Macro drainage plan analysis for flood control in the Lower Tamanduateí Basin

Débora F. F. Santos [a]

[a] MSc Program in Environmental Science and Technology, Federal University of ABC, Santo André - SP, Brazil

Abstract. The work focused on the main proposals and planning for flood mitigation in the Lower Tamanduateí basin and the urban intervention processes for flood mitigation. The general objective of the work was to analyse the evolution of the versions of the Master Plan for Macro Drainage of the Upper Tietê Basin (PDMAT - known as Plano Diretor de Macrodrenagem da Bacia do Alto Tietê), for the proposals made for the Lower Tamanduateí Basin, regarding design and restriction flows and structural proposals to mitigate floods in this basin. Qualitative and quantitative research was carried out, with a deductive method and a documentary research procedure. The main results indicated an increase in the channel flow capacity at the mouth of Tamanduateí between the three versions of PDMAT. The restriction flow value (100-year return period, at the mouth) increased by 142% between versions II and III. Regarding structural proposals, PDMATs I and II brought proposals to build 19 detention reservoirs since 2009, and only 4 of these reservoirs were built by 2022. It was concluded that the interventions made in the main streams over the years, allowed the increase of flow capacity at the mouth, but contributed to the aggravation of floods. Historically, the main modifications made to the Tamanduateí course were not only of sanitary interest but also of financial and real estate interest, due to the appreciation of the land in the floodplains. The most significant difficulty for the implementation of reservoirs is not only monetary but also physical, to find suitable sites for their construction in a basin with a high density of urban occupation. Therefore, studies are proposed to implement smaller reservoirs in lots, such as green infrastructure. Also, it's recommended that for future work on the concrete results brought about by the implementation of the reservoirs proposed in PDMAT, as to their efficiency and effectiveness in mitigating urban flooding in the Lower Tamanduateí basin, a survey be conducted with appropriate methodology and data to quantitatively evaluate how much it is possible to reduce the flood peak in different scenarios.

Keywords. Urban flooding, reservoirs, drainage plan.

1. Introduction

In February 2020, the city of São Paulo faced its heaviest rainfall in 40 years [1], which resulted in one death by drowning, more than 160 points of flooding and more than 1,043 calls about flooding to the São Paulo Fire Department. More than seven million tons of food were lost and was estimated a loss of approximately R$110 million to commerce (approx. U$22 million). According to the Civil Defense, at least 516 people throughout the state were displaced and another 142 homeless [2][3][4].

Marengo et. al [5] pointed out that climate change has impacted the extreme rainfall regime in the metropolitan region of São Paulo, making high-intensity rainfall events more frequent, which can lead to increasingly intense flood events in the urban areas of São Paulo, especially in the Lower Tamanduateí basin.

Sanitary measures adopted between the 19th and 20th centuries to solve this problem involved the rectification and canalization of the streams, which could also be enclosed in covered galleries. The paradigm break came in the 1990s when the idea of regulating water flows through detention and retention reservoirs started to be adopted. The most recent proposals, presented in the last Master Plan of Macrodrainage of the Upper Tietê Basin (PDMAT) consider a greater number of reservoirs implementation than the canalization of waterways [6].

When watersheds in urban areas undergo a rapid urbanization process, managing these watersheds becomes a challenge. Planning for flood control interventions faces difficulties due to limited and disputed space, high land costs, complex surface, and subsurface drainage patterns, government budget constraints, and even resistance from the population [7].

According to Mika et al (2019)[7], few studies that evaluate the watershed management planning process and/or assess the effectiveness of these plans have been published. This is easy to verify when conducting a bibliometric survey with terms related to the topic. The number of publications is even lower when discussing plans focused exclusively on macro-drainage in large, urbanized watersheds.

Faced with the possibility of an increase in the frequency of urban flooding events in the Lower Tamanduateí basin, and with the PDMAT having 2020 as the project horizon, this work aims to study the evolution of the versions of the PDMAT and specifically to analyze comparatively the design and restriction flows of each version and analyze the structural proposals to mitigate flooding in the Lower Tamanduateí basin as to their location and implementation.

2. Introduction to PDMAT and the concept of restriction flow

The first version of PDMAT was released in 1999, with proposals for all the sub-basins belonging to the hydrographic basin of the Upper Tietê region. This plan worked with the concept of starting any hydraulic diagnosis from the main channel of the Tietê, considering that the discharges foreseen in its expansion project constitute true discharge restrictions to any contributions from future canalization projects prepared or being prepared by the various public agencies.

This means that after the definition of restriction flows for the main rivers, no tributary can have its maximum flow increased. The methodology begins with the definition of a maximum flow rate for the main river of a basin, which will serve as a parameter for the definition of maximum flows for its tributaries, which in turn will function as restriction flows for their own tributaries and so on.

The plan also worked with the concept of regulating the flows through detention and retention reservoirs, initially making proposals for the implementation of these reservoirs and the canalization of some waterways.

The second version of PDMAT was released in 2009, aiming to update the information of the existing system, composed of the works implemented until September 2009, updating the files of the significant works for the performance of the macro drainage system. The urban indicators that reflected on the growth of the urban network during the nine years between plans were also updated [8].

As for structural measures, the proposals were updated to include new proposals for reservoirs and canalization of stretches, to account for the excess volume of precipitation. The reservoirs continued to play the main role in controlling the excess volume.

Additionally, the need was introduced for the dissemination, in the most densely urbanized areas, of measures to restore the retention and infiltration capacity of rainwater in the soil, such as the introduction of linear parks in the still available areas of the drainage basins. This was not possible for the Lower Tamanduateí Basin due to its extensive urbanization conditions and extensive soil sealing to the detriment of roads and occupation of the floodplains.

PDMAT III, released in 2014, aimed to update some of the work done in the previous version and expand the proposals to other areas of the Upper Tietê Basin as a whole. This document reported a difficulty regarding the definition of the roles and responsibilities of each intervening public body that operates under various spheres of power, so it brought the concept of Drainage Districts, as an alternative for the establishment of institutional control, where each district encompasses one or more municipalities with common rules regarding urban water management.

3. Study Area

The study area of this work is the Basin of the Lower Tamanduateí River (figure 1). This sub-basin of the Tamanduateí River is entirely inserted within the municipality of São Paulo, in the center-southeast region, with its mouth on the left bank of the Tietê River. Its drainage area is 84 km^2 (approximately 25% of the total area of the Tamanduateí basin - 330 km^2), under fully urbanized conditions [6].

Lower Tamanduateí basin was chosen because it is fully contained in the municipality of São Paulo, is the basin where the city center and important points in the history of the municipality are located. In addition, it presents different typologies of land use and occupation, and comprises one of the most densely occupied areas in São Paulo.

The entire length of the Tamanduateí River is 34.1 km long. The stretch that corresponds to the Lower Tamanduateí is 16.3 km long, with the entire stretch with channeled walls and an unlined channel bottom. As a result of direct actions by the São Paulo municipal government to improve road circulation in the valley regions, all the watercourses in the Lower Tamanduateí basin are currently channeled, with some being plugged and confined in galleries [6]

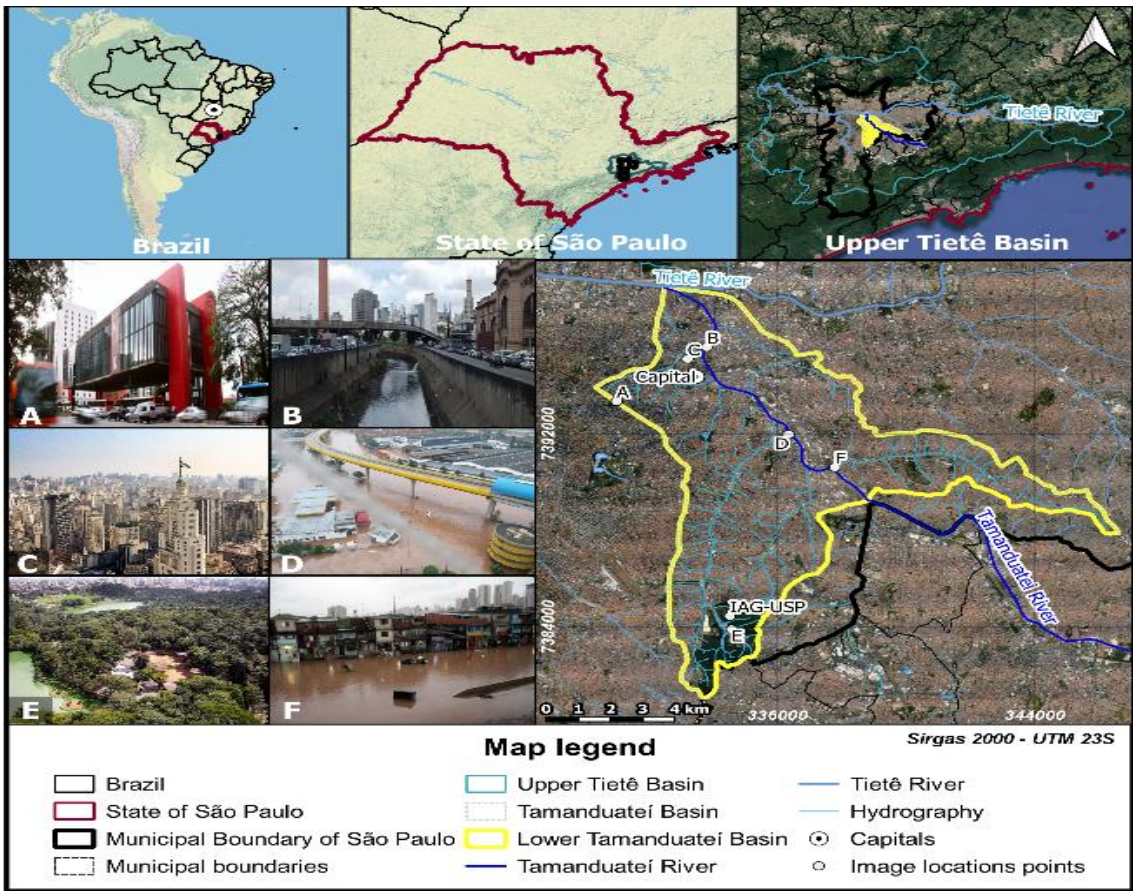

Figure 1: Study area - Lower Tamanduateí Basin in the city of São Paulo, São Paulo - Brazil. The author, 2023

4. Methods

This research work consisted of descriptive research with qualitative and quantitative approaches. Its main methods were deductive with a documentary research procedure.

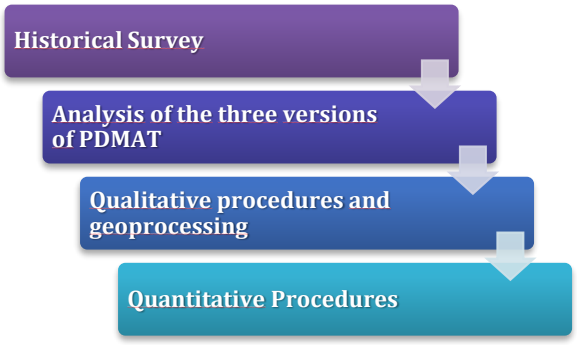

Figure 2: Research process

The main data were the three versions of PDMAT and secondary georeferenced data from IBGE and Portal Geosampa (correctly referencing the names) were also used to evaluate the evolution of the locational proposals of the reservoirs in each version, as well as hourly precipitation data from the years 1980 to 2014 from the meteorological station of the IAG-USP Observatory.

4.1 Historical servey

For the first part of the research, a survey of the history of previous interventions was carried out. Documents and works that informed about the changes in land use and occupation in São Paulo were analyzed, as well as the planning and execution of the main alterations made to the waterways of the Lower Tamanduateí basin.

4.2 Analysis of the three versions of PDMAT

In a second step, the three versions of PDMAT were analyzed, corresponding to the current macro drainage plan with proposals to be met for the Lower Tamanduateí basin and the entire upper Tietê basin, which was the focus of analysis in this work. The files of the three versions of PDMAT (complete documents of the versions, calculation spreadsheets, structural projects and commented material) were requested from the Departamento de Águas e Energia de São Paulo (DAEE), which kindly sent all the available material in its base for the development of this research.

4.3 Qualitative procedures and geoprocessing

A critical analysis was made of the information presented in the plans about the justification for the development of PDMAT I (1999) and the reasons for

the revisions that originated PDMAT II and III. The data were arranged in a spreadsheet for a comparative analysis on the difference in each version of the following data:

- Project horizon;
- Priority areas;
- Date of rainfall event considered as design storm;
- design flow and restriction for return periods of 25, 50 and 100 years;
- Proposals for structural and non-structural interventions for the Lower Tamanduateí basin;
- Quantity and location of reservoirs

4.4 Quantitative Procedures

After tabulating the information described above, the numerical data were analyzed for:

- Absolute and percentage differences between the design flows, restriction, flow capacity of the channel at the mouth, and the increase in flow in the Tietê considering a design scenario with increased urbanization of the RMSP: were calculated using the relationship between directly proportional magnitudes.

- Associated Return Period: linear interpolation between the values of duration in minutes, intensity (mm/h), and rainfall height of the design storm events (obtained from the data of the IAG-USP station) and the values presented in the forecast tables of maximum rainfall intensities (mm/h) and maximum rainfall heights (mm), according to the IDF equation for the meteorological station of the IAG Observatory

5. Results and Discussions

The first version of PDMAT was released in 1999. This plan worked with the concept of starting any hydraulic diagnosis from the main channel of the Tietê, considering that the discharges foreseen in its expansion project constitute true flow restrictions to any inputs from future canalization projects prepared or being prepared by the various public agencies. This means that after the definition of restriction flows for the main rivers, no tributary can have its maximum flow increased. The plan also worked with the concept of regulating the flows through detention and retention reservoirs, initially making proposals for the implementation of these reservoirs and the canalization of some waterways [9].

The implementation proposals for the lower Tamanduateí were divided two phases: the first with a return period of 10 years, whose limit flow was not informed in the plan, to reduce the frequency of the most recurring floods in the sub-basins. The second phase for the implementation of reservoirs considered 459 m^3/s as the design flow for a return period of 25 near the mouth [9].

The calculations were redone using as design rainfall (24h duration) the event occurred on December 8h, 2009, that occurred after the launch of PDMAT II. The flows were revised and since then, PDMAT adopted 1,550 m^3/s as the restriction flow rate at the mouth of Tamanduateí. This was due to other works and interventions that had been done at the mouth of the Tamanduateí River at the bottom of its channel and in the bottom of the channel of the Tietê River, with deepening of the channel and widening in certain parts where expansion was still possible [6].

It can be observed that there was an increase of 46 m^3/s (+9.5%) in the flow capacity at the mouth of the Tamanduateí and that the value found by PDMAT III in 2014 is close to the 50y RP design flow proposed in PDMATs I and II (547 m^3/s). Similarly, the design flow rate for 25-year RP in the third PDMAT increased by 41m^3/s (+8.9%).

The second version of the plan, despite not changing the design and restriction flow rates, the return periods of the proposed reservoir projects were redesigned from 10 to 25y RP and those of 25 to 50y

Plan	*Design rainfall event (24h)*	*Canal flow capacity at the mouth*	*Design Flow (25 years RP)*	*Restriction flow at the mouth (100 years RP)*	*Flow rate necessary to flow into the mouth influenced by greater urbanization in RMSP in 2020 – 100 years RP*	
					With the project scenario (With interventions)	**With the most critical scenario (No interventions)**
PDMAT I (1999)	February 1st, 1983 Duration: 29h Total prec.: 128.8 mm Int. (24h): 4.44 mm/h Return period: 15 years	484 m³/s	459 m³/s	640 m³/s	997 m³/s	2,020 m³/s
PDMAT II (2009)	February 1st, 1983 Duration: 29h Total prec.: 128.8 mm Int. (24h): 4.44 mm/h Return period: 15 years	484 m³/s	459 m³/s	640 m³/s	997 m³/s	2,020 m³/s
PDMAT III (2014)	December 8th, 2009 Duration: 13h Total prec.: 76.4 mm Int. (24h): 5.88 mm/h Return period: 2 years	530 m³/s	500 m³/s	1,550 m³/s	1,550 m³/s	*Not taken into account*

Table 1: Design precipitation, flow capacities at the mouth, and design and restrictions flows for each plan. The Autor, 2023.

RP, increasing the storage capacity. PDMAT III maintained the return periods of the previous PDMAT for the projects but updated the flow values. The reservoirs that have not yet been implemented, that were previously proposed in PDMAT II for 25y RP and should serve a design flow of 459 m^3/s, now must serve a design flow of 500 m^3/s.

PDMAT's first version made the proposal to build 9 reservoirs. The second version of the plan added 10 more reservoirs to this proposal (Fig. 3). The last version updated the 19 proposals and included the

perceived by the developers of PDMAT III, so no new alterations to the channels of the Tamanduateí basin were proposed.

Historically, the main modifications made to the Tamanduateí course were not only of sanitary interest but also of financial and real estate interest, due to the appreciation of the land in the floodplains. The most significant difficulty for the implementation of reservoirs in this basin is not only monetary but also physical, to find suitable sites for their construction in a basin with a high density of

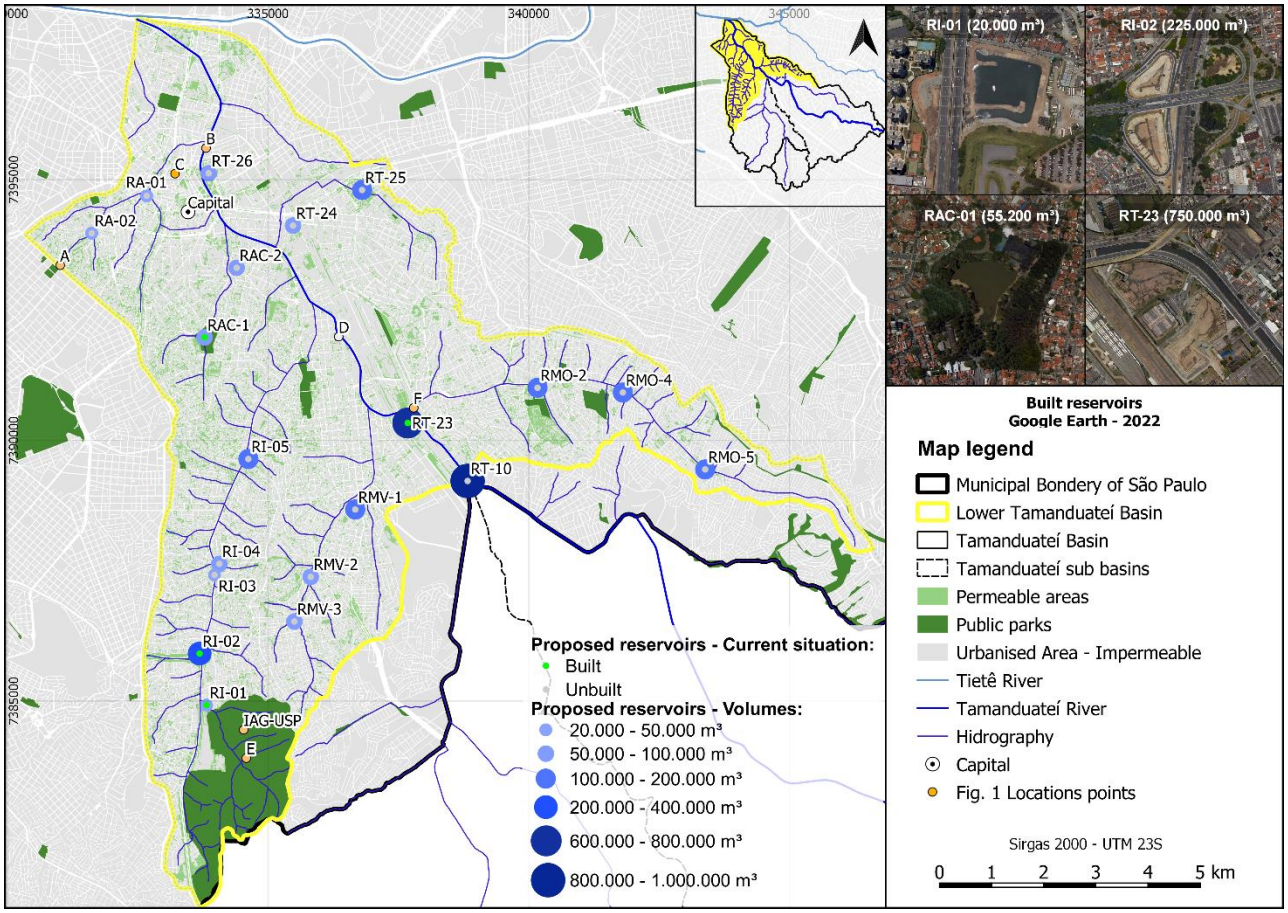

Figure 3: Reservoirs proposed by PDMAT - Current situation. The Autor, 2023

suggestion of a reservoir with a buffering capacity of up to 1,000,000 m^3 at the beginning of the basin, to reduce part of the flow arriving from the upper part of the Tamanduateí basin. So far, only 4 of these reservoirs have been built: RI-01, RI-02, RAC-02 and RT-23 and together they have the capacity to retain 1,050,200 m^3, which corresponds to 40.3% of the planned.

6. Conclusion

It was concluded that the interventions made in the main streams over the years, allowed the increase of flow capacity at the mouth, but contributed to the aggravation of floods because the smooth concrete channels considerably increase the velocity of the water runoff, increasing the volume that reaches the bottom of the basin and decreasing the capacity of the system to drain the stormwater. This was

urban occupation.

Therefore, studies are proposed to implement smaller reservoirs in lots, such as green infrastructure, for example, rain gardens, to retain part of the rainwater in a distributed way in the basin. Also, it is recommended that for future work on the concrete results brought about by the implementation of the reservoirs proposed in PDMAT, as to their efficiency and effectiveness in mitigating urban flooding in the Lower Tamanduateí basin, a survey be conducted with appropriate methodology and data to quantitatively evaluate how much it is possible to reduce the flood peak in different scenarios.

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