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# Flood Zoning in Urban Planning and Runoff Control

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## ABSTRACT

The floods in the city of São Paulo, Brazil, are an historical trouble as a result of its urbanization process. The city has a total area of 1,521 km$^2$, with 68% of urban area, where there are 1,000 km of underground streams, which represent 42% of the streams located in the urban area. Therefore, inundation problems are frequently observed due to runoff. The recurrence of floods makes government actions focused on flood control. The zoning of flood areas, associated to hydrological risk, is a technique to be used in the definition of patterns of land use and occupation, with the objective of minimizing the human and material losses resulting from the floods. This work indicates how the zoning of flooded areas can be articulated with the structural measures of flood control from the concept of the coexistence of the city with the urban waters.

## INTRODUCTION

The city of São Paulo is the largest and most populous city in Brazil, with 11,895,893 inhabitants and population density of 7,400 inhabitants per square kilometer (IBGE, 2012). It is also the main financial center of South America. This megacity historically suffers with chronic flooding problems that take place every year, especially during the summer, due to intense urbanization and high percentage of impervious areas. The City is located in the Water Management Unit of the Upper Tietê Basin, as shown in Figure 1.

São Paulo has a dense drainage system, formed by both open (natural or rectified) and underground channels, which correspond to approximately 40% of the rivers that run through the city. Figure 2 illustrates the streams in open channels and covered rivers in the Municipality.

This underground channelization has consequences that become more evident in the rainy season. During rain events, these channels are responsible for higher flow velocities. Also, the rise of imperviousness rates in urban basins is such that projections are often exceeded, resulting in runoff higher than channel's maximum flow capacity, which causes major flood inundation events, that have a series of negative impacts for the city, including material, life and security damage. Figure 3 shows pictures of the flood events over the decades in São Paulo.

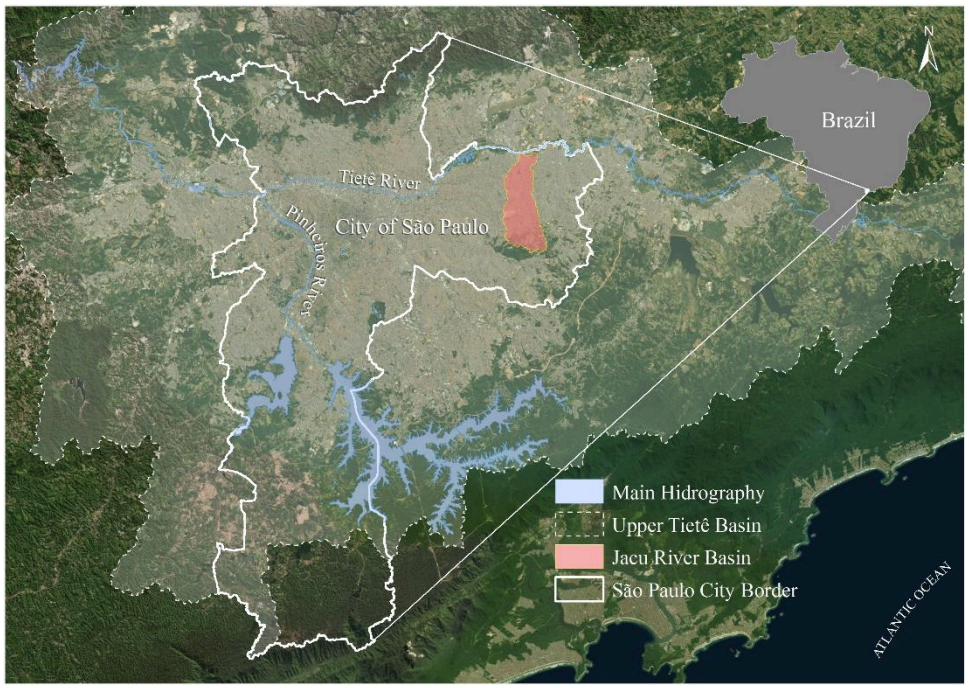


**Figure 1. City of São Paulo and the Upper Tietê Basin in Brazil**

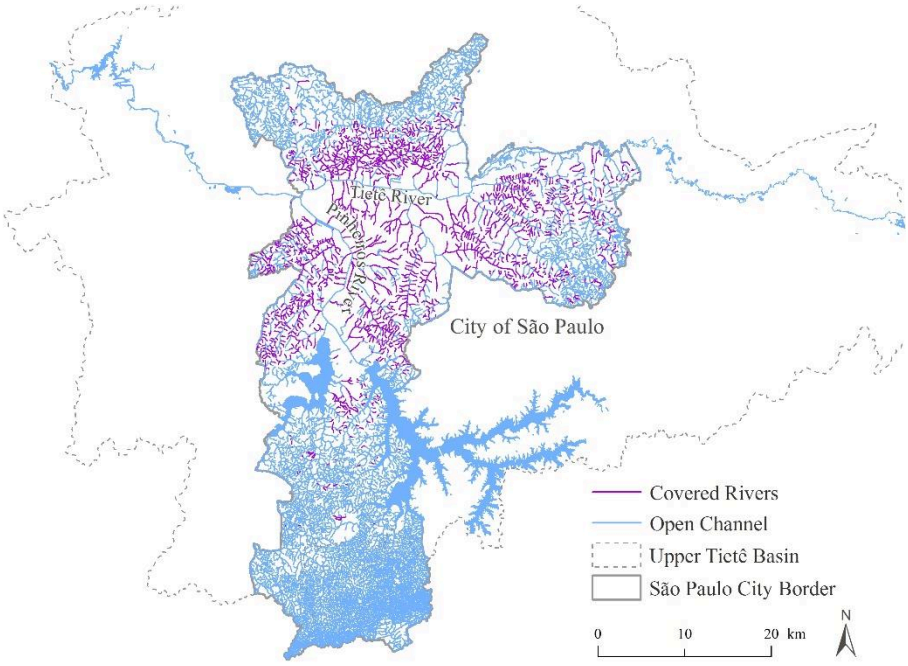


**Figure 2. Hydrographic map of São Paulo City, open and underground channels**

In São Paulo, the Strategic Director Planning (Plano Diretor Estratégico – PDE) was instituted by Law nº 16.050/2014, with the purpose of orienting municipal urban planning, including the order of territory, which consists of planning urban area occupation in order to utilize the potential of existing infrastructure, without compromising preservation of natural resources.

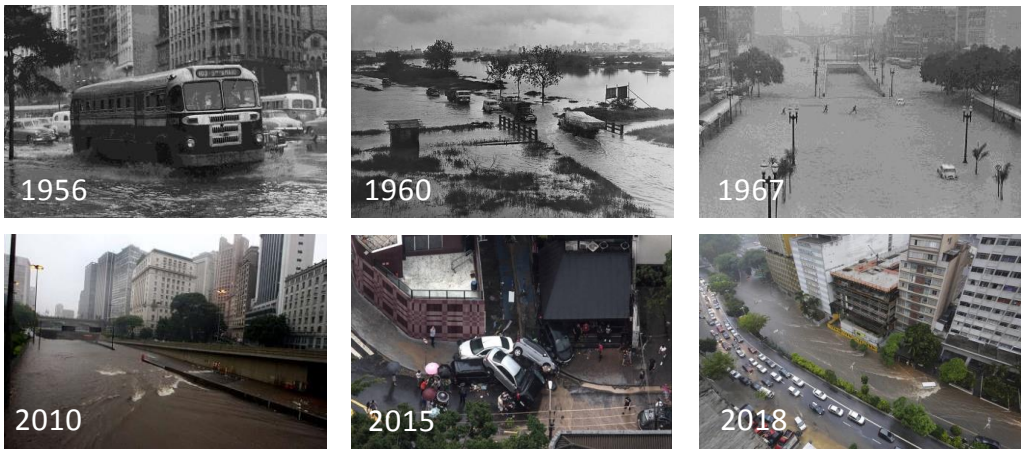


**Figure 3. Floods over decades in the city of São Paulo**

The order of territory refers to areas that present potential for urban restructuring and transformation, being able to receive new ways of occupation, combined with measures that promote economic development, rationalize and democratize the use of infrastructure and preservation of natural systems. Therefore, it allows the incorporation of new concepts and guidelines for the Law of Land Use And Occupation.

In this context, articulating stormwater management and order of territory planning aspects is an important part of flood control and urban drainage management. Thus, flood zoning can be applied as a guideline for defining regulations of the occupation of areas under risk of inundation, aiming to minimize material and life loss associated to these events, and also to add value to these areas as a new environment, for recreational or conservational use. The regulation of flooding areas can be obtained from flood zoning, according to hydrologic risk.

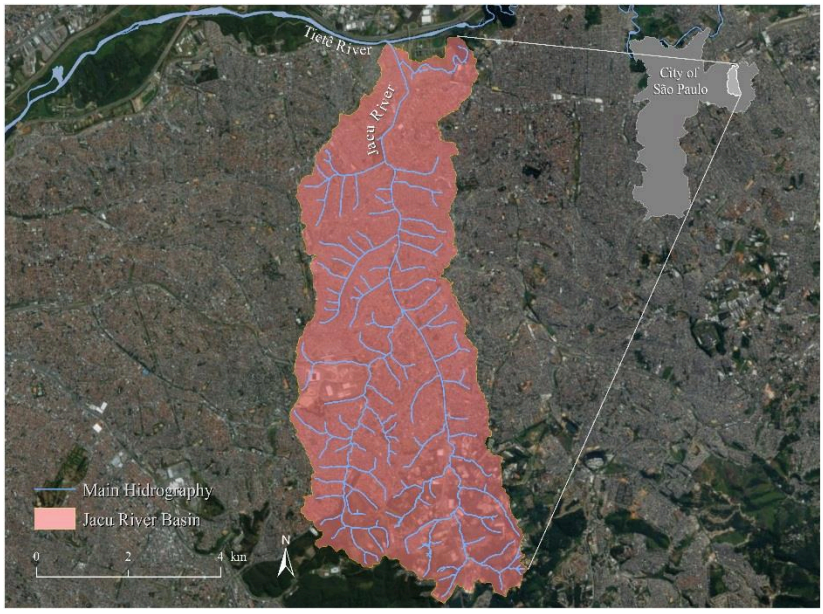


**Figure 4. Jacu River Basin in the City of São Paulo**

This article aims to present an explanation on how flood zoning can be applied in association with conventional flood control measures, applying the concept of coexistence with urban water in the city. Its method consists on the formulation of flood control alternatives, dimensioned for

25-year return period protection, for a river basin in the city of São Paulo, and proposes, for rain events with return period between 25 and 100 years, that areas directly affected by flooding are subject to land use regulation based on flood zoning. For this return period range, land use and occupation restrictions decrease as return period increases.

## CASE STUDY: JACU RIVER BASIN

The Jacu River Basin, in the east region of the city of São Paulo, has 37.6 km² of area, equivalent to 2.5% of the Municipality's total area. The maximum flow length of the Jacu River, from its spring to its outfall in Tietê River, is 13.5 km. The basin has a population of 404.000 inhabitants and a demographic density of 10745 in/km².

The map on Figure 4 illustrates the location of this watershed in the City of São Paulo.

### Land use

In terms of land use and occupation, residential and green areas are predominant in Jacu River Basin as shown in Table 1 and the map on Figure 5.

**Table 1. Land Use in Jacu River Basin**

| Land use | Area (km²) | % Total Basin Area |
|---|---|---|
| Residential, low standard, horizontal, | 7,9 | 21,0 |
| Green Spaces | 7,7 | 20,6 |
| Streets and roads | 4,9 | 13,1 |
| Residential, medium and high standard, horizontal | 4,2 | 11,2 |
| Sidewalks and other | 2,8 | 7,3 |
| Residential and commercial; services | 2,2 | 5,8 |
| Industries, warehouses | 1,9 | 5,1 |
| Urban equipment | 1,7 | 4,4 |
| Residential, low standard, vertical | 1,2 | 3,2 |
| Commercial, services | 1,2 | 3,1 |
| Residential and industries, warehouses | 0,9 | 2,5 |
| Commercial/Services and Industries | 0,5 | 1,4 |
| Residencial, medium and high standard, vertical | 0,4 | 1,1 |

### Current and projected impervious area

Impervious area was estimated by use of a Natural Resources Conservation Service (NRCS) study that consists in a relation between percentages of impervious areas and runoff coefficient values, according to different types of land use.

The minimum permeability rates, established by Law nº 16.402/2016, that disciplines the parcelling, land use and occupation in the city of São Paulo, were applied for estimating the Jacu River subbasin's maximum acceptable imperviousness. Such perviousness limits were considered as corresponding to the maximum urban densification provided for by law. The map of current and projected impervious areas, obtained as a result of this analysis, is shown on Figure 6.

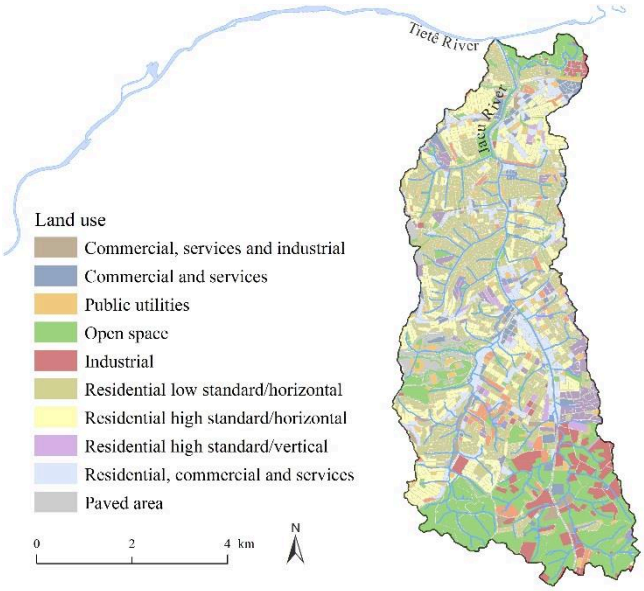


**Figure 5. Map of Land Use in the Jacu River Basin**

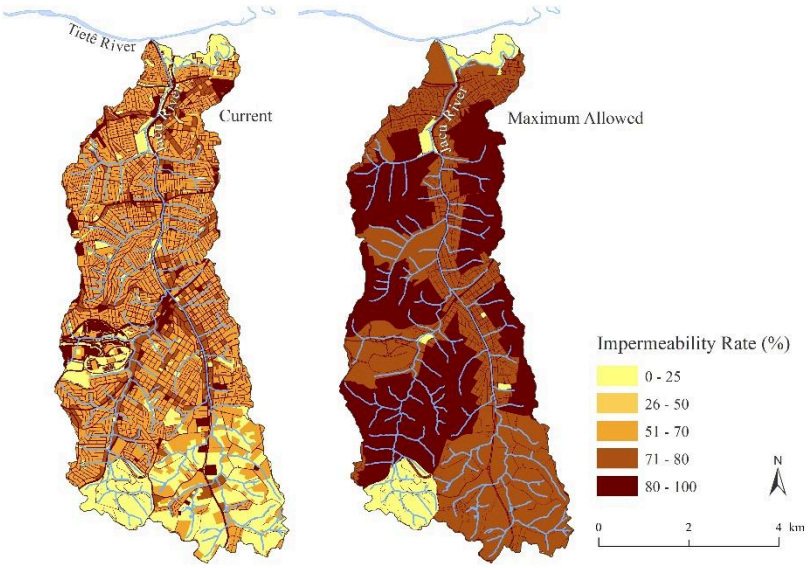


**Figure 6. Current and maximum allowed imperviousness in Jacu River Basin**

Current average impermeability in the basin is 65%, and, according to local law permission, can reach 79% of the total basin area.. It is noted that the minimum permeability rate, according to current law (Law nº16.402/2016), allows an expansion of impervious areas in the sub-basins of Jacu River Basin.

## Flood points

In the Jacu River basin, it was possible to identify some areas frequently affected by flooding, most of them spread along the main tributary streams. These areas are concentrated in the middle and inferior stretches of the basin. The outfall zone is characterized by the occurence of extensive flood areas, due to backwater effects of Tietê River. The inundation diagnosis map is visualized on Figure 7

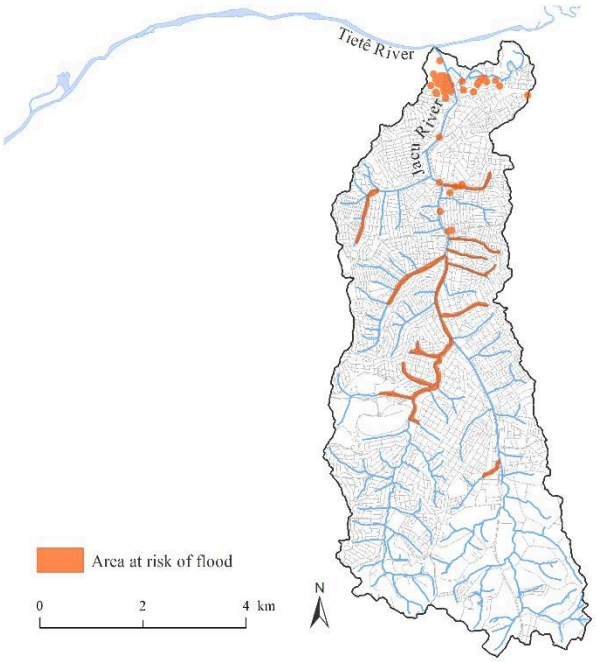


**Figure 7. Observed floods in the Jacu River Basin**

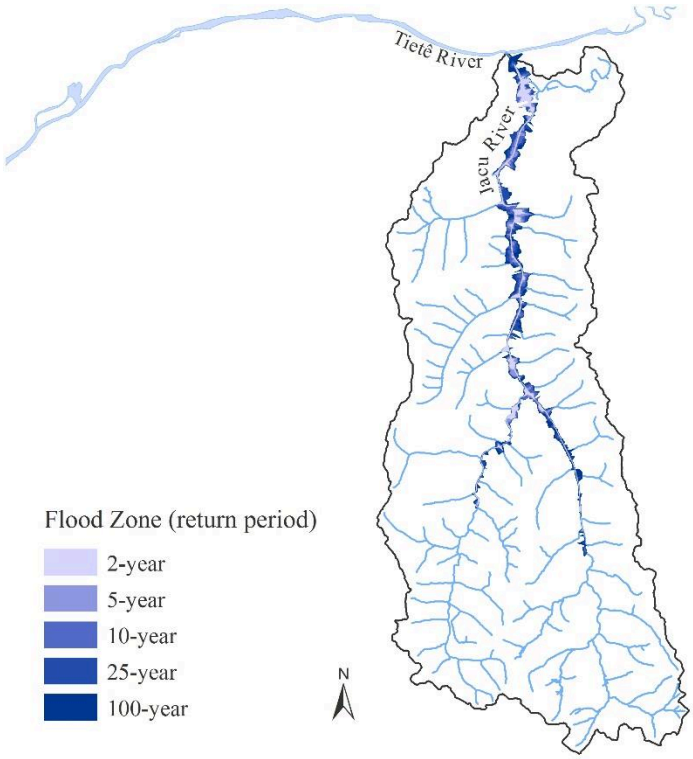


**Figure 8. Mapping of inundation areas for return periods of 2, 5, 10, 25 and 100 years in the Jacu River basin**

## Mapping of inundation areas

Maps of inundation areas are useful for the definition of land use and occupation rules, considering the recurrence associated to inundation events. In the present study, inundation

susceptible areas were mapped by applying hydrological and hydraulic modeling, considering design storms of 2, 5, 10, 25 and 100-year return periods. These rain scenarios were simulated in the Storm Water Management Model (SWMM), developed by the US Environmental Protection Agency (USEPA), through the PCSWMM graphic interface.

The SWMM estimates river flows and water levels by solving the complete Sain-Venant equations with the dynamic wave method. In the hydrological model, infiltration rates of pervious areas were estimated with the Soil Conservation Service (SCS) Curve Number method.

Inundation areas resultant for each return period in the PCSWMM model of Jacu River Basin are displayed on Figure 8.

Land use and occupation regulation, as defined by current Law, can take these modeled inundation areas into consideration when determining the following general criteria:

Flood risk-free areas, where additional measures or policies are not necessary, besides current Law;

Partially restricted occupation areas, being the allowed land uses and types of edifications (such as resilient buildings, adapted to coexisting with floods) established by Law decree, according to the situation of each area;

Total restricted occupation areas, destined to linear parks, pervious sports courts, as also determined by Law decree.

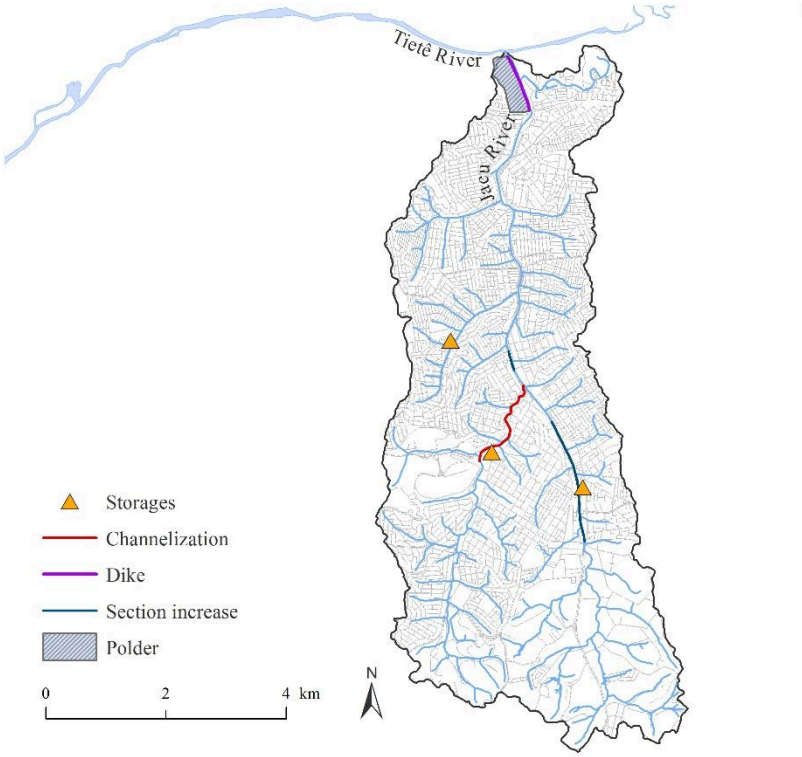


**Figure 9. Structural measures for flood control in the Jacu River basin for a return period of 25 years**

## Flood control structural measures

The flood control study of the Jacu River basin comprised, in the drainage system analysis, the inundation susceptible areas mapping as part of the adopted flood control measures, as an attempt for reducing impacts of floods. when rainfall events more severe than 25-year return

period events occur. For rainfall events of this magnitude, it is recommended that inundation areas should have restricted land use and occupation, enforced by Law.

The introduction of this concept aims to provide technical subsidies to management municipal institutions, for discussing issues as incorporation and regulation of flood zoning in the Land Use and Occupation Law.

The flood zoning concept is applied considering that a set of structural measures, necessary for protection from events of a 25-year return period, in the Jacu River basin, has already been built. These interventions consist in the construction of storage units, dikes, channelization and expansion of streams' cross-sections. Figure 9 presents the location of the suggested flood control measures in Jacu River basin.

The estimated total cost of the proposed structural interventions for 25-year protection is US$208 million. To guarantee 100-year protection for this basin, an additional investment of US$44 million would be required.

Non-structural measures, like flood zoning, can be adopted as an alternative to the 100-year structural ones. Hereby, the establishment of inundation susceptible areas was selected as a complementary action.

These areas, subject to law of land use and occupation enforcement, were obtained from model simulations with rainfall of return period of 100 years, assuming that all interventions presented in figure 9 would be already working. In other words, the basin would be protected from rainy events less severe than events with a 25-year return period and, in places reached by flooding with rainfall of return periods higher than 25 years, land use regulation should be applied.

The areas that are indicated in Figure 10 represent the areas subject to flood that should be specially regarded in future Law of land use and occupation, in the city of São Paulo.

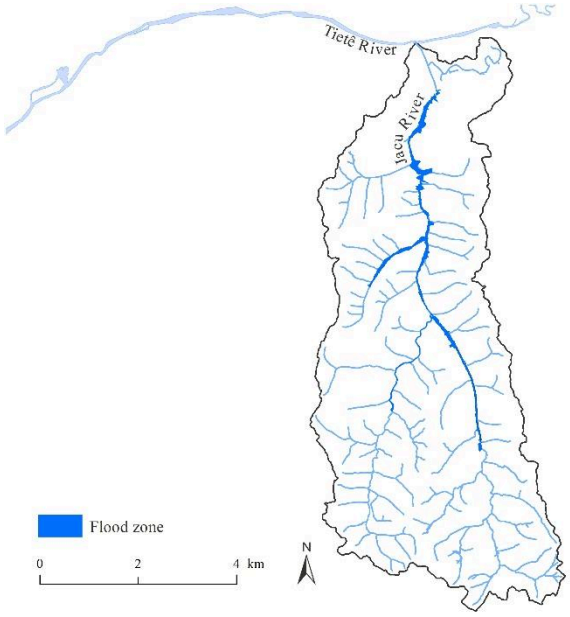


**Figure 10. Inundation susceptible areas for future regulation of Law of Land Parcelling, Use and Occupation**

In these special areas, permitted land use should be revised, since these places should be prepared for coexistence with runoff water when heavy rains occur. The law should state which

activities can be carried out at these locations. The re-evaluation of land use in these areas can lead to an urbanistic review in the basin as a whole.

Considering occupation restrictions, the legislation should orient land lords and proprietors for adapting their respective areas. Examples of criteria applied to flood-proof buildings are (SILVA, 2013):

Establishment of a floor with a level higher than the estimated water level;
Predict transportation of valuable materials to upper floors and housing for up to three months on upper floors
Temporary or permanent sealing of openings such as doors, windows and ventilation devices;
Elevation of existing structures;
Construction of new structures on pilotis;
Construction of small dikes surrounding structures;
Relocation or individual protection of items that may be damaged;
Relocation of electrical equipment to the upper floors and shutdown of the power system during the flood period;
Use of material resistant to submersion or contact with water;
Sealing and reinforcement of basement walls and floors subject to flooding;
Anchoring walls against sliding;
Predict the effects of floods on sewage projects;
Structurally, constructions must be designed to withstand hydrostatic pressure, buoyancy, momentum, and erosion;
For the planned floors subject to flood, predict the flow through the work, avoiding wall collapsing.

**Figure 11. Proposition of a linear retention park in areas susceptible to flooding in the Jacu River Basin**

Inundation susceptible areas can also receive other uses, such as linear retention parks, that have multiple purposes, like leisure spaces, recreational uses and flood control during the rainy season. The government of the City of São Paulo has prioritized flood control measures that bring rivers and streams back to view and allow a harmonious environment that enhance the