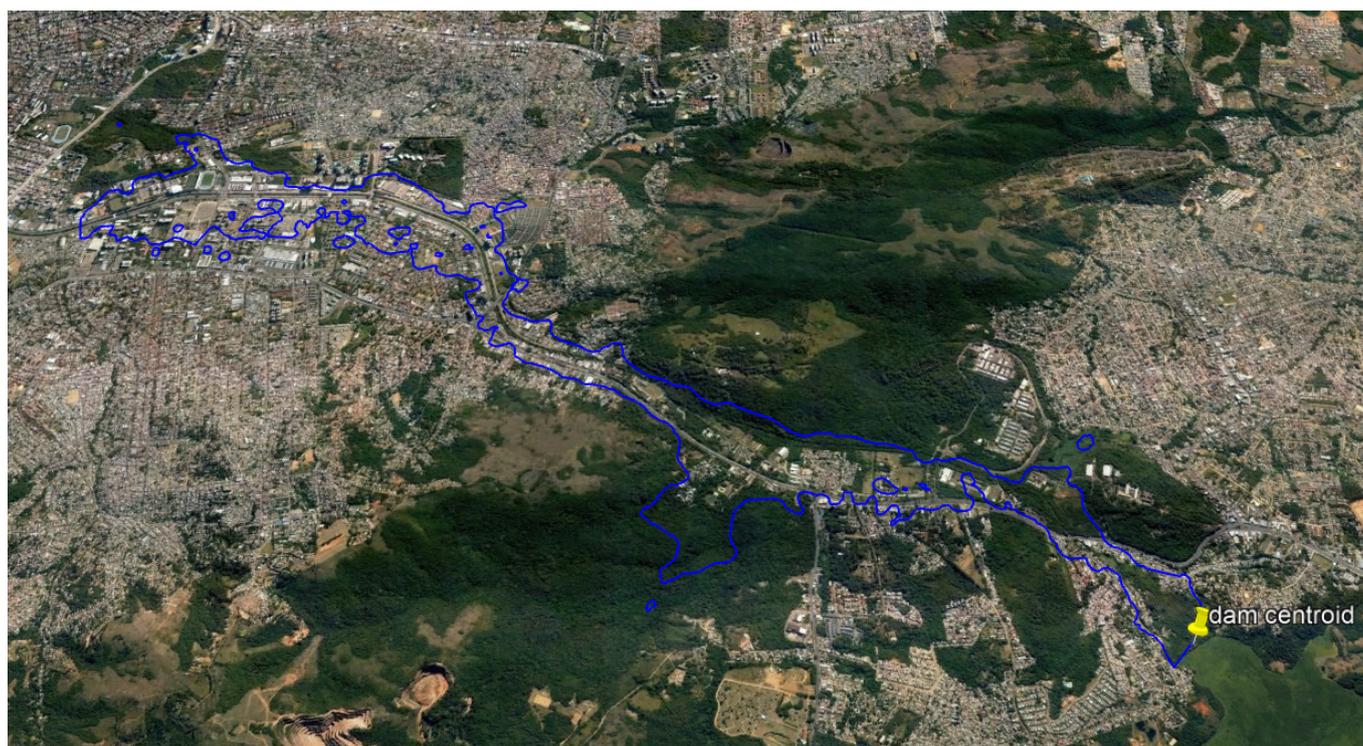


Figure 10. Flood zone shape file imported in a GIS software.

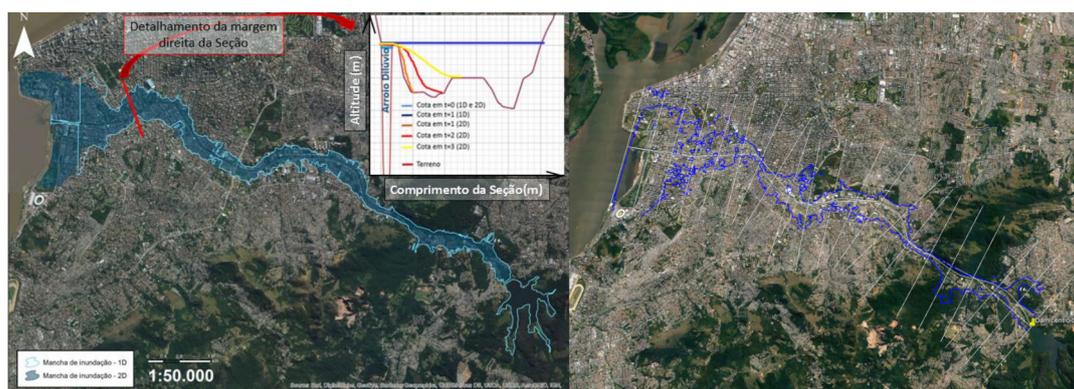


Figure 11. Comparison between the flood zones obtained by Tschiedel et al. (2017), on the left-hand side, and the flood zones obtained by the proposed implementation, on the right-hand side.

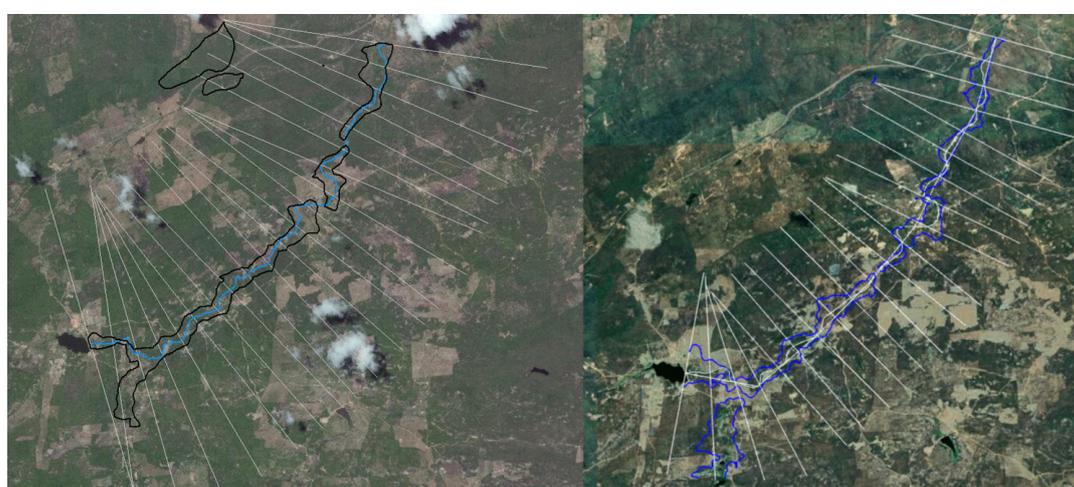


Figure 12. Visual comparison between the flood zone built for the same dam using original ANA's implementation, on the left-hand side and using the proposed Python implementation on the right-hand side.

editing tools in order to increase its realism such as modeler: join any separate polygons; adjust wet areas; eliminate unreal geometries. Alternatively, the inconsistent geometries can be ignored in the Hazard Potential analysis.

It was not possible to make a numerical comparison between ANA's implementation and the here proposed Python implementation for different reasons. However, a visual comparison was made against the zone generated in the ANA's bibliography example (Agência Nacional de Águas, 2017).

Figure 12 shows, on the left-hand side, the zone generated by the original implementation, and on the right-hand side the zone generated by the proposed methodology for the same dam.

Differences naturally exist due to different river traces and its simplification, to different sections length, to different rotations of the sections, to different algorithms making the triangulations, to different topographic profiles for the sections, to different approaches for defining the envelope around sections, to different methods used for calculate the areas below curves, to differences in the flow/height regression curves, among others.

Besides all the divergences between the implementations and executions, the zones are sufficiently similar, for the Hazard Potential analysis or to cross check the results presented by an entrepreneur. The calculated water heights for each section also show little disparity.

CONCLUSIONS

The ANA's simplified methodology is feasible for creating a flood zone in the event of a dam failure for DPA classification purposes. However, the original implementation is cumbersome.

This motivated the development of a faster and easier to operate implementation. The developed software can be quite useful for government agencies and dam entrepreneurs in a low budget. The results are similar to those produced by the original implementation and can be generated considerably in less time and with less user interaction. This software is an alternative for defining the flood zone in the event of a dam break and should only be used for DPA classification. For a complete dam break analysis other software, such as HEC-RAS, should be used.

The software is free and open-source, for this reason, we hope that the community will contribute to the development and its constantly improvement over time.

As future works, the authors suggest the implementation of different empirical equations for the maximum flow at rupture. Another enhancement could be a field for selection of the dam's material. Thus, based on different empirical equations of maximum flow at rupture, different scenarios could be generated. The Manning-Strickler roughness is a constant equal to 15 m^{1/3}s⁻¹ in the current implementation. It would be useful

to add a field to inform a value for the coefficient compatible with the valley under study.

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Roberto Mentzingen Rolo: Programming, interpretation of results, literature review, preparation of the final manuscript.

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