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# **A Flood Control Approach Integrated with a Sustainable Land Use Planning in Metropolitan Regions**

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Additional information is available at the end of the chapter

<http://dx.doi.org/10.5772/50573>

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## **1. Introduction**

The Brazilian National Water Resources Policy, instituted by Law no. 9.433 in 1997, is based on six fundamental principles that structure the whole National Water Resource Management System: 1) water is a commodity in the public domain; 2) water is a limited natural resource, endowed with economic value; 3) in situations of scarcity, the priority water resources use is for human consumption and watering animals; 4) the management of water resources must always provide multiple water uses; 5) the hydrographical basin is the territorial unit for the implementation of the National Water Resources Policy and the activities of the entities belonging to the of National Water Resources Management System; 6) the water resource management must be decentralized and have the participation of public authorities, water users, civil society and communities.

This Law and its regulatory texts incorporate municipalities, along with users and civil organisations, into the management system, ensuring a greater balance of power on water resource committees and boards. However, no legal text has clearly defined the relation between water management, which is a state or federal attribution, and land use planning, which is responsibility of the municipalities. In this sense, there remains a lack of definition regarding the fundamental role of municipal administrations as formulators and implementers of urban policies with impacts on water resources, whether through direct investment, or by means of actions of regulatory nature.

Besides the gap pointed out above, the occurrence of conflicts of competency is also observed in the hydrographical basins related to metropolitan areas, given that the 1988 Brazilian Constitution did not establish clear management rules for these territories. The definition of the needed and related administrative organisation for the metropolitan

areas is left to the federative states. On the other hand, overlaps is observed in the attributions of the local, state, or even federal administrations, and various undefined roles are identified, which make the task of coordination and sharing of the responsibilities even more complex.

Based on these elements, and departing from Brazilian reality, the proposed chapter deals with the need of integration of land use planning with water resource management, seeking to establish relations between the types of land use, urban settlements and the problems involving urban flooding.

A case study was developed for the Iguaçú-Sarapuí River Basin, located in the western portion of the Guanabara Bay Basin, which lies at the Rio de Janeiro State Metropolitan Region, in Brazil, and is one of the most critical areas in the state in relation to urban flooding. In this region, urban expansion dynamics is, in general, marked by irregular occupation of risk areas, without the appropriated infrastructure in terms of land tenure.

The significant investments in infrastructure in progress in the region, mainly the construction of the Metropolitan Ring Road<sup>1</sup> will bring substantial transformation to the region current urban configuration. The scenarios built with the aid of mathematical modelling demonstrate that the disorderly urban expansion, induced by the accessibility to the rural areas in the interior of the region, may be degrading for the medium and long term urban flooding control in this basin.

## **2. The role of the municipality in water resource management in Brazil**

The competence of municipalities in federated countries is concentrated on functions that, in general, are related with the allocation or rendering of local public services and with the functions of planning, incentive and inspection of the territorial order, environmental protection and also with some level of regulation of economic activities [1]. In the case of Brazil, recently, municipalities with greater capacity of investment have begun to incorporate functions related with the provision of more comprehensive social services, which, traditionally, were restricted to the state and federal spheres.

In the specific case of water resource management, however, municipal participation in basin committees has been the main form, if not the sole, of interaction with other public and private actors related with water. Many factors hinder the municipality action in the water management sphere, the main one being the legal impossibility, by Constitutional definition, of the municipalities directly managing water resources, even in the case of basins entirely contained by their territories. The exceptions may be associated to the transfer of some specific attributions through cooperation agreements with the states or the Federal Government.

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<sup>1</sup> The Metropolitan Ring Road is a Federal Government work, whose estimated cost is approximately US\$ 1.6 billion. It will have an intersection with five federal highways, a railroad and a link with various large scale industrial poles being set up in the Rio de Janeiro Metropolitan Region.

Although local administrations are closer to local populations, their politico-administrative role does not allow a systemic vision of the territory in which they lie. More effective participation of local governments in water management is hindered, or even made unviable, also by the absence of clear definitions about its nature and functions, and by the fact that the majority of municipalities have limited budgetary autonomy, bearing in mind that they depend heavily on fund transfers from the other levels of government administration.

Regarding the financial restrictions [2], it is alarming that most of the multilateral financial agencies, except the Global Environment Facility – GEF, still have not included, in their agenda, projects of integrated natural resources management articulated to land use planning, particularly in urban areas. There are few planning experiments implemented articulating water conservation and/or preservation measures and land use regulation, despite the dysfunctions of urban growth.

Another aspect is that the sectoral nature of local government interests makes them act more as users than as “impartial” managers of water resources [3]. The debility and lack of institutional hierarchy of local governments confronted by actors wielding greater power would lead to greater vulnerability and to the possibility of capture and politicisation in water management [3]. These aspects are aggravated in metropolitan areas, where municipal administrations often express antagonistic interests and priorities among themselves, creating atmospheres of dissension with little space for cooperation.

Although there are restrictions on the participation of municipalities as direct managers of water resources, there is no doubt related to the importance of local governments in territorial planning, as well as in its consequences to water resources conservation. It is the attribution of municipalities to devise, approve and inspect instruments related with territorial order, such as master plans, zonings, development of housing programs, delimitation of industrial, urban and environmental preservation areas, among other activities with impacts on water resources, mainly in the case of predominantly urban hydrographical basins.

These attributions have recently been strengthened upon approval of the Brazilian Statute of the City. This is a Federal Act, established in 2001, which proposes standards of public and social interest to govern the use of the urban property in favour of the collectivity safety and welfare, as well as the environmental balance. The urban policy established aims to organise the fulfilment of the social functions of the city and of the urban property by the application of a set of general guidelines, from which the following topics are detached:

- the guarantee of the right to sustainable cities, meaning the right to urban land, housing, environmental sanitation, urban infrastructure, transport and public services, work and leisure for present and future generations;

- the democratic management through people's participation representing segments of the community in the formulation, implementation and monitoring of plans, programs and projects for urban development;
- the planning of city development to prevent and correct the distortions of urban growth and its negative effects on the environment;
- the supply of urban infrastructure and community equipments, transport and public services to serve the interests and needs of the population;
- the protection, preservation and restoration of the natural and built environment, besides cultural, historical, artistic and landscape heritages.

Several important urban management tools were made available in the context of the Statute of the City and the Urban Master Plan is considered to be the basic instrument for the urban developing policy.

The possibility of achieving a sustainable water resource management must necessarily pass through a clear articulation with land use plans. What is observed in Brazil, however, is the disarticulation between instruments of water resource management and land use planning, reflecting, perhaps, the lack of legitimacy of planning and urban legislation in Brazilian cities, marked by a high degree of informality, and even illegality, in land use occupation. According to Tucci [4], the greatest difficulty for the implementation of integrated planning arises from the limited institutional capacity of municipalities in facing complex interdisciplinary problems, and in the sectoral ways in which local administrations are organized.

Here, however, it is worth stressing the differences among municipalities: while in large cities, mainly metropolitan cores, it is possible to find efficient administrations, with good capacity to access information and with relatively modern legislation, in other minor cities, like peripheral municipalities in metropolitan areas, a total obsolescence in the legislation is verified. This is aggravated by the absence of reliable general data and information about the processes of urban structuring and also by the small number and low qualification of the technical staff [5].

This inequality in the municipal scale presents a great obstacle for a greater effectiveness of water resource management structures and for the cooperation among the different hierarchical levels of government.

### **3. Flood control in the Baixada Fluminense lowland**

Baixada Fluminense lowland is located in the western portion of the Guanabara Bay basin, in one of the most critical regions of Rio de Janeiro State, in terms of urban flooding. It is particularly interesting as an empirical study, considering the following aspects:

- its location is in the metropolitan periphery;
- there are areas with consolidated urban and industrial growth;

- there rural areas in a process of urban development
- the basin also contains rural areas still protected from urbanisation;
- several areas present land use patterns that do not ensure minimal standards of living, especially those of poor drainage;
- consequently, several serious flooding problems occur in the watershed plain areas;
- water sources found in the basin area are used for complementing the Metropolitan Region drinking water supply;
- Tinguá Biological Reserve, the main remnant of the Atlantic Forest in Rio de Janeiro State, is situated in this territory;
- organised social movements, congregating federations of residents associations and entities involved in matters of environment, sanitation, housing, among others, are present in the basin, what demonstrates the great organisation capacity of its population vis-à-vis the questions related to citizenship and quality of life;
- local administrations are becoming more committed to efficiency in public affairs, although in a still timid process;
- the presence of major private and public investments in infrastructure will lead to significant transformations in the present urban configuration of the region.

### 3.1. Physical and socio-economic characteristics of the basin

The Iguaçu-Sarapuí River basin is situated in Baixada Fluminense lowlands. Its drainage area covers around 727 km<sup>2</sup>, all of which is situated in the Rio de Janeiro Metropolitan Region. Iguaçu River springs in Serra do Tinguá massif, at an altitude of 1,600m. Its course runs southeast for approximately 43 km, until it reaches the outfall at Guanabara Bay. Its main tributaries from the left margins are Tinguá, Pati and Capivari Rivers, and, from the right margins, Botas and Sarapuí Rivers.

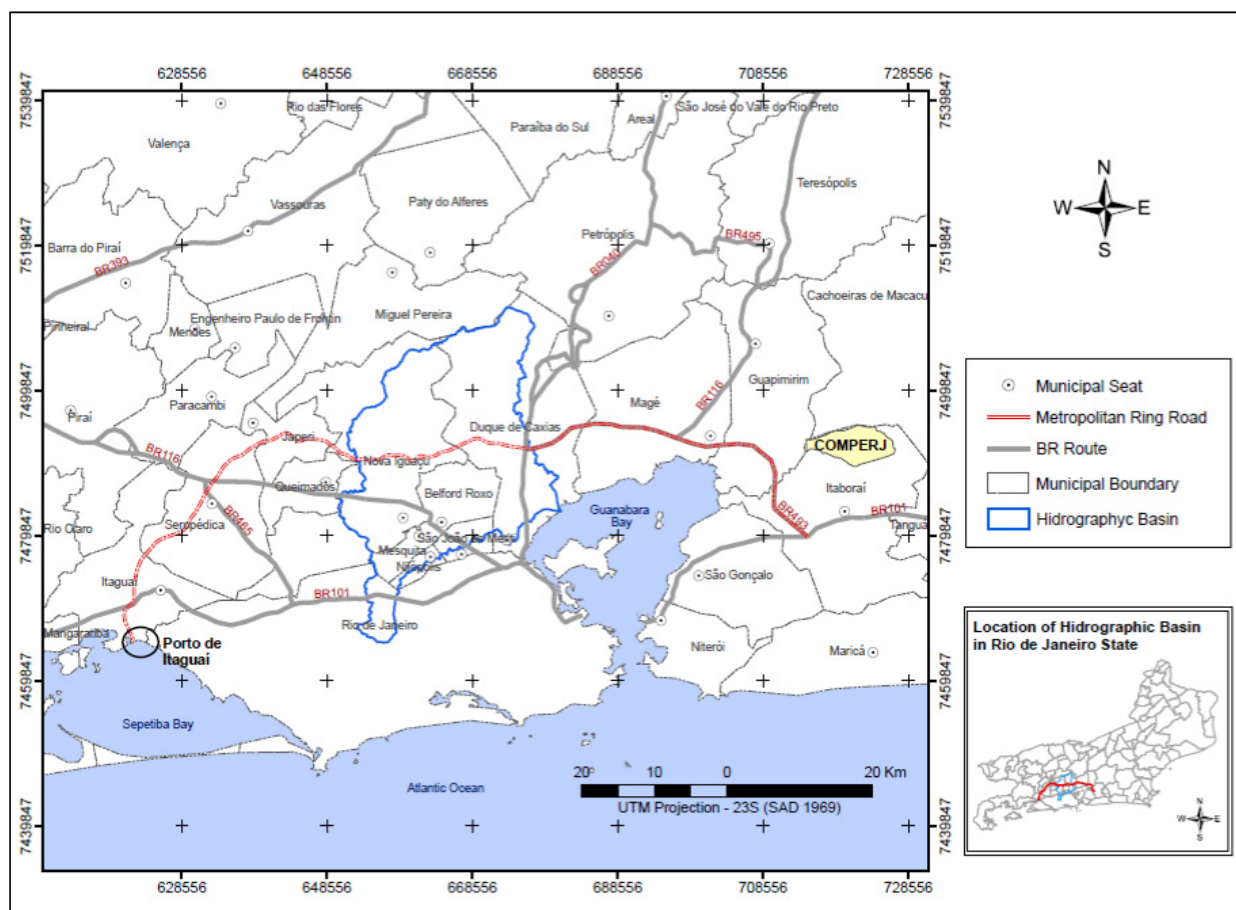
The physiography of Iguaçu-Sarapuí river basin is characterized by two main elements: the Serra do Mar Mountains and Baixada Fluminense lowlands, with a marked difference in altitude. The climate in the basin is hot and humid with a rainy season in the summer, the average annual precipitation being around 1,700mm, and the mean annual temperature approximately 22° C. The rivers run down the mountains in torrents with great erosive force, losing speed after reaching the plains, often overflowing their banks into large wetlands.

The basin fully encompasses the municipalities of Belford Roxo and Mesquita, also hosting part of the municipalities of Rio de Janeiro (covering the neighbourhoods of Bangu, Padre Miguel and Senador Câmara), Nilópolis, São João de Meriti, Nova Iguaçu and Duque de Caxias (Figure 1). According to the 2010 Brazilian census, the population of these municipalities reached 9,225,557 habitants (Table 1). However, just two of these municipalities are totally inserted in the basin.

City	Municipal Population			Total Area <sup>1)</sup> (ha)	Area inside the basin <sup>(2)</sup> (ha)	% (*)
	Urban	Rural	Total			
Belford Roxo	469.332	-	469.332	7.350	7.350	10
Duque de Caxias	852.138	2.910	855.048	46.570	27.359	38
Nilópolis	157.425	-	157.425	1.920	1.042	1
Mesquita	168.376	-	168.376	3.477	3.477	5
Nova Iguaçu	787.563	8.694	796.257	53.183	27.894	38
Rio de Janeiro	6.320.446	-	6.320.446	126.420	3.290	5
São João de Meriti	458.673	-	458.673	3.490	2.293	3
<b>Total</b>	<b>9.213.953</b>	<b>8.694</b>	<b>9.225.557</b>	<b>242.410</b>	<b>72.705</b>	<b>100</b>

Source: (1) demographic census of 2010, with the territorial division of 2001, (2) Adapted from the Iguaçu Project; (\*) percentage of the municipal area in relation to basin area.

**Table 1.** Municipal population, total municipal area, and insertion in Iguaçu-Sarapuá River Basin



**Figure 1.** Iguaçu-Sarapuá River Basin

It is in the lower parts of the basin, with elevations near the medium sea level, where it is concentrated mostly of the urban area, with something about 1.5 million people living there. Calculations from IBGE, the Brazilian Institute of Geography and Statistics, show that the incidence of poverty in these municipalities is quite significant, especially in Belford Roxo, Nova Iguaçu and Duque de Caxias, affecting more than half of their populations (Table 2).

<b>Municipality</b>	<b>%</b>
Belford Roxo	60,06
Duque de Caxias	53,53
Mesquita	-
Nilópolis	32,48
Nova Iguaçu	54,15
Rio de Janeiro	23,85
São João de Meriti	47,00

Source: IBGE, Demographic Census of 2000 and Household Budget Survey - POF 2002/2003.

**Table 2.** Poverty and inequality map – Brazilian Municipalities, 2003- Poverty incidence in Baixada Fluminense Lowlands

The structural analysis of per capita income and the capability to finance investments by municipalities in the region, according to the Observatory of the Metropolis [6], demonstrate the strong differences between the municipalities belonging to the Metropolitan Region of Rio de Janeiro. Such differences constitute obstacles to cooperation in solving common problems. Moreover, the fragile financial structure, coupled with the shortage of technical capacity, particularly in the areas of planning and budget, strengthen the uncertainty, discouraging long-term partnerships in infrastructure projects that could be used to promote social and economic development for the region.

After a century of intense population growth, Brazil has entered the new millennium with quite modest rates of population growth. As shown by the data of the last Census, the Brazilian population grew at an average rate of 1.6% per year in the 1990s, following a decline trend after the strong growth happened from the 1950 to 1970. Projections developed recently estimated that the Brazilian population is growing at rates below 1.3% per year.

The city of Rio de Janeiro has been the centre of services for the Metropolitan region, although this characteristic has not reflected in a high degree of attractiveness for population in recent times. The region remained with the lowest population growth rate among large Brazilian cities. It should be noted, however, that in absolute terms, there was a warming of migration in the last decade towards Rio de Janeiro. Between 1980 and 1991 the total number of migrants towards the metropolitan area of Rio de Janeiro was around 570,000 people, while between 1995 and 2000 (just in five years) the total migration reached 330,000 people. The capital of the state remained the main pole centre, receiving these migration flows and housing 195,000 migrants, i.e. 62% of the total [6].



According to Britto and Bessa [7], historical investments were made in the region by different state governors, like the one of the 1980s, with an amount up to R\$ 3 billion, without, however, effectively guaranteeing universal access to environmental sanitation, housing and a better quality of life. Explanations for this are related with: (i) the lack of a profound diagnosis of the dimension of the problem in the region to correctly orient the profile of the interventions; (ii) the discontinuity and non-integration among the programs and projects implemented throughout these years; (iii) the political disputes in the region often decharacterised the projects, again lacking continuity; (iv) the fragility of social control in the process, once the format of the implemented programs have not provided an effective participation of the population (although this component existed in various of these projects); (v) the lack of institutional capacity, allied to the centralizing culture of the state governors in relation to sanitation management; (vi) the strong clientelistic culture in the municipal administrations; (vii) the growing demobilisation of organized social movements, which need members qualification for following up the policies implementation.

### **3.2. Flood control in the Baixada Fluminense lowlands**

Floods in the Iguaçu-Sarapuí River Basin are aggravated basically by the f inadequate land use occupation, in the particular conditions of the lowlands of Baixada Fluminense. In this process, the most important factors are: lack of adequate urban infrastructure; deficiency of the sewage services and solid waste collection; uncontrolled exploitation of mineral deposits, mainly sand for construction purposes; disorderly, illegal occupation of river banks and floodplains; lack of adequate treatment for public roadways pavements; obstruction or strangulation of drainage due to structures built without the proper concerns (railway and road bridges, and water pipelines interferences), as well as walls and even buildings that partially obstruct river channels. At the heart of these problems one always finds either inadequate legislation regarding land use, or, in the great majority of cases, non-compliance with the existing legislation.

It is estimated that floods in the basin directly affect 189,000 people. However, the damage caused and the total number of people indirectly affected by floods are both difficult to estimate. Included in this latter category there are, for example, employees who cannot reach their workplaces and the interruption of traffic and commerce along the flooded roadways or nearby areas that become inaccessible.

In this context, in order to properly discuss the adequate possible planning actions for mitigating these problems, and to figure out the cause-effect process related to future scenarios, a mathematical model will be applied as an aiding tool. The case study alternatives are then introduced in order to allow the development of the discussions in practical terms, using examples of what may happen in the future without the proper concerns. The aim of hydrodynamic modelling was to evaluate the possible impacts of the expansion of urbanisation towards the interior of the basin without the adequate planning

process and considering the construction of Metropolitan Ring Road, which is being taken as an urban development inductor factor. Another objective of the modelling consisted of evaluating the impact of an average rise in mean sea level, regarding the drainage system conditions, according to forecasts made by the Intergovernmental Panel on Climate Change (IPCC) [8]. In both situations, which may critically combine effects, planning actions are required in order to control future negative effects, otherwise the human and material losses could become irremediable.

### 3.2.1. Brief Description of MODCEL

In order to proceed with the proposed analysis, it was necessary to choose a mathematical model to support the simulations. With this aim, a hydrodynamic model for representing rural and urban floods – MODCEL [9, 10 e 11] was used.

The construction of MODCEL, based on the concept of flow cells [12] intended to provide an alternative tool for integrated flood solution design and research. MODCEL is a model that integrates a hydrologic model, applied to each cell in the modelled area, with a hydrodynamic looped model, in a spatial representation that links surface flow, channel flow and underground pipe flow. This arrangement can be interpreted as a hydrologic-hydrodynamic pseudo 3D-model, although all mathematical relations written are one-dimensional. Pseudo 3D representation may be materialised by a vertical hydraulic link used to communicate two different layers of flow: a superficial one, corresponding to free surface channels and flooded areas; and a subterranean one, related to free surface or surcharged flow in storm drains.

The representation of urban surfaces by cells, acting as homogeneous compartments, in which rainfall run-off transformations are performed, allows the integration of all the basin area. The cells interact through hydraulic laws, represented by cell links capable to model different possible flow patterns. Different types of cells and links give versatility to the model. The cells, considered individually as units or taken in pre-arranged sets, are capable to represent the watershed landscape, composing more complex structures. Therefore, the task related to the topographic and hydraulic modelling is an important phase of the process. In large floodable areas, when leaving the drainage network, the water can follow any path, dictated by the topography and by the urban built patterns. Marginal sidewalks may become weirs for the spilling waters from the rivers, the streets may act as canals and the buildings, parks or squares may act like reservoirs. In this situation, it is perceived that overflowed waters may have an independent behaviour from the drainage network, generating their own flow patterns. These characteristics are adequately represented in MODCEL.

The modelled area of Iguaçú-Sarapuí River basin extended from Guanabara Bay to Botas River confluence. The upstream reaches of the basin, which were not divided in cells, had their flows determined through a hydrological model called HIDRO-FLU [13].

### 3.2.2. Simulation criteria

The main objective of the modelling of the lower and middle reaches of the Iguaçu River was to evaluate impacts caused by the expansion of uncontrolled urbanisation towards the middle/upper basin, arising from the development expected from the construction of the Metropolitan Ring Road, an important axial roadway.

The effective rainfall calculation method used was that of the SCS [Soil Conservation Service] of the Department of Agriculture of the USA - USDA. The *Curve Number* (CN), the main hydrological parameter of this method, varied for each of the simulated scenarios in accordance with different stages of urbanisation, as described below:

1. Past situation: the CN values were defined based on soil types and land use mapping from 1994 (LANDSAT satellite images) [14].
2. Present situation: the CN values were determined by land use mapping, made on the basis of images from the 2006 Aster sensor [14].
3. Future situation: assumed that the flat, still rural areas of the sub-basins of the Rivers Iguaçu (upper reach), Botas, Capivari, Pilar and Calombé, and the Outeiro canal will suffer a disorderly process of urbanisation, following the trend of peripherisation in progress in Baixada Fluminense lowlands. This future scenario corresponds to a horizon of approximately 20 years (2030).
4. Controlled future situation: assumed an alteration in the current pattern of urbanisation of these areas, with the introduction of land use control by means of urban planning actions and adoption of more sustainable urban drainage techniques.

Each modelled cell in the basin representation had an individualised CN, depending on its particular characteristics.

Another objective of the modelling consisted of evaluating the impact of the mean sea level rise, as forecasted by the IPCC, on the drainage conditions of the hydrographical basin. The proposed scenarios tested the isolated and/or associated effect of the following variables:

- a. different hydro-meteorological conditions, alternating typical tidal situations and the effect of meteorological tide;
- b. variation in the soil impervious rates arising from the behaviour of future urbanisation, considering the maintenance of the current rates (without any increase in new urban areas); an increase in the impervious rates due to unplanned urban expansion; and a moderate increase in the rates due to planned control of urban expansion. For each of the simulated scenarios, CN values were adopted as presented in Table 3.

It is important to stress that this paper does not intend to look for final solutions in order to minimise present flood conditions (although this discussion will be considered conceptually in the context of this study, in a next topic). The main aim refers to the possibility of discussing future conditions worsening due to the inadequate planning process that take place today.

Basin	Past CN	Current CN	Future CN	
			without control	with control
Iguaçu	65	66	77	72
Botas	81	81	82	81
Capivari	67.5	65	77.9	72
Outeiro	72	84	84	84
Pilar	75	76	78.2	76
Calombé	68	79	79.8	79

**Table 3.** Curve Number (CN) used in each simulated scenario

The return period considered for the design rainfall was 20 years. The hydrologic parameters and rainfall information adopted were based on the Iguaçu Project [15] calculations. Regarding to the impacts caused by alterations in mean sea level, a local tide table was used as the base information. This table was produced by the Diretoria de Hidrografia e Navegação da Marinha do Brasil (Hydrography and Shipping Directorate of the Brazilian Navy), with values ranging from 0.09 to 0.90m, representing the tidal variation on the Rio de Janeiro coast. The meteorological tides were considered to influence this value with a majoring of 0.80m. Besides, a possible increment of 0.60m in the mean sea level was also considered (IPCC forecast), due to climate change expectative. With the values mentioned, the proposed scenarios were simulated, considering the tidal variations, the dynamics of urbanisation, the rise in the mean sea level, and combinations among these variables.

#### 4. Results obtained in the modeling

Figure 2 represents the areas susceptible to flooding for the former conditions of urbanisation (at the time of Iguaçu Project [15]), in the 90's, without taking into account the meteorological tides and the effects of climate change. It is, therefore, a condition of reference for the current and future scenarios comparison, referring to flooding conditions of more than 15 years ago. It is observed that there are significant differences in floods in past conditions from those in the present scenario. The alteration already occurred in the land occupation in the upper reaches of the basin in the period justifies this result.

The flood maps presented in Figures 3 and 4, respectively, were obtained through the following conditions: current situation of urbanisation in the basin, without considering meteorological tides and the effects of climate change (Scenario 1); and future condition of the basin urbanisation, considering disorderly urban expansion, typical tides and without the effects of climate change (Scenario 2).

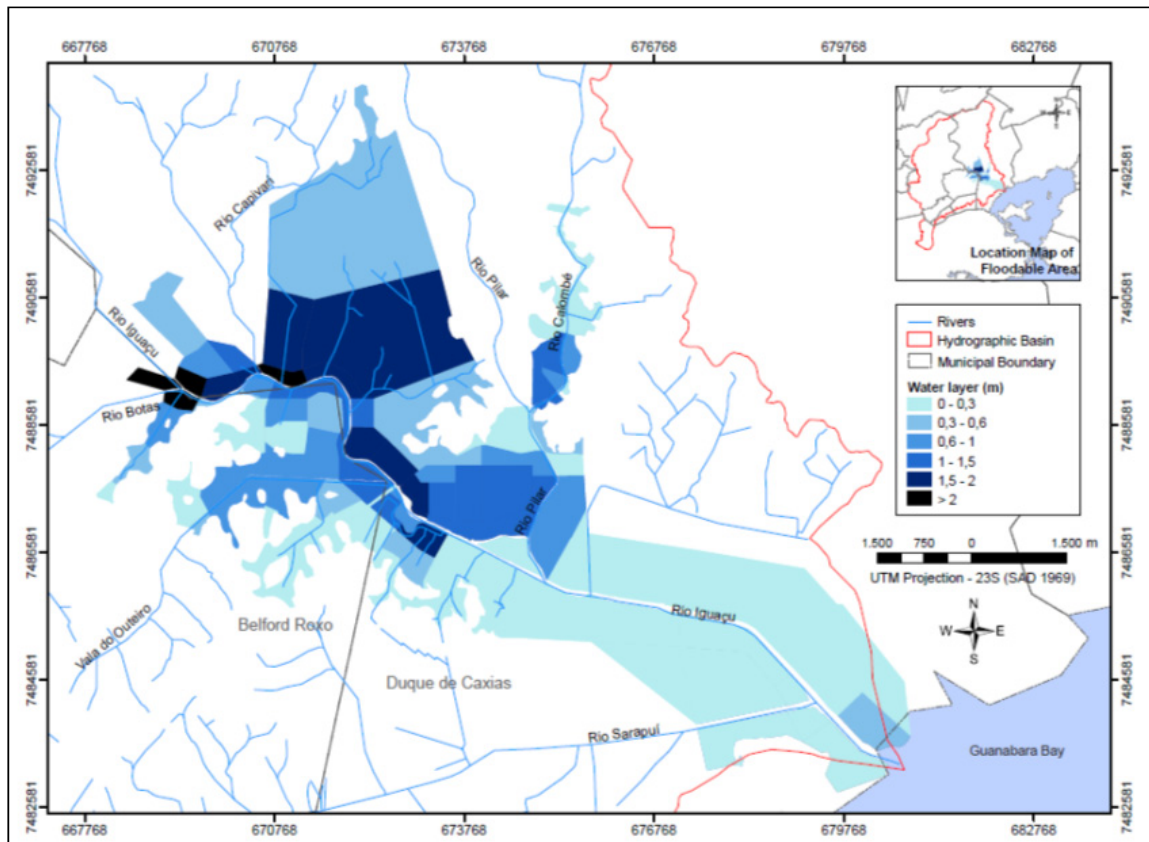


Figure 2. Reference flood map for former urban condition

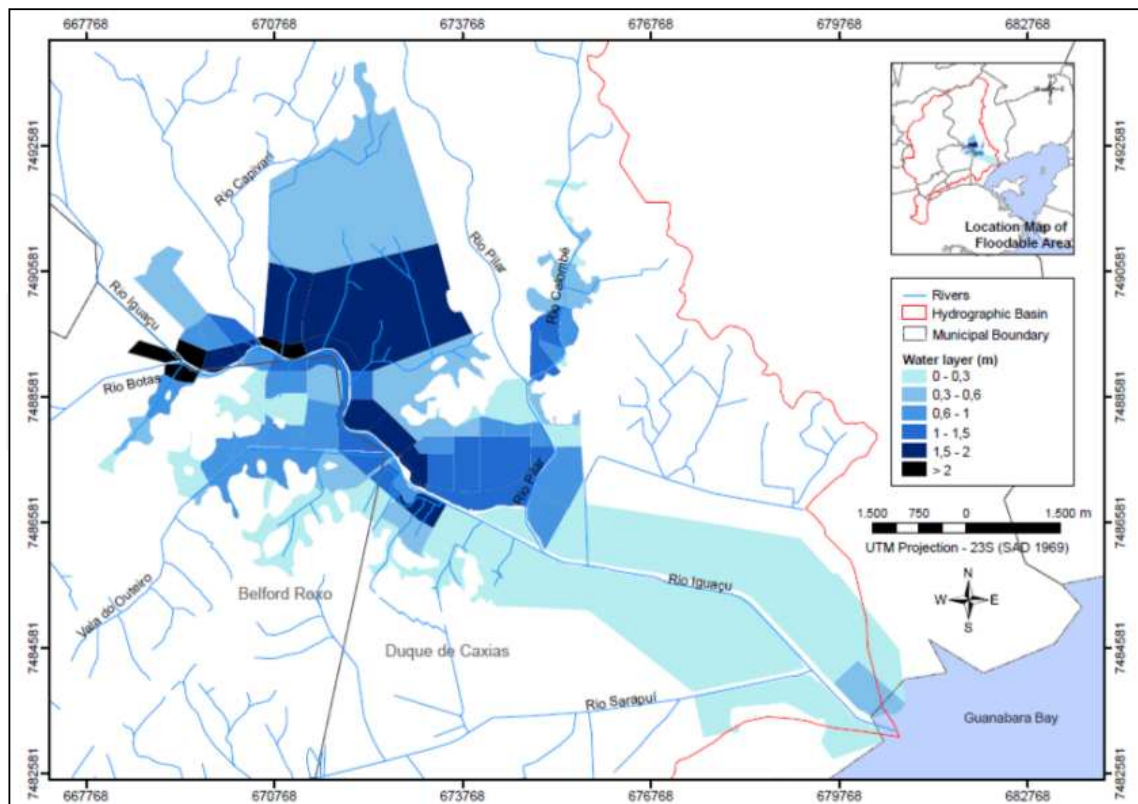
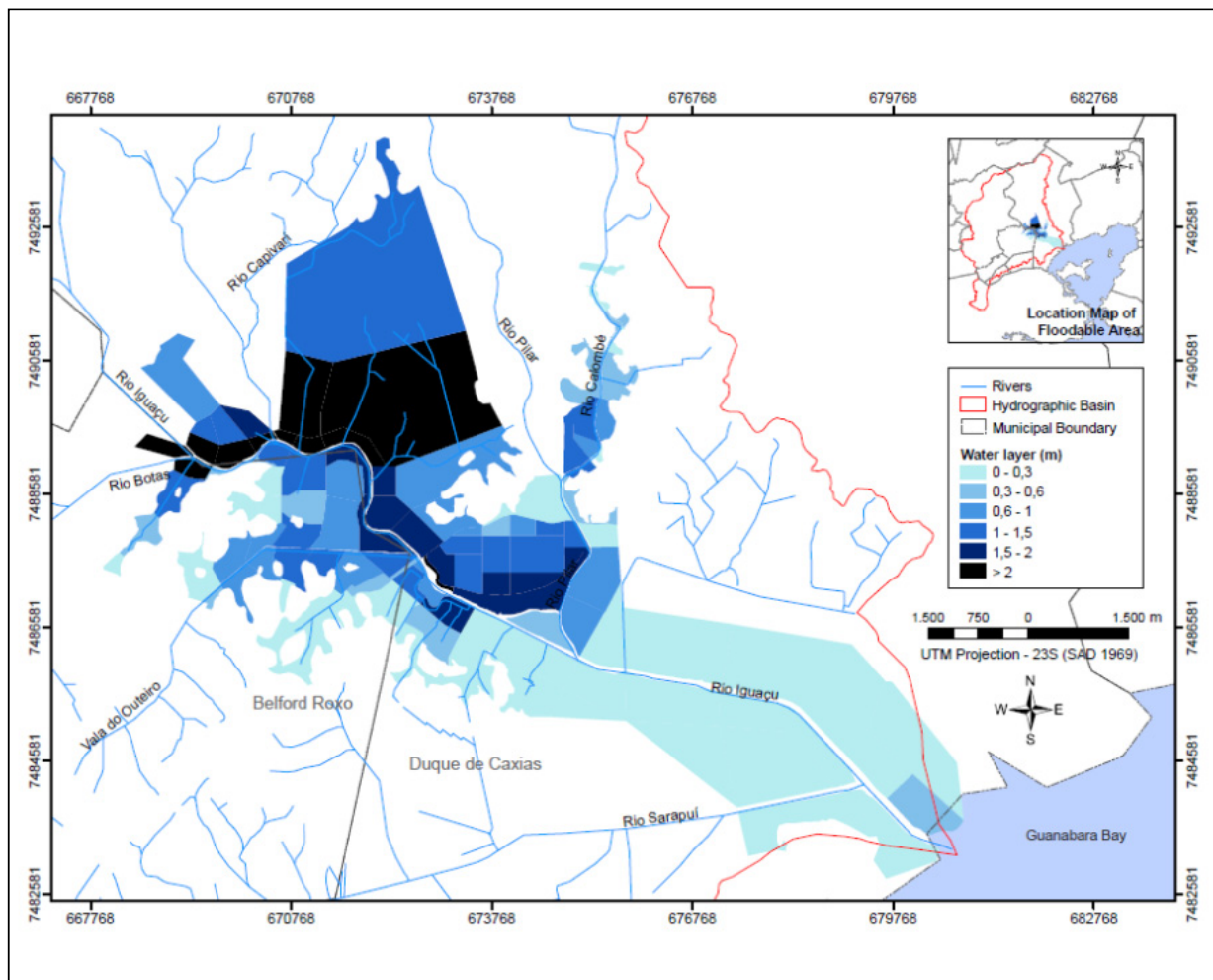


Figure 3. Flood map obtained for the present condition - Scenario 1



**Figure 4.** Flood map obtained for future condition - Scenario 2

The comparison among these three scenarios allows the assessment of the isolated effect of the urban expansion in the flooding aggravation. When the CN is altered for the upper reaches of the drainage area, in the simulation corresponding to Scenario 2, a significant worsening is noticed in flood conditions, even without any other worsening factor acting, as seen in the comparison of Figures 3 and 4

If effective measures were implemented for land use development control, in order to prevent disorderly occupation in the middle and upper reaches of the basin, it can be seen, in Figure 5 (Scenario 3), that it is possible to avoid the worsening of floods in the referred sub-basins. It is perceived a reduction in the water levels in the densely urbanized areas, when compared with the previous development situation, without any control over land occupation.

The figures 6 and 7, presented in sequence, correspond to the following scenarios:

- Figure 6: Flood map obtained for the future conditions of basin urbanisation with urban expansion without control over land use; meteorological tide of 80 cm and a 60 cm rise in the mean sea level due to climate changes (Scenario 4);

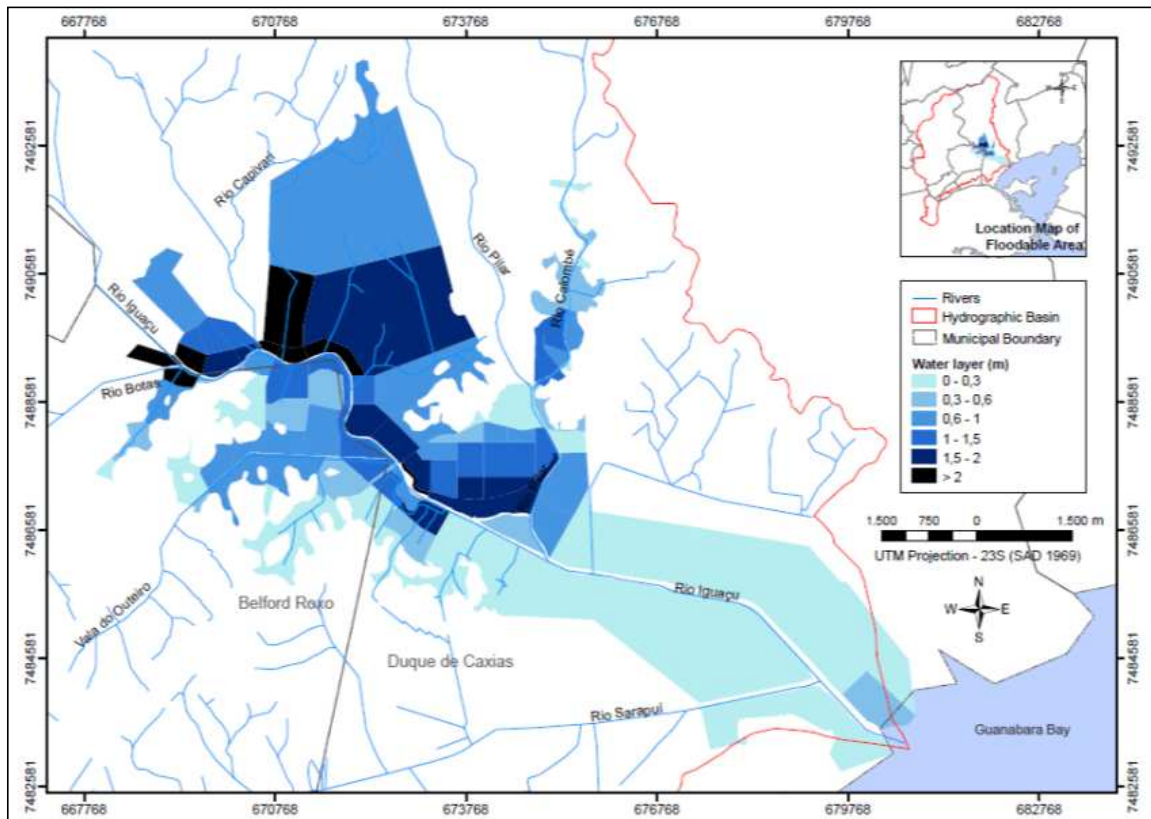


Figure 5. Flood map obtained for controlled future condition - Scenario 3

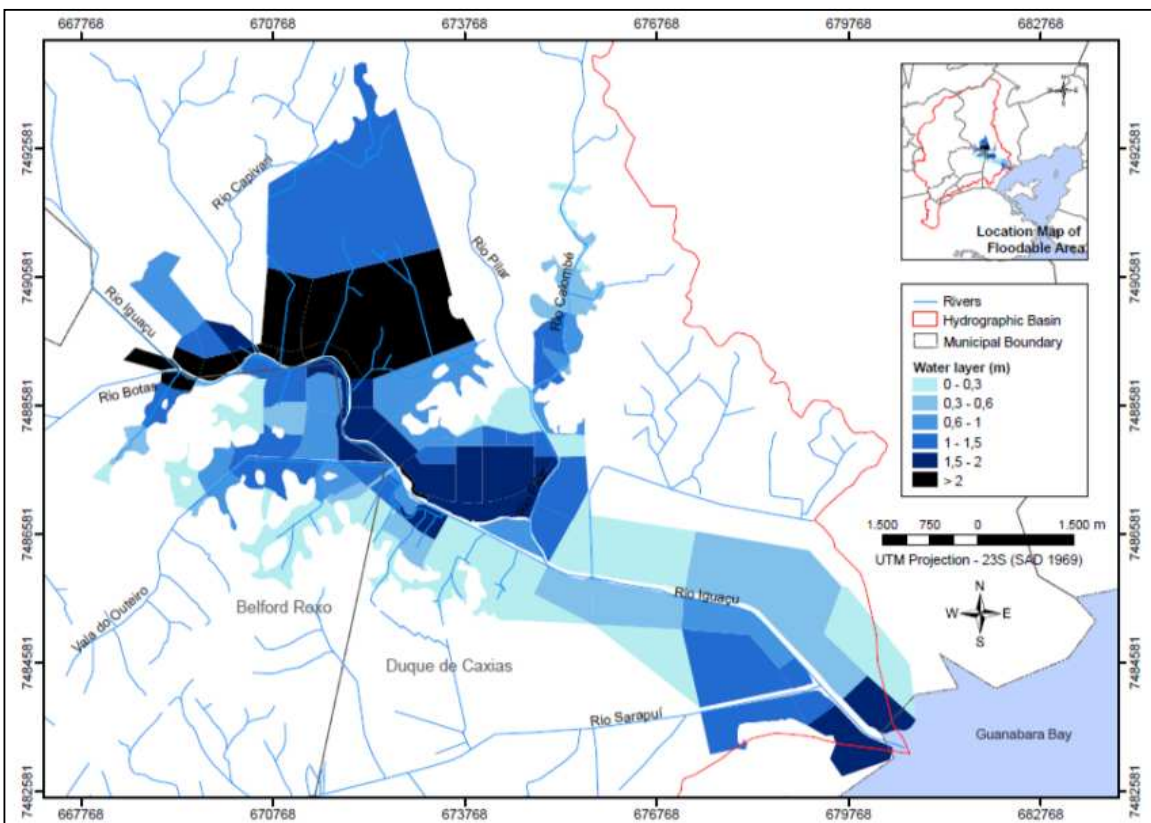
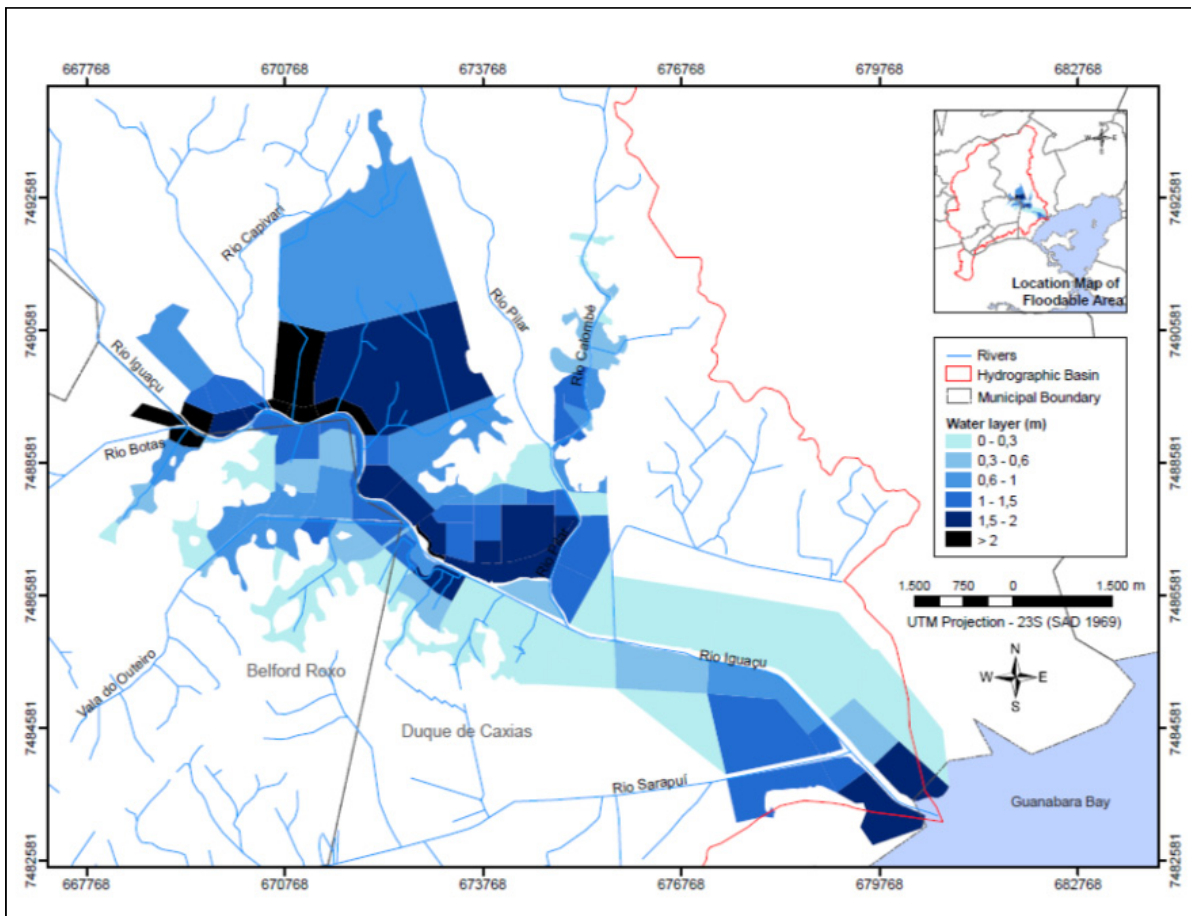


Figure 6. Flood map obtained for future condition, in the context of climate changes - Scenario 4

- Figure 7: Flood map obtained for the future conditions of basin urbanisation, with control over the land use development; meteorological tide of 80cm and climate change effects, with a 60 cm rise in mean sea level (Scenario 5).



**Figure 7.** Flood map obtained for controlled future condition, in the context of climate changes-Scenario 5

These two scenarios test the conjugated effect of the three variables considered in the simulations: urbanisation of the upper basin, presence of meteorological tide and mean sea level rise. Based on these scenarios, it is possible to conclude that the disorderly urbanisation of the upper basin causes flooding aggravation in the downstream urban areas already consolidated, while the tidal variations cause even greater floods in the lower reaches (under tidal influence). The sea level rise will worsen the floods in the urban areas situated at low elevations, near the Iguaçú River estuary.

Both the urban expansion and the sea level rise are going to cause great impacts on the urban areas of the basin. Despite having their causes explained by independent variables, these factors, if combined, would lead to serious impacts on the population resident in the basin. If planning measures are not taken in advance, it will be very difficult to mitigate their impacts later.



## 5. Conceptual discussion

The urban drainage system includes two major subsystems: micro-drainage and macro-drainage. The micro-drainage system consists of the paving of streets, gutters, gullies, stormdrains and channels of small dimensions, intending to collect the runoff and conduct it to the macro-drainage net. Macro-drainage generally consists of natural or built channels of larger dimensions, receiving the input from micro-drainage, concentrating flows and discharging in the receiving water body. A complementary set of structures also take part in drainage systems, among which is possible to mention: reservoirs, protective dikes, and pumping stations. All these structures are arranged and designed to work in an integrated way, intercepting, conveying, possibly infiltrating or temporarily storing and discharging the generated runoff. Ultimately, the receiving water body is the sea and this is the case of Iguacu-Sarapuí Rivers.

The urban flooding process, by its turn, is directly associated with the failure of these subsystems, due to lack of maintenance, obsolescence, disordered urban growth or, as stated in recent discussions, due to the possibility of climate changes worsening flow conditions. Specifically to the drainage systems, the negative effects that may arise from the situation of climate changes refer to the increase of extreme rainfall events intensity, and to the restriction imposed by the expected sea level rise at the basin outfall. Evaluating this context, the increase in the mean sea level causes a reduction in the discharge capacity of the system, causing the drainage net to lose efficiency. The worsening of the extreme rainfall events intensity works in the other part of the problem, generating greater volumes to be drained by a system whose discharge capability diminished because of the new outfall restrictions. In this situation, in a context of already serious urban flooding problems, the effects generated by the possibility of climate changes can dramatically increase flooding areas, causing them to reach locations not previously affected by floods, increasing inundation depths and residence times, making the situation even worse.

Understanding how urbanisation affects floods is very important for urban flood control design. In general, it is possible to say that the urban flood control conjugates the adoption of structural measures that change the landscape of the basin, introducing interventions inside and outside the drainage network, to act directly in minimising the problem, and non-structural measures, associated with land use planning, environmental education and several possible other measures that allow a more harmonious coexistence with the phenomenon of flooding. The combination of structural and non-structural measures, in a context of planning integrated with urban growth, allows a composition capable of solving the problem of flooding in a harmonious and sustainable way. This approach, which is relatively recent, is being considered more appropriate to treat the urban flooding problem, by treating the problem in a systemic way and proposing actions that seek to minimize the impacts of urbanization.

This trend, though not motivated by the possibility of climate change, also goes toward this theme, with the possibility of reaching effective results, in opposition to the traditional approach that basically considers propositions of rectifying and canalising water courses. In this perspective, the traditional approach treats the consequence of the problem, related to the generation of exceeding superficial flows. The possibility of the mean sea level rising, however, limits the discharge capacity of the system and makes the traditional approach to fail. Thus, in this context, it is necessary to treat the problem of flow generation, acting in the causes of flooding, while trying to introduce infiltration and storage measures spread over the urban basin landscape in order to reduce and delay flood peaks, allow groundwater recharge and seek to restore the approximate natural flow conditions. This approach introduces the sustainable urbanization concept, proposing that the flood should not be transferred in space or time. This way, storage and infiltration measures may be important measures for sustaining adequate drainage conditions. Storage measures should consider detention or retention reservoirs, acting in-line with rivers or in the base of hill slopes, or combined in multifunctional landscapes in parks and public squares, or even in the plot level, as an on-source control option. By its turn, infiltration measures may involve reforestation actions, the use of pervious paving, or infiltration trenches, among others. All these measures, properly designed in an integrated manner, might be able to work preventively or correctively, if necessary, modifying the spatial and temporal distribution of flows, to face the new challenges.

The storage measures, because of their applicability and diversity of use, in different combinations with the drainage net configuration, are highlighted in this conceptual discussion. The reservoirs are able to attack the problem of flooding worsening, both from the point of view of the uncontrolled urban growth, as well as from the point of view of possible climate changes. The storage capacity of these reservoirs allows facing the larger volumes and to control surface runoff released to the network, minimising chances of system failure, with a time of response that matches the velocity of the critical superficial processes that generates floods. Infiltration measures are very important, because they are able to reduce flow volumes, but infiltration process takes more time and, in this case, time may be a critical factor when trying to control floods. So, infiltration measures are desirable, but may usually they do not prescind from storage measures.

## **6. Proposed solutions for Iguaçu-Sarapuí River Basin**

The Iguaçu Project, related to the first Water Resources Management Master Plan, was the reference scenario used in this study. After more than one decade, the revision of the Water Resources Management Master Plan for Iguaçu-Sarapuí River Basin started in 2007 and finished in 2009. Lack of an adequate urban land use control and unplanned city growth led to several problems, as discussed previously. In the newer version of The Master Plan, the original set of proposed measures was reviewed. Part of these measures was maintained,

especially in consolidated areas; however, whenever possible, new concepts on sustainable urban drainage were introduced. The basin was considered in an integrated way and environmental recovery concerns were added to the new plan. Irregular occupations of risky areas, subjected to frequent flooding, and especially riverbanks occupations, were considered not appropriated and people living in these houses without proper safe conditions needed to be relocated.

Both structural and non-structural measures were proposed for flood control purposes, ranging from short to long-term actions. Some of the proposed actions aiming to give more sustainable solutions considered:

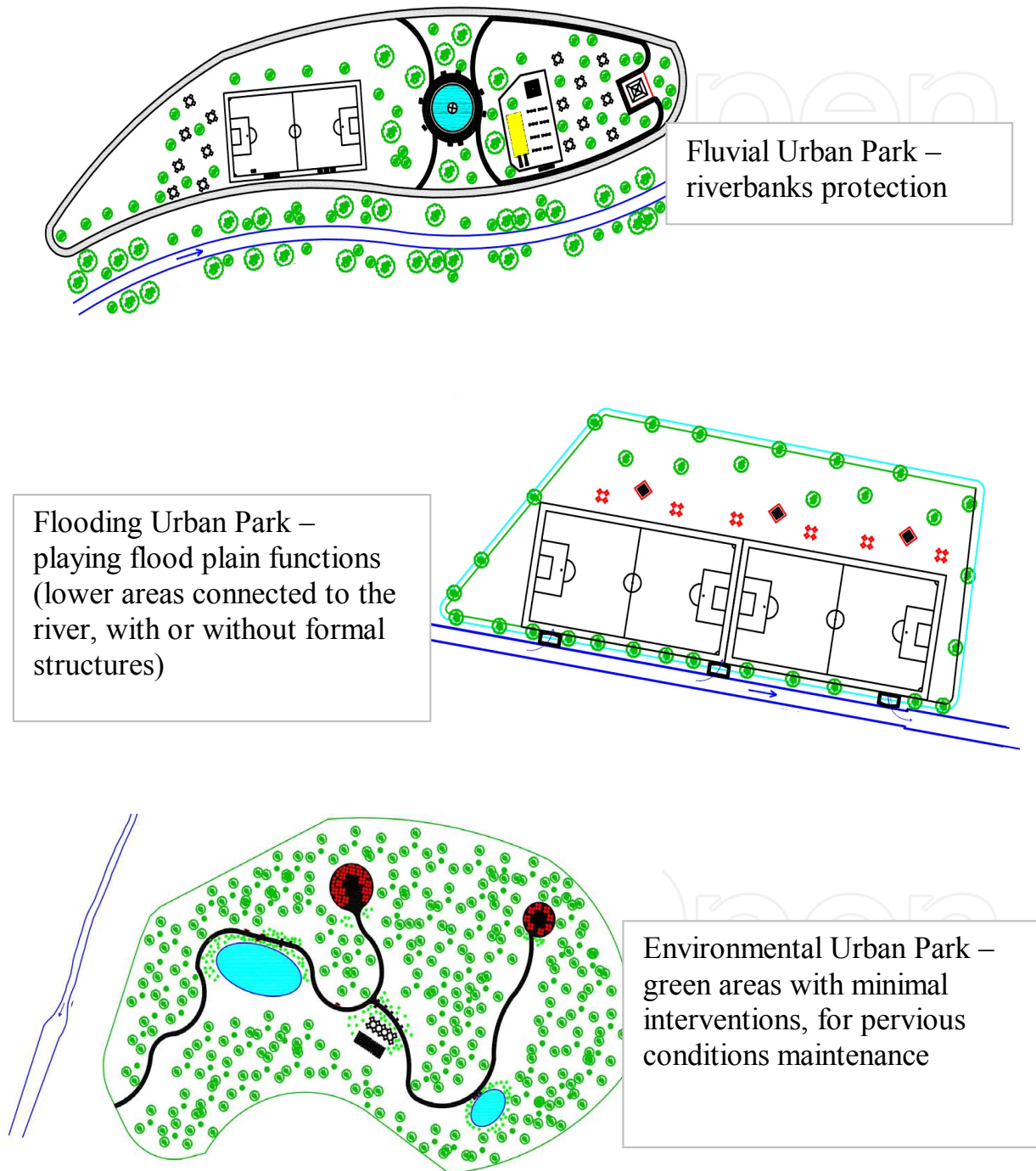
- the maintenance of natural spaces free from urbanisation, preventing vegetation removal and the aggravation of flooding at the consolidated urban areas;
- the recovery of lost vegetated areas;
- a land use regulation and control, by means of the establishment of formal Environmental Preservation Areas;
- the implementation of urban parks;
- the creation of public consortiums for integrated planning of policies for multi-counties interests (recognising the importance of the metropolitan planning);
- the revision and adaptation of the municipalities urban planning instruments.

In terms of flood control, riverbanks protection and natural vegetation preservation, three types of parks were proposed, as basic measures to be reproduced in a distributed way over the basin, encompassing the following functions (figure 8):

1. Fluvial Urban Park – longitudinal parks along rivers, with the purpose of protecting river banks from irregular occupation by low income population.
2. Flooding Urban Park – longitudinal parks implemented in low elevation areas to allow frequent inundations, with a storage function intending to help in damping flood peaks.
3. Environmental Urban Park – parks with greater dimensions, flat or not, with the purpose of environmental preservation and land use valuing, aiming to minimise runoff generation and maintaining a buffer of pervious surfaces.

The figures 9 and 10 show two more detailed examples of the proposed parks, in practical conditions, being one for Sarapuí River, and another for Iguaçu River.

Complementary actions held by the State include the articulation with every Municipality in the basin, in order to implement the proposed measures, create local conditions for urban land use control and develop environmental education campaigns, with the financing of the Federal Government, through a specific Program of Developing Acceleration (PAC, in Portuguese). Besides, a habitation program is also being conducted in the basin, in order to support and allow people relocation from risky areas to safer near areas.



**Figure 8.** Fluvial parks typology – proposed distributed measures for flood control and environmental recovery

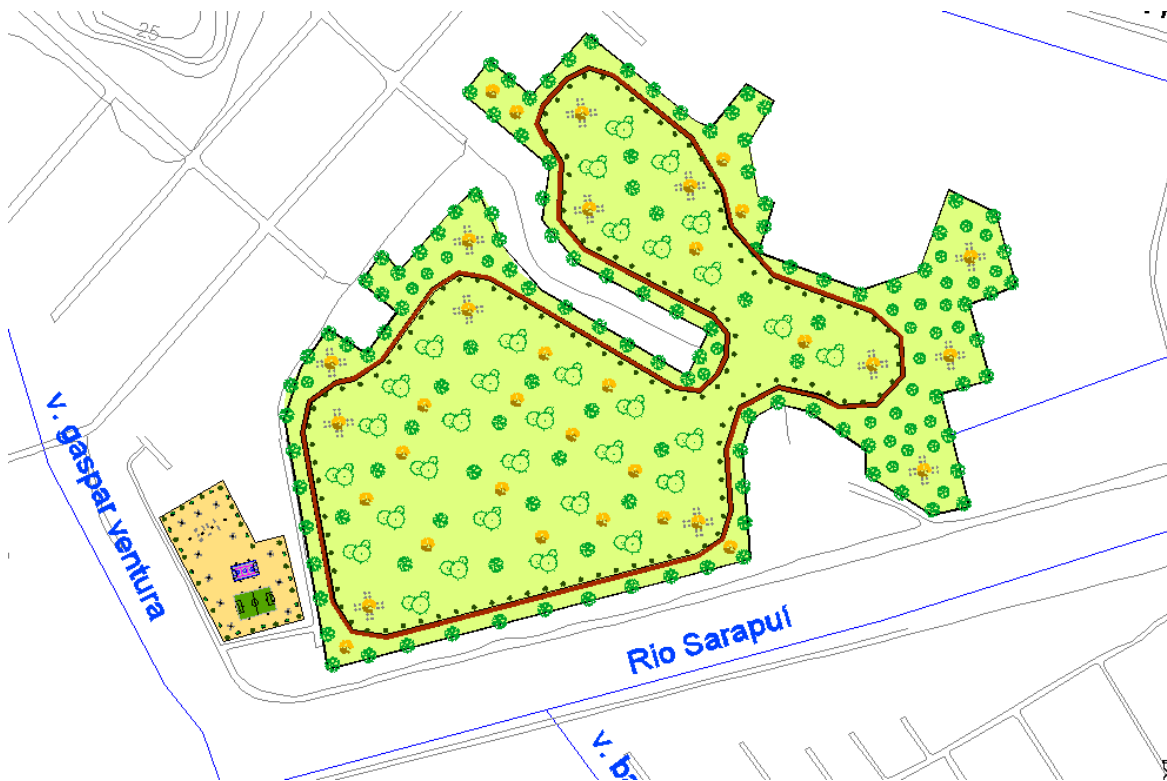


Figure 9. Flooding Urban Park examples – Sarapuí River

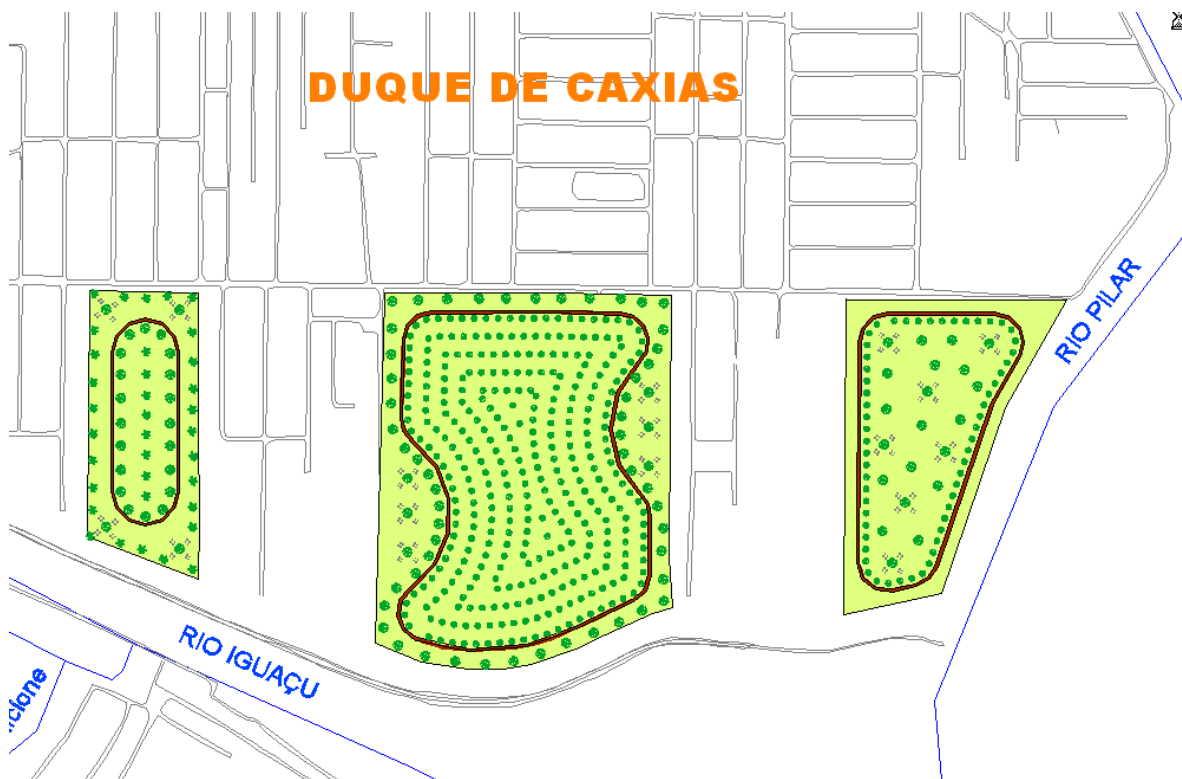
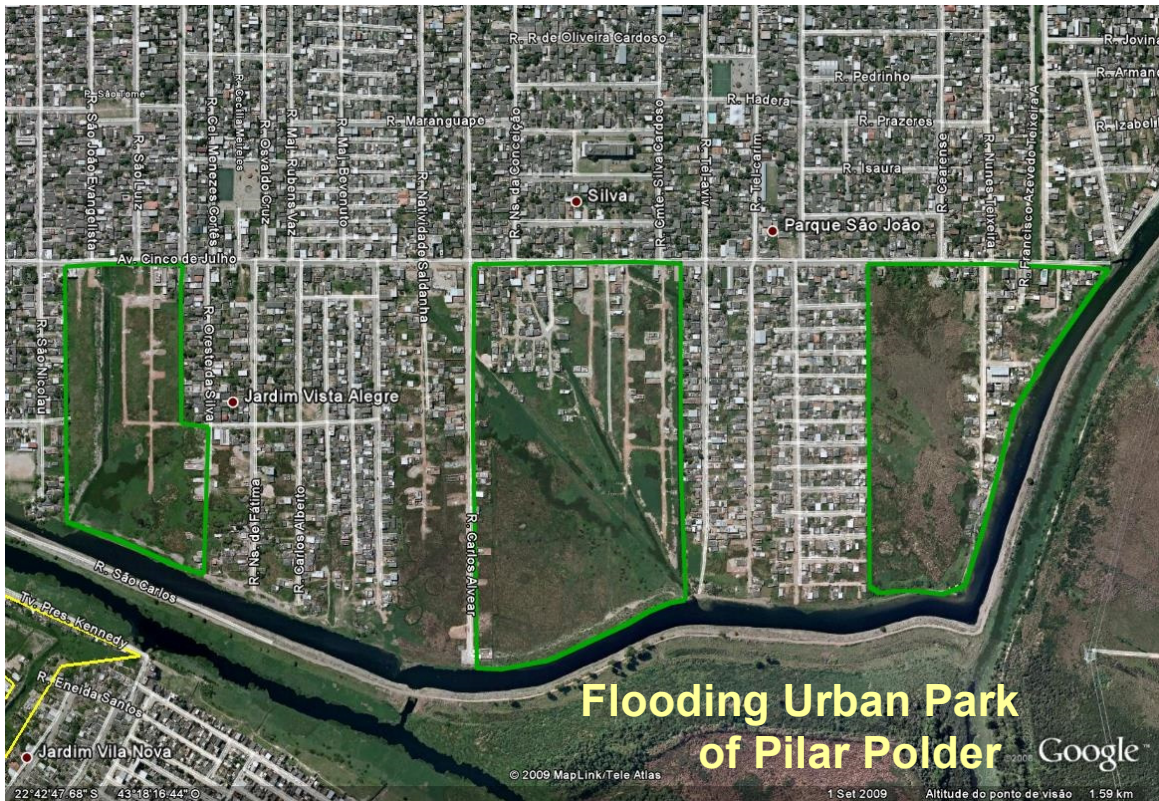


Figure 10. Flooding Urban Park examples – Iguaçu River

## 7. Conclusion

- a. Promoting integration of public policies that interact with the water resources is probably the most urgent and complex task on the agenda of public administrators who are really committed to a sustainable future for the metropolitan areas.
- b. There are reasons to believe that the new institutional arrangements in place in the country offer alternatives for the shared responsibilities involving states and municipalities, mainly in the large urban agglomerations. Specifically, in relation to municipalities, there is a vast spectrum of possibilities to be pursued within the Statute of the City. The new Master Plans can and must incorporate more effective mechanisms for land use management, using a greater range of legal, economic and fiscal instruments focused on urban development on a sustainable basis. However, master plans for urban development still lack mechanisms of inter-municipal coordination and regional agreements orientations that may prevent eventual unintended consequences of land use regulations, from one municipality to another.
- c. The Iguaçu-Sarapuí River basin still embodies conditions favourable to planning for urban flooding, albeit devised to apply for the long term. A significant part of its territory remains in the form of areas still not incorporated into the urban fabric – notably the areas situated between the mountains that rise abruptly and the lowland itself. This enables the maintenance of areas with high soil pervious rates, provided that the urban fabric does not expand to those areas.
- d. The disorderly occupation in Baixada Fluminense lowlands is going to increase the frequency and intensity of the urban floods, causing major damage to the already urbanized areas. The main limiting factor for the expansion of the urban perimeter is the lack of highway connection and regular mass transport lines in the upper parts of the basin, maintaining low occupation rates and rural activities in these areas. It is also worth highlighting the lack of preparation of local administrations to deal with the probable resulting impacts of climate change, above all in urban areas situated at low elevations in relation to the sea level.
- e. Some of the actions proposed by this study were:
  - maintenance of spaces free from urbanisation, preventing the aggravation of flooding at the consolidated urban areas;
  - land use regulation and control, by means of the establishment of formal Environmental Preservation Areas;
- f. implementation of urban parks, mainly for storage purposes, minimising flooding impacts and preparing the basin for future worse climatic conditions;
  - creation of public consortiums for integrated planning of policies for multi-counties interests (recognizing the importance of the metropolitan planning);
  - revision and adaptation of the urban planning instruments for the municipalities.
- g. Complementary actions of state responsibility include articulation with every Municipality in the basin, in order to implement the proposed measures, create local conditions for urban land use control and develop environmental education campaigns about the risks of worsening the floods.

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## Acknowledgement

The first author is grateful to the Support Program Postdoctoral CAPES/FAPERJ. The second author acknowledges CNPq for his research support.

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