SCENARIO EVALUATION OF ALTERNATIVES FOR FLOOD CONTROL IN THE ANHANGABAÚ WATERSHED, BRAZIL

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ABSTRACT: Flooding and overflows are common and recurring problems in several Brazilian cities, which usually undergo disorderly development. Their causes vary from increased impervious surface areas, deficiency / inefficiency of drainage structures and their maintenance, siltation of rivers, channel obstructions and climatic factors. This situation is even aggravated when occurred in large cities. The Anhangabaú Watershed lies in the central portion of São Paulo – Brazil and covers a drainage area of 5.4 km². The region is highly urbanized and is crossed by an important north-south road connection. During heavy rain period, portions of this interconnection passage become compromised, disrupting the flow of vehicles, creating a chaotic situation for the population, as well as losses to the national economy.

In seeking solutions to the problems of flooding in the basin, which have been studied for decades, the São Paulo City Hall hired Hydraulics Technology Center Foundation (FCTH) to evaluate the performance of two traditional alternatives already proposed for the region system drainage and to offer a new alternative, based on modern concepts of water resources management. Therefore 3 alternatives intended to mitigate the flooding problem in the lower valley were evaluated: (i) 2 flood detention reservoirs and reinforcement of main gallery system, designed to ensure safety against 25-year return period events; (ii) reinforcement of the main gallery and flow derivation tunnel leading to the Tamanduateí River for a 100-year return period; (iii) distributed linear retention spread over the watershed in stages of return periods of 10/25/100-years. The comparison of alternatives was given by a multi-criteria analysis based on six subjects, namely, alternative efficiency, prevented damages, permanent environmental impacts, temporary environmental impact, costs and public response. The evaluation of technical criteria analysis was based on a complex modeling network employing PCSWMM application, representing both road and drainage systems and their interconnections. The alternatives were simulated for different scenarios corresponding to a combination of drainage system, urban occupancy, adoption of LID (Low Impact Development) controls, modeling dimension and rainfall time series.

Modeling outputs showed that all alternatives presented relevant results in solving the flooding at critical locations. However, that the alternative regarding linear retention offered better overall effect to solve the problems of flooding in the Anhangabaú Watershed.

Key Words: Urban flood, Hydrologic and hydraulic modeling, Retention structures.

1. INTRODUCTION

The Anhangabaú Watershed lies in the central portion of São Paulo – Brazil, emptying into the Tamanduateí River, which arises from other municipalities in the metropolitan region. The city of São Paulo was established in a flat area between the Tamanduateí and Anhangabaú rivers. For over 300 years, life in SP existed only because of these two rivers: the Anhangabaú was a smaller one with clean drinking water, while the larger Tamanduateí was served to navigation. With consequent urban development, the rivers, which were the reason for the city existence, have become obstacles to its growth. The construction of the Chá Viaduct in 1892, upon the valley of Anhangabaú River was the first achievement in overcoming the barriers that rivers imposed on the city expansion. In the 1920s, the Anhangabaú Park was created, upon its river, which was already rectified and buried. In the late 1930s, a city road plan was proposed aiming the use of valley bottoms for the construction of new avenues. This avenue plan started a practice that has been established as a model in the city structuring, where the path of waters gave way to cars (Ferraz, 2009). Floods in the Anhangabaú Watershed have become a critical and chronic problem for the city, which has been studied for decades. The region is highly urbanized and is crossed by important road connections. During heavy rain period, portions of this road network become compromised, due to floods at the bus terminals, main streets and tunnels, completely disrupting the flow of vehicles, creating a chaotic situation for the population, as well as losses to the national economy.

Two recent studies that occurred between 2004 and 2006 proposed various alternative solutions to the problem in the Anhangabaú Watershed. Looking to finally settle the issue, the São Paulo City Hall hired Hydraulics Technology Center Foundation (FCTH) to evaluate the performance of these two traditional alternatives already proposed and also to offer a new one, based on modern concepts of water resources management (FCTH, 2014). It was then elaborated a complex modeling network employing PCSWMM application, seeking to represent all road and drainage system and their interconnections. With the assessed model, the alternatives that intended to mitigate the flooding problem in the lower valley were evaluated with different scenario variations. Each scenario corresponds to a combination of drainage system, urban occupancy, adoption of LID controls, modeling dimension and rainfall time series. As a result, the best solution was determined by a multi-criteria analysis technique, which takes into account not only the solution efficiency and avoided damage from performance indices generated by hydrologic and hydraulic simulations, but also factors such as cost, permanent and temporary environmental impacts and public attention.

The objective of this paper is to brief the hydrologic and hydraulic modeling and the scenario structuring that guided the analysis of the alternatives proposed for the flood issues in Anhangabaú Watershed.

2. METHODOLOGY

2.1 Site description

The Anhangabaú Watershed is located in the central region of São Paulo, covering an area of approximately 5.4 km². The Anhangabaú River is formed by the confluence of three streams: Saracura, Itororó and Bixiga. The basin macro-drainage system consists of a set of buried galleries that drain waters of these tributaries under the main avenues that cross the basin, joining each other under Praça da Bandeira. It is noteworthy mentioning Moringuinho River tunnel as part of the drainage system, which was built as an initiative to reduce flooding in the Anhangabaú Valley region, diverting part of the Itororó River flow directly to the Tamanduateí River. Figure 1 illustrates the basin location in the city of São Paulo, its main hydrographic and road main points of interest.

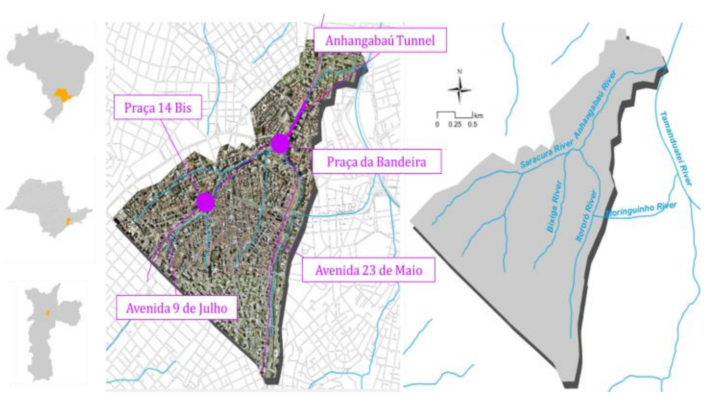

Figure 1: Location, main rivers and points of interest at the Anhangabaú Watershed

The floods that occur on public roads and private areas of the Anhangabaú Watershed are extremely frequent. Data provided by local traffic engineering company show that the average occurrence of floods between the years 2008 and 2012 at the Anhangabaú Tunnel was 4 times p.a., at the Praça da Bandeira and at the Avenida 23 de Maio, 10 times p.a. and at the Avenida 9 de Julho, 5 times p.a.

2.2 Alternative design

The studies were based on the analysis of three technical alternative interventions. Two alternatives, A and B, have been proposed in previous work prepared by PMSP and analyzed according to their unique characteristics. On the other hand, Alternative C was developed especially for this analysis.

- **Alternative A:** The scheme corresponding to alternative A was proposed and developed by the partnership between Hidrostudio Engenharia and JMR Engenharia, and was completed in 2004. The design flow for this particular alternative correspond to a 25-year recurrence time. Alternative A consists of a reservoir under Praça da Bandeira (46,000 m³), a reservoir under Praça 14-Bis (36,000 m³), their interconnection galleries, overland flow catchment and partial reinforcement of existing galleries under Avenida 9 de Julho.

  The reservoir under Praça da Bandeira was designed with 2 wells and adjacent circular format. According to the project, only those structures would protect Anhangabaú tunnels against events of about 5 years of recurrence. In a second phase of constructions, it is proposed a reservoir under Praça 14-Bis consisting of two adjacent polygonal wells and the replacement or repair of existing galleries along Avenida 9 de Julho, ensuring protection against originally planned 25-year return period events.

- **Alternative B:** Alternative B design was originally conceived by PMSP in 2005 and detailed by Figueiredo Ferraz Consultoria e Engenharia de Projeto Ltda. in 2006. The main assumption for this alternative was causing as little interference with the transportation system of the region as possible, being projected for a 100-year recurrence time. Alternative B proposes the derivation of the full flow of the catchment area upstream Praça da Bandeira (estimated at 137.6 m³/s) in a tunnel with about 1.6 km long and 6.2 m in diameter, in addition to providing a system of galleries at Avenida 9 de Julho by the application of non-destructive methods. Similarly, considering the position of the bypass tunnel upstream Praça da Bandeira, it would not be necessary to extend the galleries along Avenida 9 de Julho until the existing galleries in Anhangabaú Valley.

  Due to legal requirements, it had also to be considered for Alternative B the implementation of a control valve at the exit of the tunnel to somewhat weaken the impact of high flows from Anhangabaú Watershed on Tamanduateí River. For flows with return periods of less than 100 years, the valve would be partially closed thereby reducing the discharges in Tamanduateí River, taking advantage of the tunnel damping capacity at the same time.

- **Alternative C:** The original conception of Alternative C was developed during the proceedings of the Master Plan of Drainage and Stormwater Management in São Paulo (PMAPSP) developed in 2011 by FCTH. At the time, the use of tunnels and large transverse dimension galleries was considered to be deployed along the basin valley bottoms, in order to linearly soften discharges generated by heavy rainfalls. More recently, the original design was slightly modified, introducing the concept of retention distributed over the basin, projecting conduits to be spread in small watersheds (less than 50-ha catchment area). To do so, FCTH took advantage of the expertise and advice of Italian consulting firm ETATEC Studio Paoletti S.r.l., which has already developed several similar projects in Europe.

  The interventions proposed for the basin consist of the replacement of existing drainage network pipes for conduits with larger section, constituting a network of linear distributed reservoirs. Tunnels and galleries distributed along public roads and watercourses were designed, seeking to follow, wherever possible, existing minor drainage networks. In addition to promoting flood control over wider areas, this proposal allows the reduction of constructive impacts on the most critical regions of the basin. Among the planned measures are substitutions and / or reinforcement of existing galleries under Avenida 9 de Julho and Avenida 23 de Maio and other main streets. Flow control over various segments of linear reservoirs (known as supertubes) should be possible through discharge control elements. For this purpose, fixed orifices were chosen, complemented by weirs that would drain all the excess volumes after filling the segment.

Alternative C was analyzed by two variations:

- Variation 1: Linear reservation system built by non-destructive processes; and
- Variation 2: Linear reservation system built by conventional process, with open trenchs.

Logically, the entire network construction method in Anhangabaú Watershed should adopt both systems, depending on several local factors. From the hydrological point of view, both systems would present equivalent performance. The implementation of the supertube system should be conducted in 3 stages, according to the hydrological security desired for the basin: 1st, 2nd and 3rd stages corresponding to 10, 25 and 100-year recurrence interval design storm, respectively. Network extensions of 7.5 km, 11 km and 19 km were then estimated as a function of said steps, respectively.

Figure 2 shows the area of the Anhangabaú Watershed with the layout of mentioned alternatives.

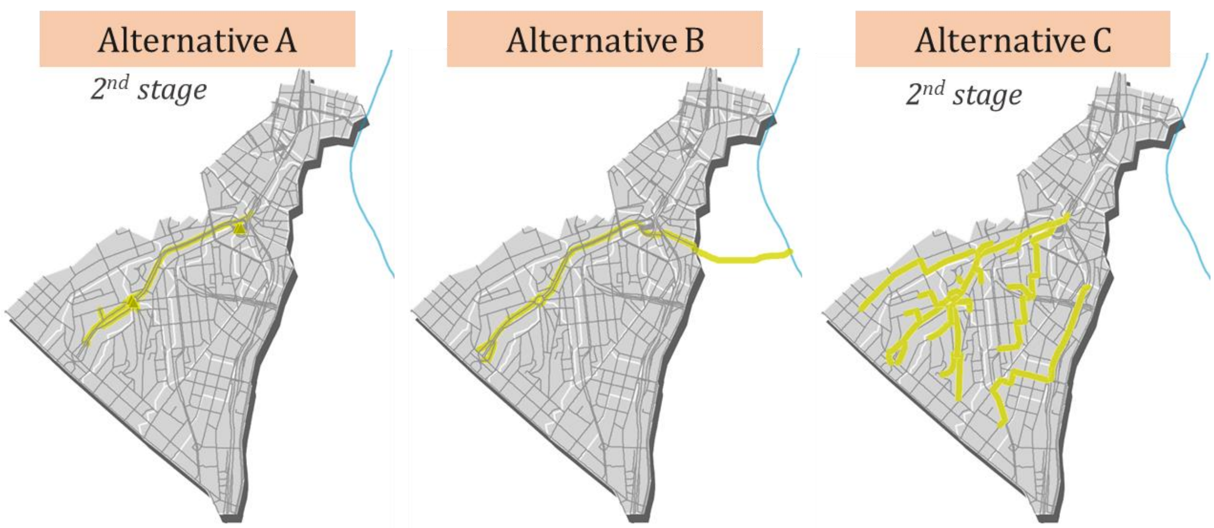

Figure 2: Alternative layouts

2.3 Model development

The hydraulic efficiency of the three alternatives was evaluated using a computational model for hydrological and hydraulic simulations with identical criteria for all alternatives. The model used was the Storm Water Management Model (SWMM), available by US Environmental Protection Agency (EPA), with the PCSWMM interface, developed by Computational Hydraulics International (CHI).

The study used the Soil Conservation Service (SCS) curve number (CN) method to calculate the infiltration process, and the dynamic wave method to route flows through the drainage system, which is the most complex and accurate model to simulate the occurrence of conduit overflow through manholes. The proposed solutions were evaluated with the application data outputs, provided in the form of hydrographs or velocity and water depth diagrams, corresponding to overland flows. The modeling is related to the physical characteristics of the watershed in order to represent the dynamics of natural phenomena:

- Simulated rainfall represents observed rainfall events or defined design storms;
- Subcatchments contain the information necessary to represent the processes of infiltration, interception and surface runoff;
- Buildings act as obstructions to overland flow;
- Pathways temporarily store and drain runoff according to surface information; and
- Drainage grates and curb inlets make the connection between the surface flow and subsurface drainage network, which can also work under pressure.

For the assessment of surface water depths generated above the underground gallery network, a representation was created on two levels, connected by orifices, known as dual network. The first level is composed by the surface drainage system, which is represented by the ground surface directly above the galleries, i.e. roads and terrain that receive subcatchment runoff inputs. These inputs enters the second level of modeling according to established rules for the interconnection between these levels. The second level is made of hydraulically underground galleries that once surcharged, may cause the energy grade line to surpass the ground level, generating floods just above the ground, again respecting the rules of communication between the underground network and routes. Figure 3 illustrates the processes described.

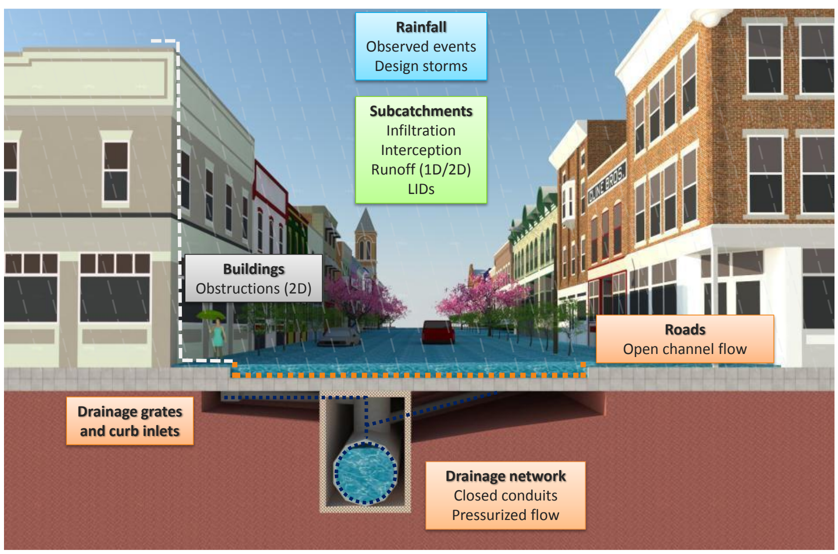

Figure 3: Schematic modeling representation

PMSP official cartography basis – the Digital City Map (MDC) – was applied to represent the relief, geometric conformation, land occupancy, buildings, sidewalks, public roads and streets and other (plazas, gardens and green areas, for example), as well as the subcatchments natural drainage elements that influence the inflows to the macro-drainage system. The MDC is the result of an effort from PMSP to standardize its database, developed through modern aerial survey techniques with flights performed in 2004, which generated maps in the scale of 1/1000 and contour lines of 1 m vertical intervals.

To ensure more homogeneous subcatchment contributions, the basin was divided into small catchment areas, discharging into superficial nodes from the hydraulic network, following the discretization of the road network. The surface road system (excluding tunnels) was represented by 2,196 nodes, and then the basin was divided into an equal number of subcatchments.

The geometric characteristics of the basin main macro-drainage system, consisting of underground galleries and all its singularities and manholes, were obtained from previous studies and projects developed for PMSP. Data from surveys performed in the 1990s were used, supplemented by surveys conducted by the Consortium Hidrostudio / JMR in 2003 and also by recent gallery inspections conducted under this project. The minor-drainage system is formed by a set of storm sewers with diameters up to 1.2 m, which slopes were estimated trying to follow surface slopes wherever possible, considering a minimum cover of 1 m. The connection between underground and surface networks is made through orifices that obey rules proportional to the characteristics of structures such as drainage grates and curb inlets, which were acquired from municipal records, supplemented with field surveys. These representative structures are not only consistent with the inflow entry process in storm sewers, but also meet in case of overflows from underground network to the road system channels. The rules of entry and exit of such structures have been defined for each type of drainage grates or curb inlets, with estimated parameters such as height, width and runoff coefficient, based on the studies of Tomaz (2002).

The existing network features were initially introduced into the model, followed by those of the designed systems. The basic hydraulic model represents, altogether, 110 km of roads, 50 km of drainage networks and 2,802 joint structures as curb inlets and drainage grates. Figure 4 shows the distribution of model elements in the region.

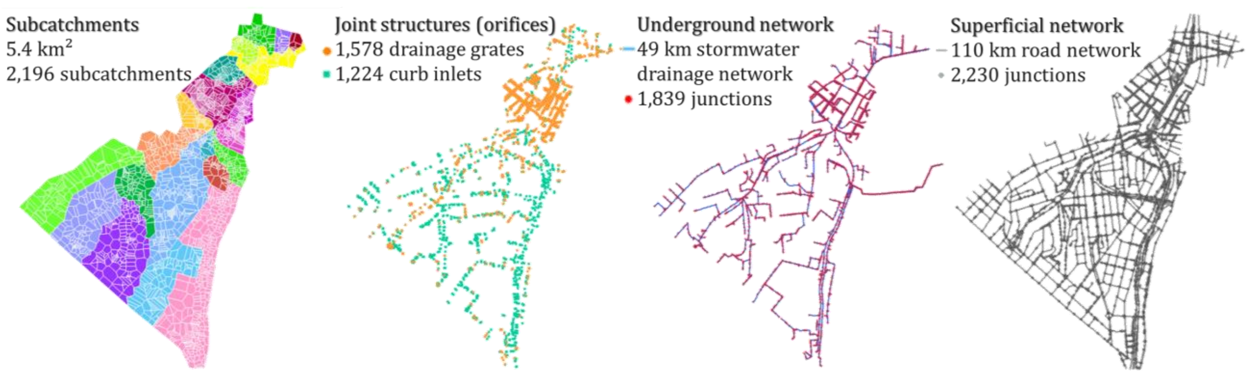

Figure 4: Modeling network for current scenario

One has to also consider the influence of the Tamanduateí River flow regime, which could worsen the conditions of the Anhangabaú Watershed discharges during events of critical intense rainfall in Tamanduateí Watershed. On the road system outfalls, spread around the basin, free boundary conditions were chosen, while the outfalls at Tamanduateí River have fixed levels depending on the simulated return period, estimated from old hydraulic studies of Tamanduateí River, performed in 1995.

In the case of the simulation of the alternatives, in addition to inserting the layout and properties of each alternative project, some assumptions were also adopted:

- Alternative A: the drainage grates and curb inlets had their capacities expanded in the region upstream to the reservoirs;
- Alternative B: the drainage grates and curb inlets had their capacities expanded along the renewed galleries upstream to the bypass tunnel; and
- Alternative C: the drainage grates and curb inlets had their capacities expanded along the supertubes. Furthermore, the dimensions of the orifices and weirs that control the flow between

supertube reaches were optimized according to their stages of implementation, aiming to maximize supertube storage and minimize the effects of flooding on roads and tunnels.

2.4 Simulation scenarios

Hydrologic and hydraulic modeling of the Anhangabaú Watershed was made considering its current situation and projected scenarios corresponding to the three mentioned alternatives. Each scenario corresponds to a combination of drainage system, urban occupancy, adoption of LID controls, modeling dimension and rainfall time series:

- The drainage system reflects the basin current situation or proposed alternatives, also regarding their stages (in case of alternatives A and C) or variations (alternatives B and C).

- The land use and occupation features in the Anhangabaú Watershed were gathered from the interpretation of the MDC. Average rates of imperviousness were assigned for each type of identified land use. Considering the whole Anhangabaú Watershed, an average of 77.5% impervious areas resulted for current conditions. The trend imperviousness scenario was generated according to the Regional Strategic Plan to the local borough, which establishes a minimum rate of permeability of 15%. In order to obtain a critical scenario, a minimum imperviousness rate of 85% was adopted, persisting higher values estimated in the current scenario. Therefore, the basin average impervious rate would be 86.1%. Alternative situations also considered an increase in the stormwater retention capacity at the allotments, applied in 25% and 50% of the building areas in reference to a municipal law, considering the trend occupancy condition.

- Low Impact Development (LID) controls were selected considering limited space availability for retaining and runoff infiltration structures. The resulting simulation parameters were estimated through a combination of porous pavements, bio-retention cells and infiltration trenchs.

- Beyond one-dimensional (1D) conventional modeling, PCSWMM application is able to generate models of urban flooding that combine SWMM model outputs to a two-dimensional (2D) model that represent the formation of flood spots, allowing an easily understood visual analysis of the results. 2D modeling considers a dense superficial mesh, which demands precision land representation data and requires significant processing time.

- The design storms applied were characterized through the intensity-duration-frequency (IDF) relations, which assign the average precipitation intensity at a given duration and probability of occurrence, usually expressed as a period that is the inverse of frequency. These relations are obtained by a series of intense rainfall data, sufficiently long and representative. The equation used for our studies is inferred from the station IAG / USP - E3-035 (23°39'S, 46°38'W). Its applied data period is 1933-1997 (65 years), as described by Martinez Jr. & Magni (1999). In this study, the alternating block method is applied to the temporal distribution of rainfall obtained using IDF relations, adopting a 2-hour critical duration. This distribution is not related to physical phenomena, but it is an empirical method that characterizes a critical condition. Return periods selected correspond to 10, 25 and 100 year and an areal reduction factor of 0.992. The 10-year return period matches national guidelines for microdrainage network projects and the 1st stage of Alternative C, while 25-year return period live up to the period for which alternatives A and C (2nd stage) were designed and 100-year return period corresponds to the period for which alternatives B and C (3rd stage) were projected.

  In addition to the design storm events, observed rainfall records measured at discrete points nearby the river basin through land rain gauges were applied. The automatic rain gauges are tipping bucket, with a resolution of 0.2 mm and 10-minute accumulated temporal resolution and are operated by the Flooding Alert System of São Paulo (SAISP). Three events in 2013 were selected to calibrate the rainfall-runoff model: on the 14th and the 18th of February and 8th of

March, 2013, the basin has suffered from flooding caused by rainfall events; points observed in these flooding events were identified in the modeling network and compared to simulation results.

Figure 5 summarizes options for each criteria in the scenario structuring process.

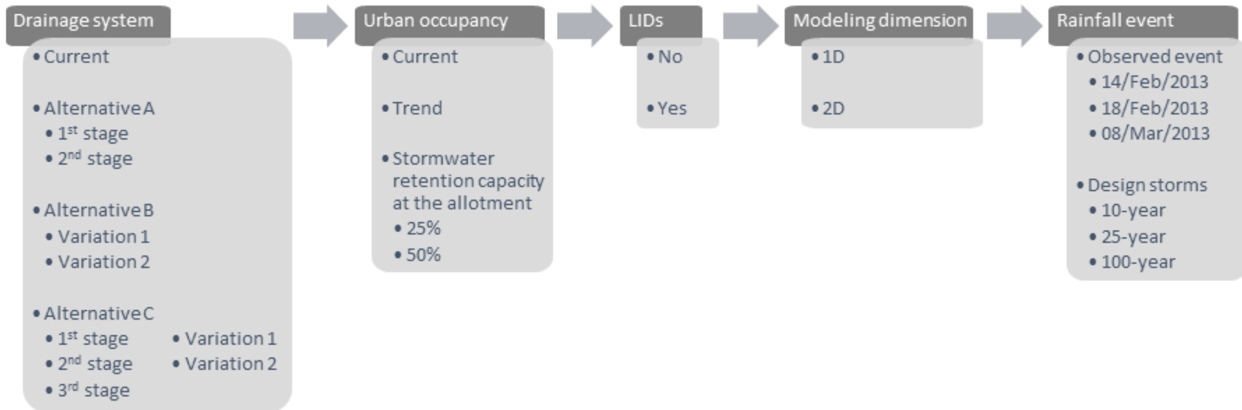

Figure 5: Scenario builder

Given the large number of results obtained in the scenario simulations, some scenarios were selected to have the results presented, which would allow a better analysis of the effectiveness of the solutions:

- Current situation of the drainage system;
- Alternative A in its 2nd stage of proposed construction, i.e. its full implementation;
- Alternative B in its original conception (variation 1), i.e. tunnel with free discharge in Tamanduateí River; and
- Alternative C in its 2nd and 3rd stages of proposed construction, i.e. the corresponding 25 and 100-year return period projects, respectively, considering variation 2, which contains structures scaled to the conventional construction process.

The presented results refer to simulations with design storms with a return period of 25 and 100 years, considering the trend scenario occupation of the basin.

2.5 Hazard indices and vulnerable assets

The comparison of the alternatives performance through various scenarios was deemed with the assessment of hazard indices. The methodology aims to contrast hazard areas at different levels of hydraulic risk, considering the depth of water on the roads and runoff velocity. The classification of different levels of hazard is shown in Figure 6, which was adapted from the work of Giunta Regionale della Lombardia (2012).

From the surface flood levels, a flood risk analysis of buildings was carried out, quantifying the risks into low, medium and high. In total 10,730 buildings were evaluated. This analysis was conducted from a flood elevation assigned to the building, originating from the DTM, compared to the water head in the road segment closest to this building. This analysis tool is part of the differentials of the PCSWMM interface. Low risk was classified when the flood level is restricted to street level, average risk was rated for situations where the water depth reaches 15 cm on the sidewalk and high risk was assigned to locations where the water depth reaches up to 15 cm on the sidewalk. The Figure 7 illustrates these criteria.

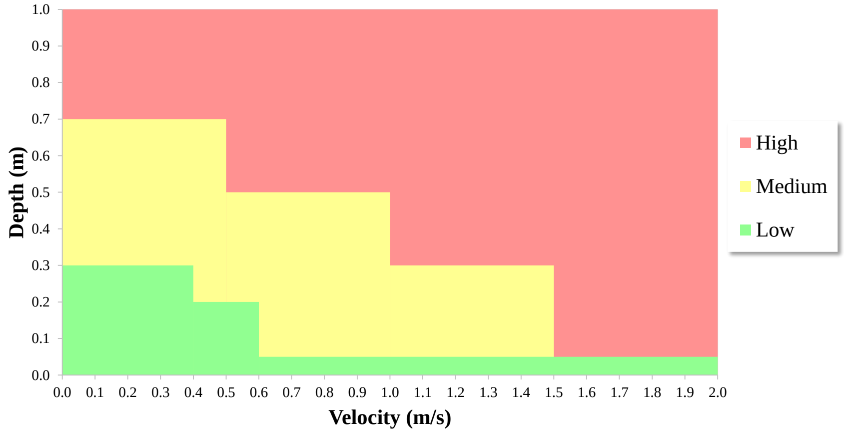

Figure 6: Hazard analysis criteria

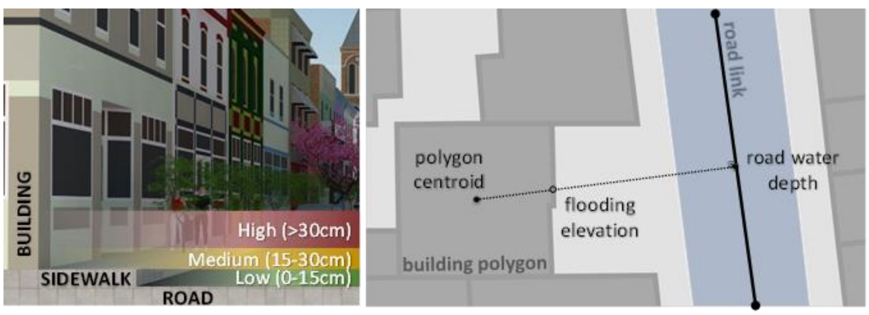

Figure 7: Vulnerable assets criteria

3. RESULTS AND DISCUSSIONS

Through the model output analysis, it was intuited that the events chosen for the calibration process should not cause significant impacts, but little vestiges of flooding. By analyzing the volume and intensity of such events, it was found that these were not critical storms with high return periods, so the floods caused by them may be linked not only to the small flow capacity of hydraulic structures, but to the current situation of galleries and the drainage system efficiency, which is significantly reduced in urban basins due to several obstructions. The high levels observed in Tamanduateí River also reduce the flow conditions in the Anhangabaú and Moringuinho Rivers, causing flooding upstream.

This behavior suggested several questions and an interpretation of what would have happened in the days of these events was sought. One of the feasible hypotheses to explain the phenomenon occurred is the loss of efficiency of the drainage network, due to the accumulation of waste in the galleries, trash clogging drainage grates e curb inlets and conduits in poor condition. Given this interpretation, the model was structured with some additional energy losses in the ducts and hydraulic elements. The results showed that, with the introduction of energy losses, it was then possible to represent the events occurred. The simulation with energy losses sought not to truly represent what happened in the events, but to show that, depending on the condition of the drainage system, it is indeed possible that smaller rains cause significant impacts in the basin. These exaggerated loss coefficients, however, were not maintained in the simulation of the scenarios presented in this paper, which should not pose any harm to the comparison of the alternatives, since they all were analyzed under the same conditions.

Flood levels for the selected scenarios were analyzed from the simulation results. Figure 12 illustrates the depths of flooding in the basin for the 25 and 100-year return period design storms. This analysis shows the result for the current network situation, Alternative A (2nd stage, i.e. its full implementation), Alternative B (variation 1, i.e. tunnel with free discharge) and Alternative C (2nd and 3rd stages, i.e. corresponding to 25 and 100-year recurrence interval design storms; variation 2 - structures scaled to the construction by conventional process), all simulated with urbanization trend scenario with no LID controls. Figure 13 illustrates 2D modeling results for the 100-year design storm simulations at the main points of interest of the study.

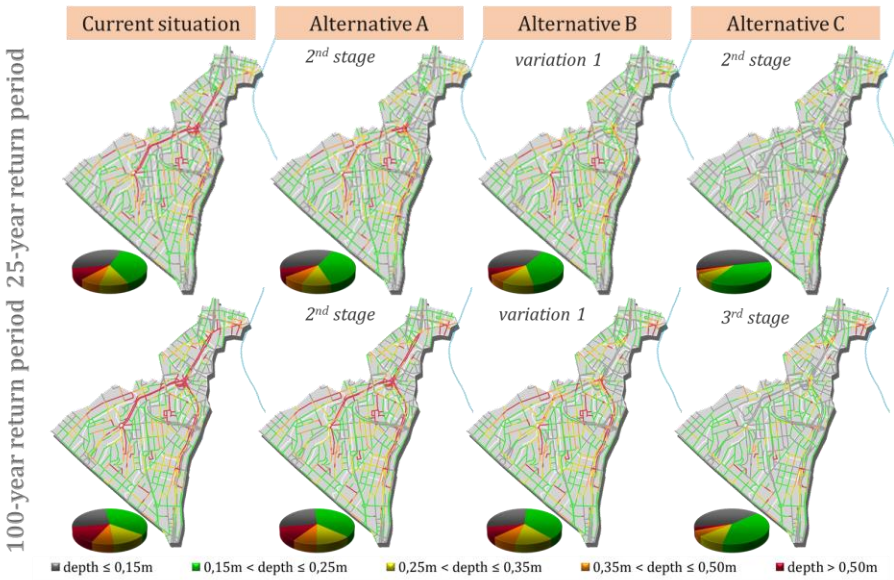

Figure 12: Surface water level results

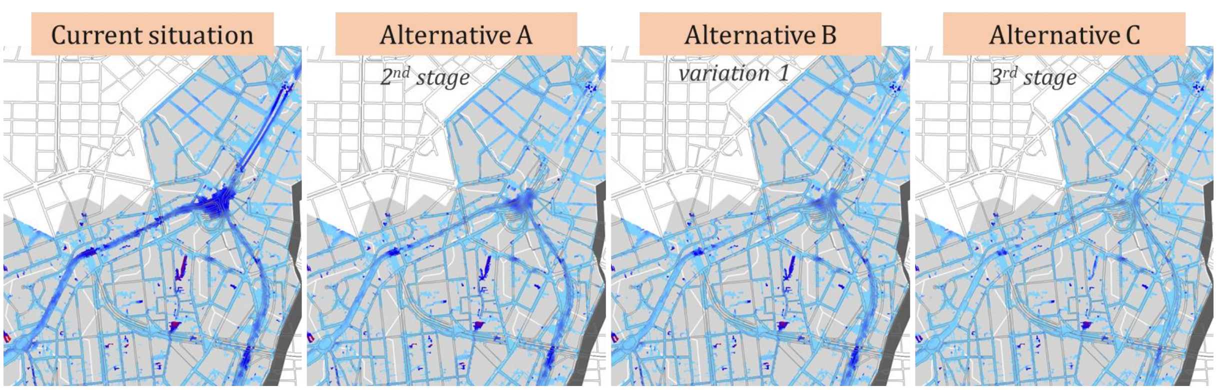

Figure 13: 2D results for 100-year design storm simulation

As expected, the three alternatives somehow reduce flooding in the region of the Anhangabaú Valley. Alternative A still maintains critical water depths at Avenida 9 de Julho for both return periods, while Alternative B has lower depths, which was expected due to the fact that it was designed for superior flow rates. The Alternative C shows to be advantageous in reducing floods in a distributed manner over the basin, especially in locations outside the axis of Avenida 9 de Julho.

For the 25-year return period simulations, the current system has 10.6% of its roads with water depths greater than 50 cm and 33.7 % with less than 15 cm. When compared to alternative A, the road share with depths greater than 50 cm decrease to 7.9 %, and the ones with less than 15 cm, to 34.9 %. Alternative B shows intermediate results, since 5.9 % of pathways remain with depths above 50 cm and 36.2 % were in the range of less than 15 cm. In alternative C, there is a percentage of only 1.8% of the roads with more than 50-cm water depth and 49.3 % with depths smaller than 15 cm.

Comparing the three alternatives, one can notice that Alternative C reduces the largest proportion of flooded roads with critical water depth, indicating its better efficiency. The simulation results show the improved efficiency of Alternative C solution in relation to the other in terms of the control of floods occurring throughout the Anhangabaú Watershed, not only in the Anhangabaú Valley and Avenida 9 de Julho.

The results of the hazard analysis for selected scenarios are shown in Figure 13.

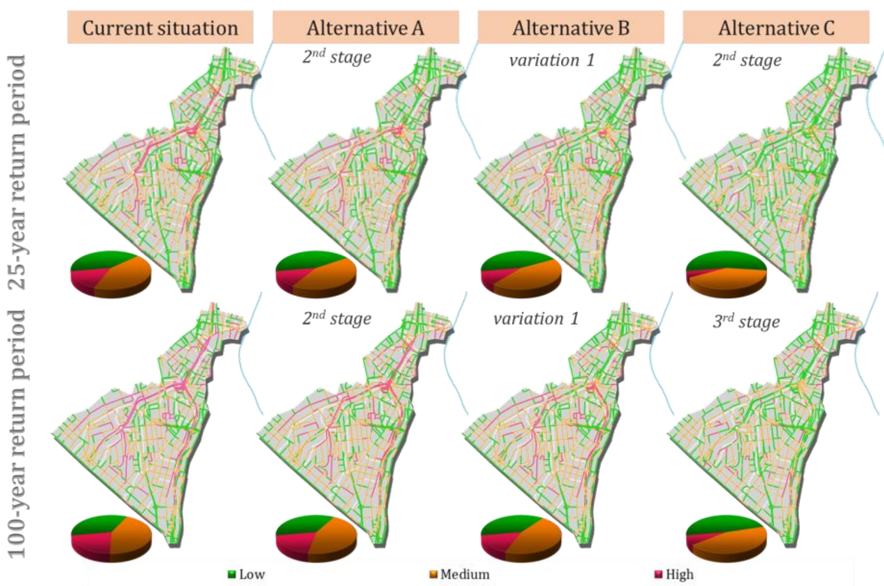

Figure 13: Hazard analysis results

For a 25-year design storm simulation, the current system has 16% of its roads with high hazard, 43.1% with medium hazard and 40.8% with low hazard. When analyzing the effects of the alternatives to reduce the hazard indices, the results showed 13.4%, 11.3% and 5.2% of the road network with high hazard regarding alternatives A, B and C, respectively, while the corresponding low hazard were 43.3%, 44.7% and 54.8% respectively. The benefits observed for 100-year alternative simulations again indicate the efficiency and safety of alternative C compared to others.

Figure 14 produces a quantitative comparison between the share of buildings classified in terms of flood risk obtained from the simulation of the alternatives and the current drainage system. When comparing alternative A with the current system, a reduction of 80 buildings at high risk is noticed (7% reduction) for 25-year return period and 127 buildings for 100-year return period (8% reduction). The analysis for alternative B with the current system showed that there was a reduction of 135 buildings classified as high risk (12% reduction) for 25-year simulation and 186 for 100-year storm (also 12% decrease). Alternative C showed the best results, because it reduced 63% of the number of buildings at high risk (726 buildings) for the 25-year storm and 60% (943 buildings) for the 100-year storm. This analysis shows the effectiveness of the Alternative C in the control of impacts at constructions caused by flooding in the Anhangabaú Watershed.

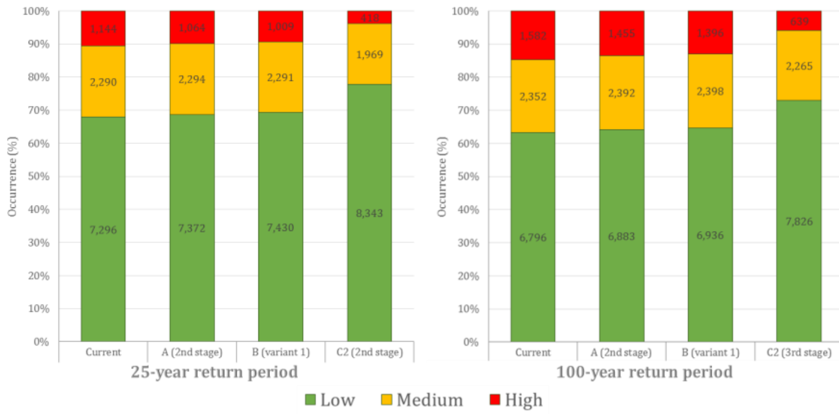

Figure 14: Flood risk at vulnerable assets

4. CONCLUSIONS

For the basin current situation, floods with a high hazard levels are centered in the valley bottoms along Avenida 9 de Julho, Praça da Bandeira and Tunnel Anhangabaú, however, the problem is also distributed along several avenues and points throughout the basin. All alternatives somehow solve flooding at major points of interest: (i) Alternative A had not performed as expected in terms of reduced flooding along Avenida 9 de Julho and Praça da Bandeira, perhaps because of its insufficient storage volume or by the lack of capacity of surface abstractions and main galleries in Avenida Nove de Julho; (ii) Alternative B also did not confirm expected performance, although scaled to a return period of 100 years, showing various flooded points along major roads, due to lack of capacity of surface abstractions and the micro-drainage system distributed over the basin; and (iii) Alternative C has the best performance in terms of reduction of peak flow and reduction of flood risk and hazard levels. As the assessment was taken globally, Alternative C Showed better distributed outcomes.

Taking into account also the results of multi-criteria alternatives analysis, which considered not only the constructive flexibility, alternative efficiency and prevented damages, but also permanent and temporary environmental impacts, costs and public response, Alternative C was chosen as the best choice to solve the drainage problems in the Anhangabaú Watershed.

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