

Integrated Management of Water Resources and Land Use in Urban- Metropolitan Basins: Flood Control in the Iguaçú-Sarapuí River Basin (Rio De Janeiro, Brazil)

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Abstract This research concerns the integration of urban land use planning to water resources management, focusing on flood control. A case study regarding the Iguaçú-Sarapuí River Basin, located in the western portion of the Guanabara Bay Basin, which lies in the Metropolitan Region of Rio de Janeiro is discussed. This is one of the most critical areas in the state regarding urban flooding. This region is densely occupied and presents great urban and industrial development areas, as well as wide rural zones in an urbanising process, and reminiscent areas of natural vegetation on the upstream reaches of the basin. This case study intends to illustrate and to show how complex the interaction of urban drainage problems and the city growth can be in a context of an unplanned and non-integrated reality. In this region, urban expansion dynamics is, in general, marked by irregular occupation, in terms of land tenure and urban regularisation, and lack of sanitation. This creates a cycle difficult to treat: the urbanization without proper control compromises the drainage system which, in turn, fails and affects the urban environment, degrading it and creating situations of risk and losses. This paper aims at elucidating the challenges and perspectives to water resources management in densely urbanized basins in Brazil.

Keywords Flood Control, Integrated Water Resources Management, Land Use Control, Urban Water Basins, Urban Planning

1. Introduction

The National Water Resources Policy of Brazil (Política Nacional de Recursos Hídricos do Brasil), instituted by Law n°. 9.433 in 1997, is based on six fundamental principles that structure the whole National Water Resource Management System (Sistema Nacional de Gerenciamento de Recursos Hídricos).

The sixth principle establishes that water resource management must be decentralized and have the participation of public authorities, users, civil society and communities.

This Law and its regulatory texts incorporate municipal-ties, along with users and civil organizations, into the management system, ensuring a greater balance of power. The text has clearly defined the relation between water

management committees and boards. However, no legal land use planning. 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 action of a regulatory nature.

Besides the gap pointed out above, the occurrence of conflicts of competency is also observed in the hydrographic basins situated in metropolitan areas, given that the 1988 Constitution did not establish a defined management mode for these territories, leaving its creation and the formulation of its administrative organization to the states. On the one hand, overlap is observed in the attributions among local, state, or even federal administrations, and, on the other, undefined roles are identified, which make the task of coordination and sharing of responsibility even more complex. Based on these elements, the article deals with the need for integration of land use planning with water resource man-

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agement, seeking to establish relations between the forms of land use, urban settlements and the problems involving urban flooding.

The case study was developed for the Iguaçú-Sarapuí river basin, located in the western portion of the Guanabara Bay Basin, which lies in the Rio de Janeiro State Metropolitan Region, 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, in terms of land tenure and urbanistic regularization.

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

2. 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, which, in turn, are related, among others, with 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 for 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, municipal participation in basin comitees has been the main, if not the sole, form of interaction with other public and private actors related with water.

Many factors hinder municipality action the sphere of water management, the main one being the legal impossibility, by Constitutional determination, of the municipalities directly managing water resources, even in the case of basins entirely contained in their territories unless by transfer of some attributions through cooperation agreements with the states or the Federal Government¹.

Although local administrations are closer local populations, its scale of politico-administrative activity does not allow a systemic vision of the territory in which it lies. 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 the majority of municipalities have limited budgetary autonomy, bearing in mind that they depend heavily on funds' transfers from other levels of government.

With regard to the financial restrictions[2], warn that most multilateral financial agencies, except the Global Environment Facility – GEF, still have not included, in their agenda,

projects of natural resources' integrated management, articulated to land use planning, particularly in urban areas. There are few planning experiments implemented articulating water conservation/preservation measures and land use regulation in the face of (dys)functions 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 politicization 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 as 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 zones, local urban transport plans and systems, among other activities with impacts on water resources, mainly in the case of predominantly urban hydrographic basins.

These attributions have recently been strengthened upon approval of the Statute of the Cityⁱⁱ. Thus, the possibility of constructing sustainable water resource management must necessarily pass through a clear articulation among the guidelines, objectives and goals of the water resource and land use plans.

What is observed in Brazil is the disarticulation between instruments of water resource management and land use planning, reflecting, perhaps, the lack of legitimacy of planning and urbanistic legislation in Brazilian cities, marked by a high degree of informality, and even illegality, in land use. 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 sectorial fragmentation of local administrations.

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

This intermunicipal inequality presents a great obstacle to greater effectiveness of water resource management structures and to cooperation among hierarchical levels of gov-

ernment.

3. Flood Control in the Baixada Fluminense Lowland

This 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, on account of:

- its location in the metropolitan periphery;
- possessing areas with high urban and industrial growth;
- covering rural areas still protected from urbanization;
- having areas where land use patterns do not ensure minimal standards of living, especially those of poor drainage;
- presenting serious flooding problems;
- possessing water sources utilized for complementation of the Metropolitan Region's supply;
- the Tinguá Biological Reserve, the main remnant of the Atlantic Forest in Rio de Janeiro State, being situated in its territory;
- possessing organized social movements, congregating federations of residents associations and entities involved in matters of the environment, sanitation, housing, among others, which demonstrates great capacity of organization of its population vis-à-vis the questions related to citizenship and quality of life;
- a process, still timid, of making administrations more committed to efficiency in public affairs management;
- the presence of major private and public investments that will lead to significant transformations in the present urban configuration of the region.

3.1. Physical and Socioeconomic Characteristics of the Basin

The Iguaçú-Sarapuí river basin is situated in the Fluminense Lowlands and is one of the main sub-basins of the hydrographic region of the Guanabara Bay basin. Its drainage area covers around 727 km², all of which is situated in the Rio de Janeiro Metropolitan Region.

The Iguaçú River's headwaters lie in the Serra do Tinguá massif, at a maximum altitude of 1,600m. Its course runs southeast for approximately 43 km, eventually debouching into Guanabara Bay. It is joined from the left by its main tributaries, the Tinguá, Pati and Capivari, and, from the right, by the Botas and Sarapuí.

The physiography of Iguaçú-Sarapuí river basin is characterized by two main relief units: the Serra do Mar mountain range and the 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 descend from the mountains in torrents with great erosive force, losing speed upon reaching the plain, often overflowing their banks into large wetlands.

The basin fully spans the municipalities of Belford Roxo, Mesquita and part of the municipalities of Rio de Janeiro (covering the districts of Bangu, Padre Miguel and Senador Câmara), Nilópolis, São João de Meriti, Nova Iguaçu and Duque de Caxias, all of which belong to the Rio de Janeiro Metropolitan Region (Figure 1).

The urban area is concentrated on the lowland. According to the 2000 IBGE Census, 45% of the households in the municipalities of the basin, excluding Rio de Janeiro, had an average monthly per capita income of one minimum salary.

The population of these municipalities, according to the same Census, was 8,591,621. It is estimated, based on IBGE data for 2000, that about 1.4 million live in the territory covered by this basin.

According to Brito and Bessa[6], historical investments made in the region by different state governments as of the 1980s amount to R\$ 3 billion, without, however, effectively guaranteeing universal access to environmental sanitation, housing and a better general 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 intervention; (ii) discontinuity and disintegration among the programs and projects implemented throughout these years in the region; (iii) the political disputes in the region often decharacterize the projects; (iv) lack of social control, as, although this component exists in various of these projects, its format has not permitted effective participation of the population; (v) the lack of institutional capacity, allied to the centralizing culture of the state governments in relation to sanitation management; (vi) the strong clientelistic culture in the municipal administrations; (vii) the growing demobilization of organized movements, which need qualification of new staff members for critical accompaniment of the implementation of policies.

3.2. Impact of Floods Arising from Urban Expansion and Climate Change

The flooding in the basin is caused basically by the process of inadequate occupation and land use in the particular conditions of the Fluminense Lowlands. In this process, the aggravating factors are: lack of urban infrastructure; deficiency of the sewage services and collection of waste; uncontrolled exploitation of mineral deposits; disorderly, illegal occupation of river banks and floodplains; lack of adequate treatment to public roadways pavements; obstruction or strangulation of drainage due to structures built without concern for their interference (rail and road bridges, and water pipelines), as well as walls and buildings that 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 189 thousand people are directly affected by floods in the basin. However, damage caused and the number of people indirectly affected by floods are difficult to estimate. Included in this latter category are, for example, employees who cannot reach their workplaces, and

the interruption of traffic and commerce along the flooded roadways.

The aim of hydrodynamic modeling was to evaluate the possible impacts of the expansion of urbanization towards the interior of the basin with the construction of axial highways, the most important being the Metropolitan Ring Roadⁱⁱⁱ (Figure 1). Another objective of the modeling consisted of evaluating the impact of an average rise in sea level on the drainage conditions in the hydrographic basin, according to forecasts made by the IPCC [Intergovernmental Panel of Climate Change]. In both situations, planning actions are required in order to control negative effects at the future, otherwise the human and material losses could become irremediable.

3.2.1. Brief Description of ModCel

For hydrodynamic modeling of the basin a mathematical model of rural and urban floods - ModCel[7, 8 e 9] was used. With the aid of this model it was possible to analyze flows and variations in water level caused by spates, as much in water bodies as on stretches on plains. The modeling through cells was extended only from Baía da Guanabara to the confluence with the Botas River. The areas that were not divided into cells had their flows determined through the Hidro-Flu System[10]. Based on it, hydrograms were calculated, which served as input conditions for stretch areas modeled by cells.

The basins of natural or canalized rivers in urban areas, generally in areas that are predominantly flat, have potential for forming large floodable areas. In leaving the drainage network, the water can follow any path, dictated by patterns of urbanization. Marginal sidewalks become spillways for the rivers, whose overflowing waters, upon reaching the streets, make veritable canals, able to flood constructions, parks or squares, which can then act like reservoirs, concentrating water that will not return to the drainage network.

In this situation, it is perceived that overflow waters may exhibit behavior independent of the drainage network, generating its own flow patterns, especially when the micro-drainage does not correspond to the function expected of it. In the extreme case, where the micro-drainage does not work, which is not uncommon, due to maintenance failures and blockages, for example, or where it is underdimensioned, floods in urban areas can start even without overloading the macro-drainage network, also generating a particular flow pattern, distinct from that of the canals. In this context, it is noticed that there are indications for use of a model with systemic characteristics, capable of representing hydraulically and hydrologically, in a distributed form, the basin surface. This need is supported in the conception of flow cells. The representation of the urban space by cells, which act as homogeneous compartments integrating the space in the basin, and make it interact according to the flow that occurs over it, leads to the objectives of the urban flood modeling[7-9].

3.2.1.1. Criteria Utilized in the Simulations

The main objective of the modeling of the lower and middle stretches of the Iguaçú River was to evaluate impacts caused by the expansion of urbanization towards the middle/upper basin, arising from the construction of axial roadways, the most important of which being Metropolitan Ring Road.

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

1) Past situation: the CNs were defined based on soil types and land use mapping from 1994 LANDSAT satellite images [11].

2) Present situation: the CNs were determined by land use mapping, made on the basis of images from the 2006 Aster sensor[12].

3) Future situation: assuming that the flat, still rural areas of the sub-basins of the Rivers Iguaçú (upper stretch), Botas, Capivari, Pilar and Calombé, and the Outeiro canal will suffer a disorderly process of urbanization, following the trend of peripherization in progress in the Fluminense Lowland. This future scenario corresponds to a horizon of 20 years (2030).

4) Future situation: assuming alteration in the current pattern of urbanization of these areas, but with the introduction of control over land use by means of urban planning actions and adoption of sustainable urban drainage techniques.

Another objective of the modeling consisted of evaluating the impact of an average sea level rise, as forecast by the Intergovernmental Panel on Climate Change (IPCC), on the drainage conditions in the hydrographic basin.

The scenarios utilized tested the isolated and/or associated effect of the following variables:

a) different hydrometeorological conditions, alternating typical tidal situations and the effect of meteorological tide; b) variation in the impermeabilization index of soil arising from the behavior of future urbanization, considering the following: i) maintenance of the current index (without any increase in new urban areas); ii) increase in the index due to unplanned urban expansion; iii) moderate increase in the index due to planned control of urban expansion. For each of the simulated scenarios, CNs were adopted corresponding to the degree of impermeabilization of the soil, as presented in Chart 1.

The recurrence time utilized for the spates was 20 years^{iv}. The precipitations and the times of concentration of the basins were extracted from the Iguaçú Project[11].

With regard to the impacts caused by alterations in sea level, a tide table was used, based on that produced by the Diretoria de Hidrografia e Navegação da Marinha do Brasil [Hydrography and Shipping Directorate of the Brazilian Navy], the values ranging from 0.09 to 0.90 m, representing

the tidal variation on the Rio de Janeiro coast. To it were added meteorological tides of 0.80 m and an increment in sea level of 0.60 m (IPCC forecast), due to the climate changes.

Chart 1. Curve Number (CN) utilized in each simulated scenario

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

With the values mentioned, several scenarios were simulated, considering the tidal variations, the dynamics of urbanization, rise in sea level, and combinations among these variables.

4. Results Obtained in the Modeling

As described in item 3.2.1, the representation of physical space in the model is by means of cells, which act as homogeneous compartments that integrate the basin space and interact according to the flow that occurs over it. Therefore, the cell – grey polygons in Figures 2 and 9 - represent homogeneous typologies that, in turn, correspond to a certain value of CN. As the main objective of the mathematical modeling was to simulate the impact of the urban expansion on the behavior of floods in the upper stretch of the basin, the

areas represented in the cells are areas subject to flooding, the majority being urbanized.^v

Figure 2 represents the areas susceptible to flooding for the former conditions of urbanization in existence at the time of the Iguaçú Project[10], 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, as they refer to the shading representing flooding in the basin 15 years ago. It is observed that there were significant differences in floods in past conditions from those in the current scenario. The small alteration in the land occupation in the upper reaches of the basin in the period justifies this result.

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

The comparison among these three scenarios permits dimensioning of the isolated effect of the expansion of urban areas in the aggravation of flooding. When the coefficient of impermeabilization is altered for the upper stretch of the drainage basin (increase in the CN) in the simulation corresponding to Scenario 2, a significant worsening is noticed in spate conditions, even in normal meteorological conditions. Comparing Figures 3 and 4, an increase in water levels is perceived in some cells of the model.

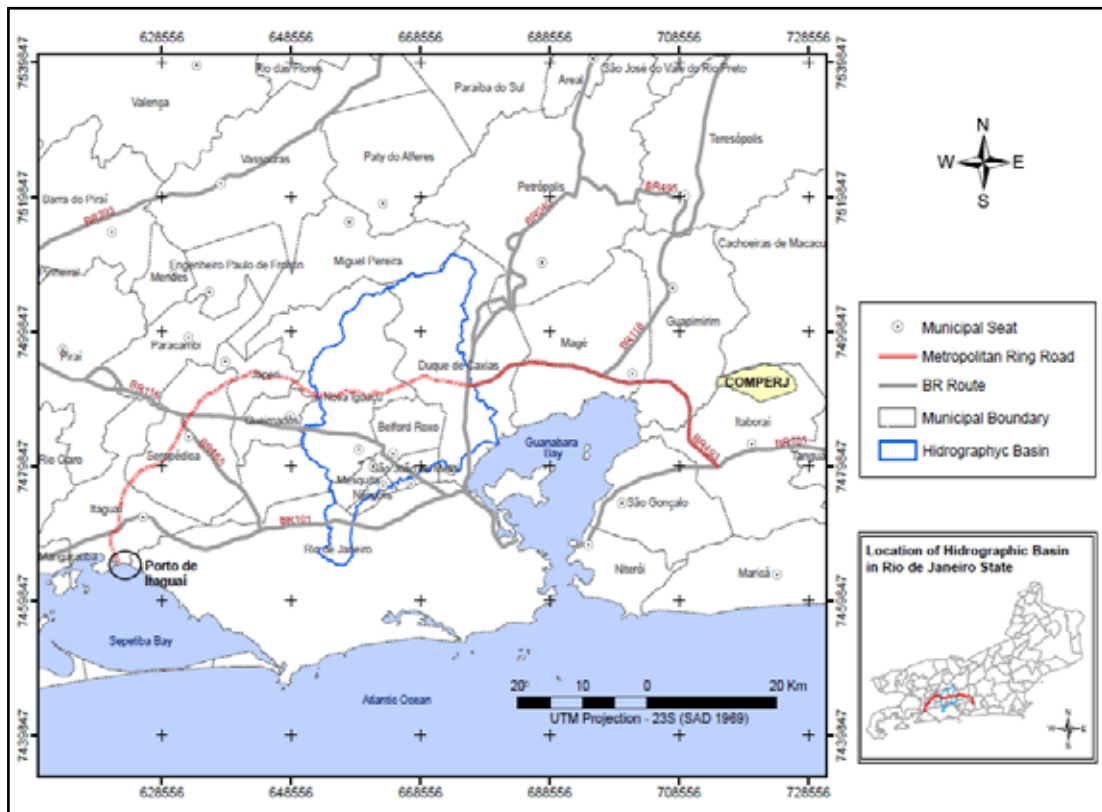


Figure 1. Iguaçú-Sarapuá River Basin

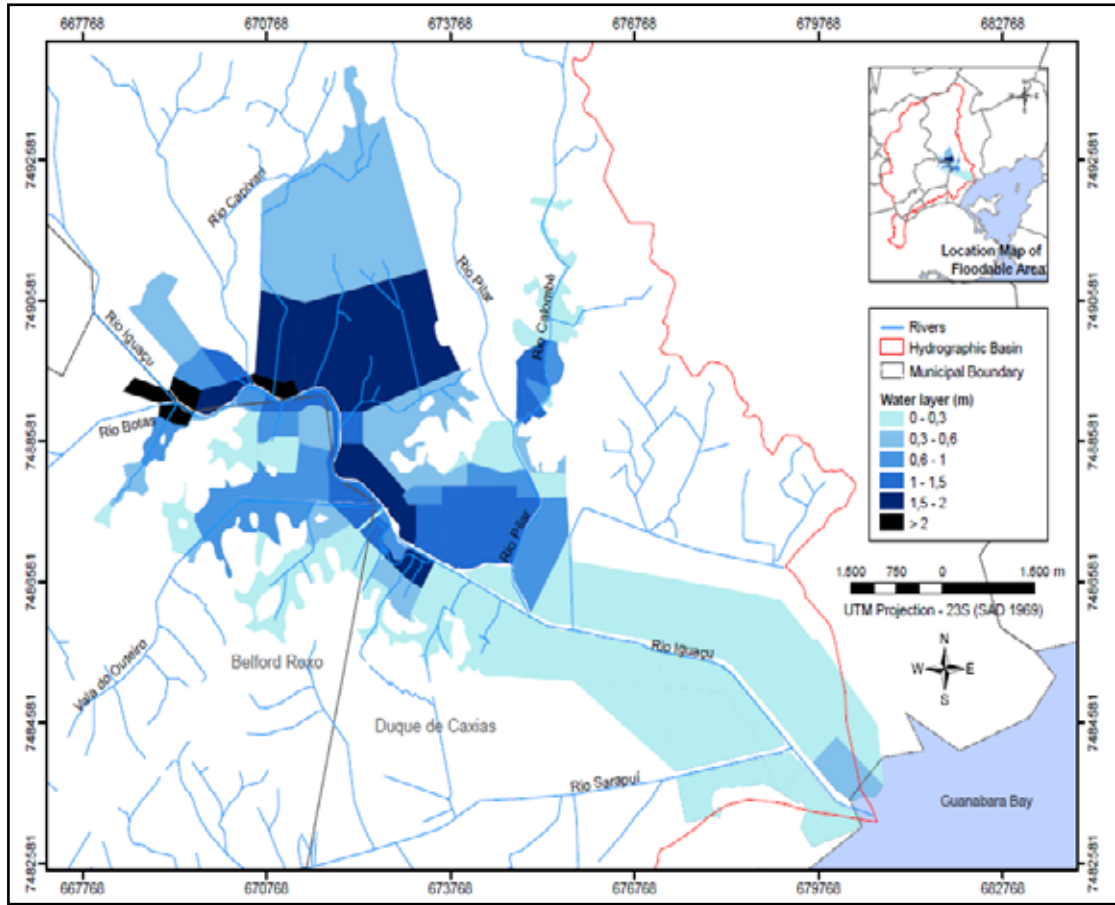


Figure 2. Shading obtained for the past condition

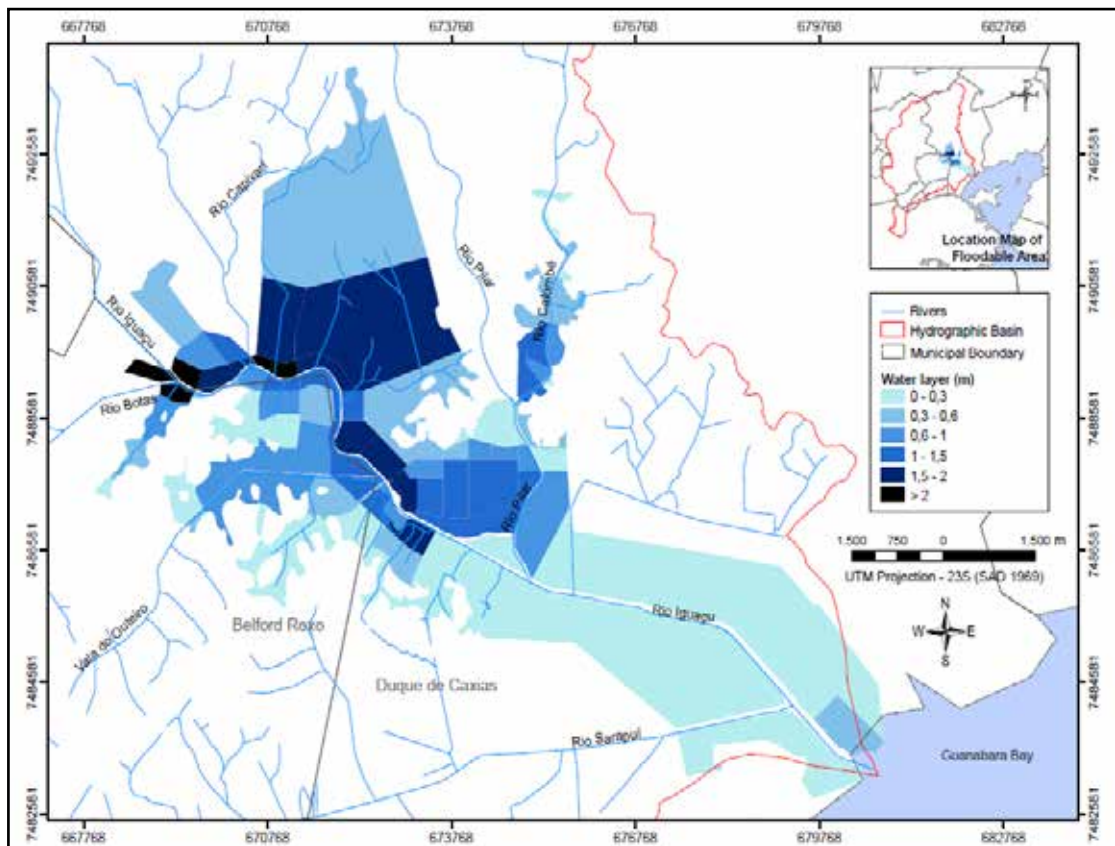


Figure 3. Shading obtained for the present condition - Scenario 1

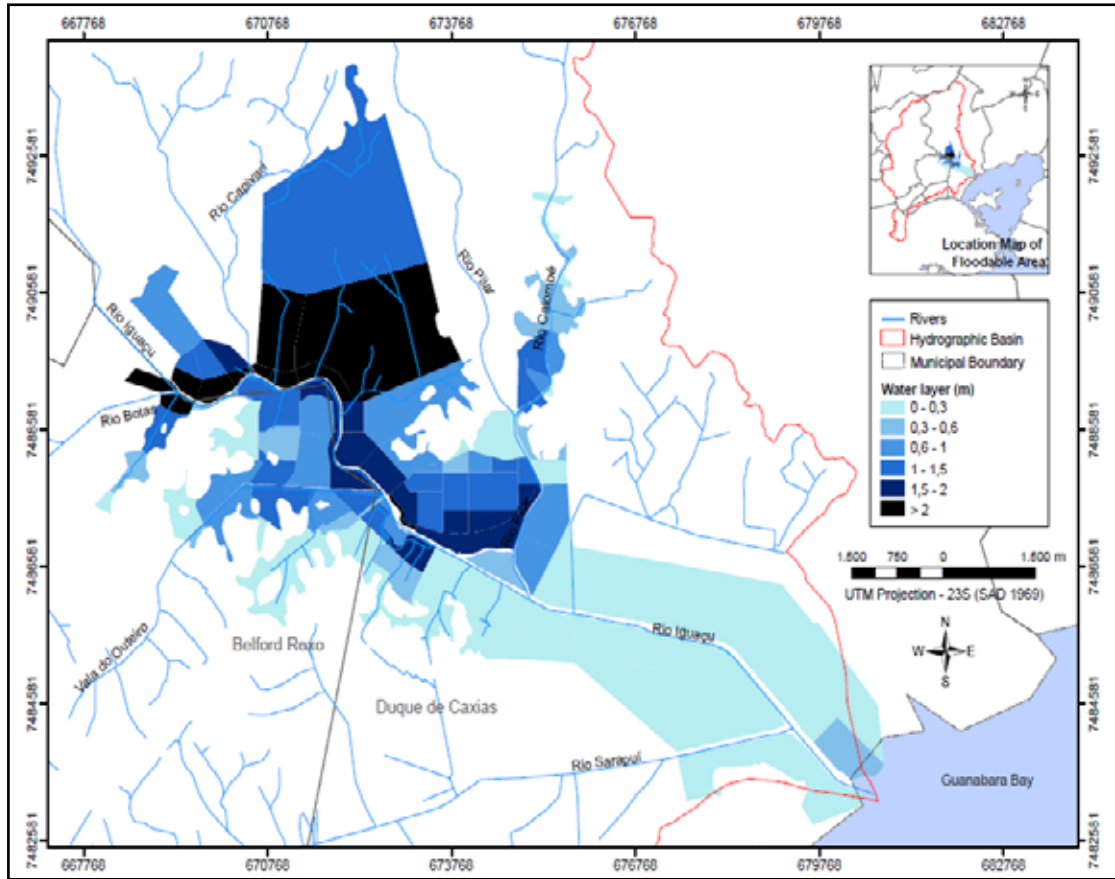


Figure 4. Shading obtained for the future condition - Scenario 2

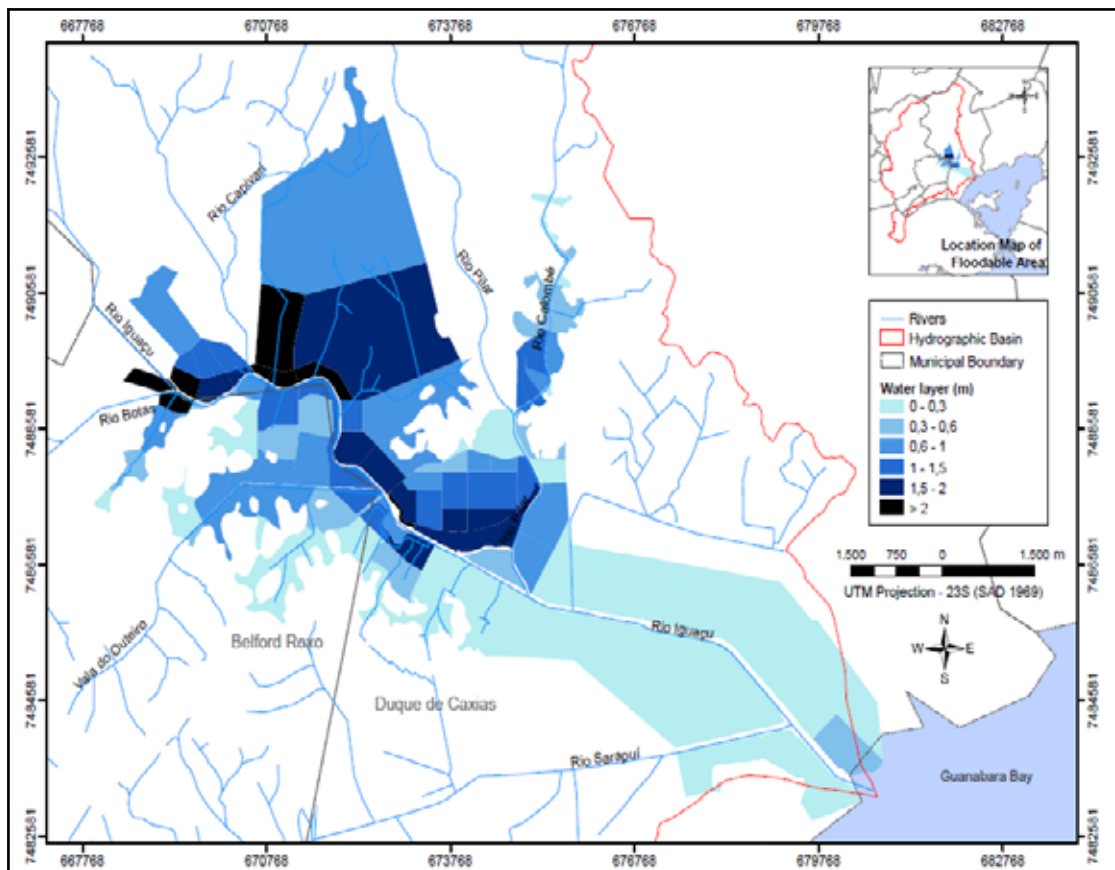


Figure 5. Shading obtained for the future condition - Scenario 3

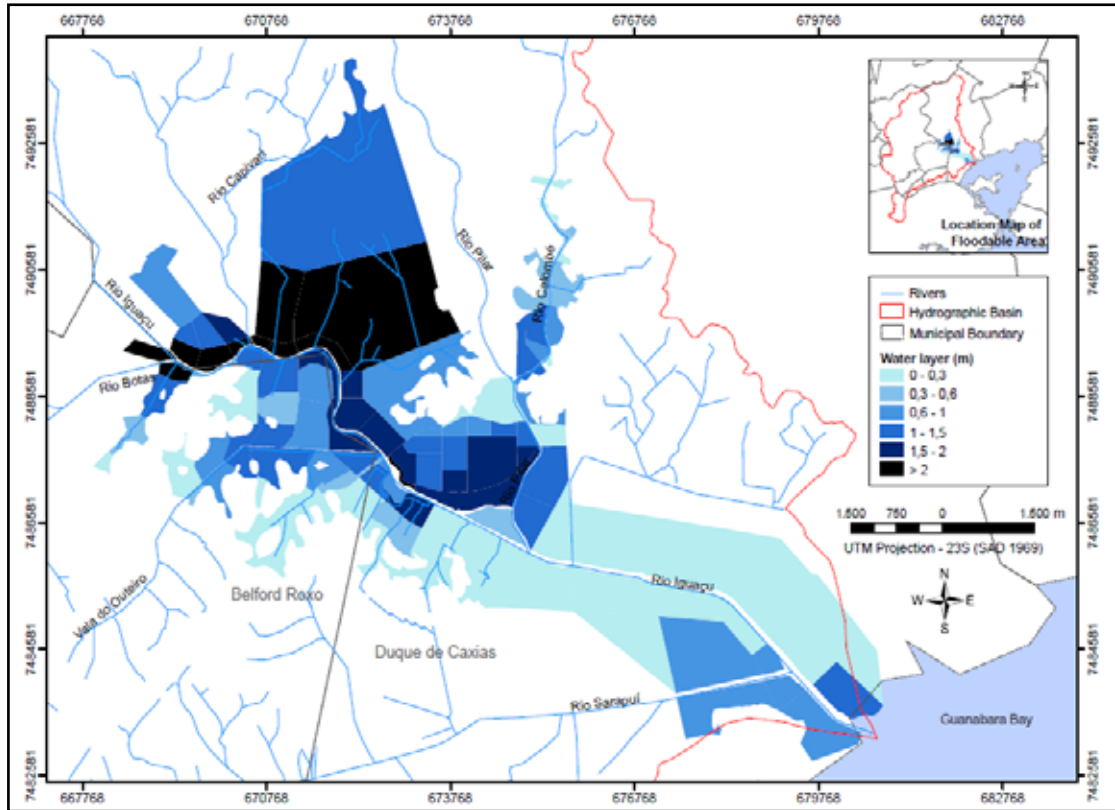


Figure 6. Shading obtained for the future condition - Scenario 4

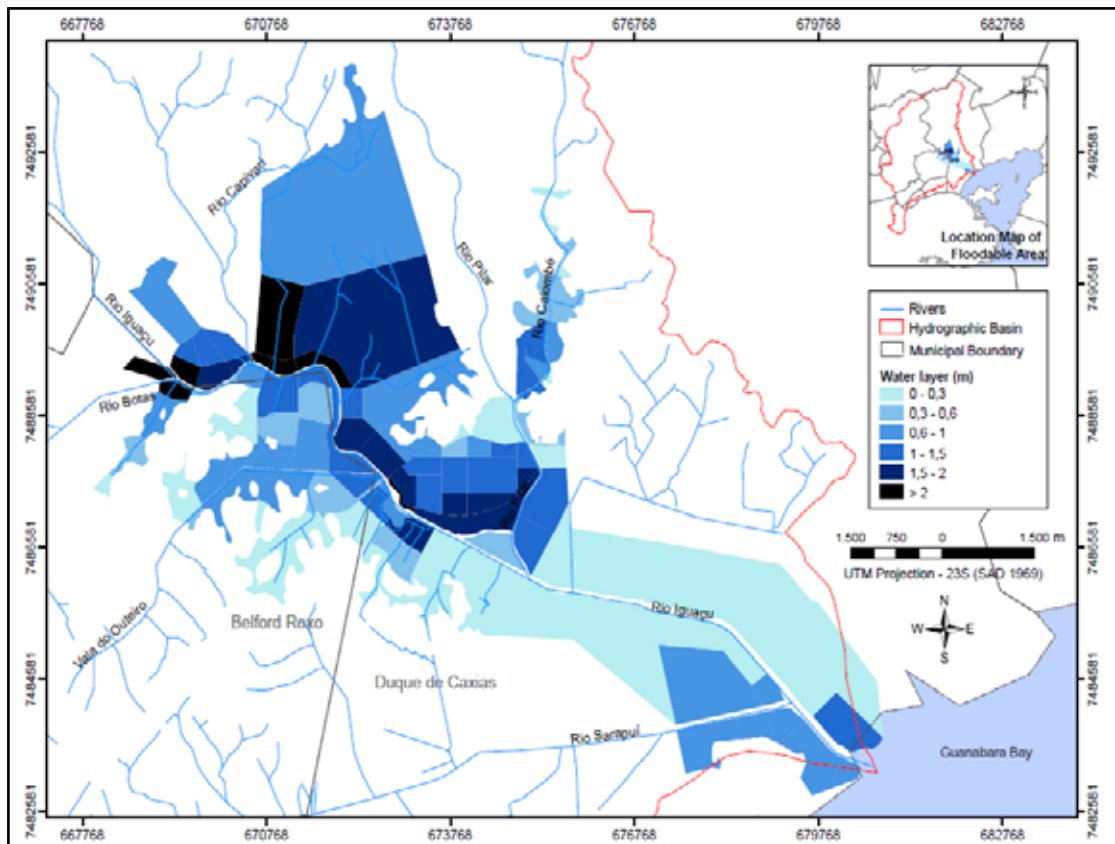


Figure 7. Shading obtained for the future condition - Scenario 5

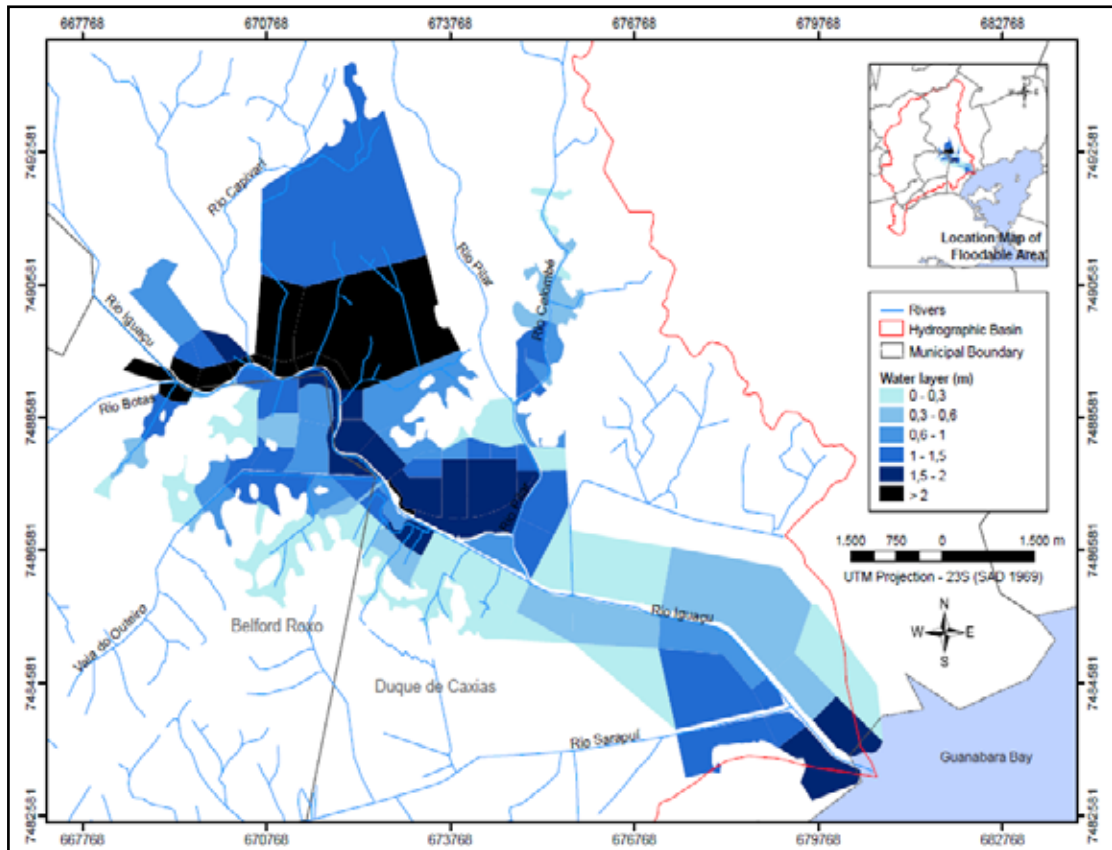


Figure 8. Shading obtained for the future condition - Scenario 6

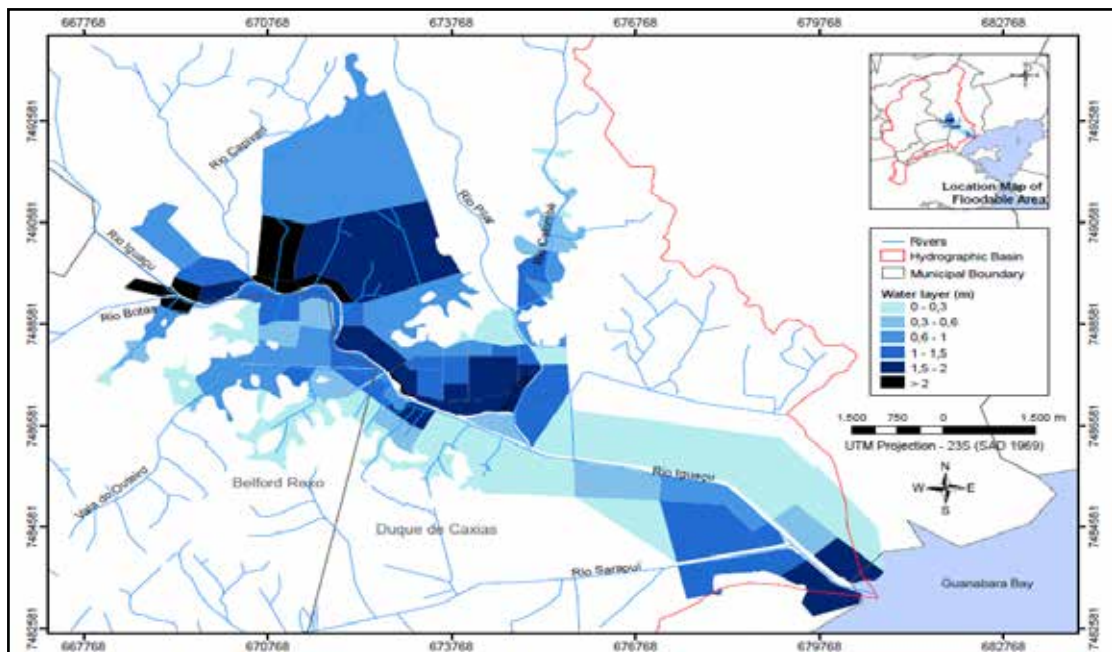


Figure 9. Shading obtained for the future condition - Scenario 7

Figures 6 and 7 consist of the following scenarios:

Figure 6: Shading obtained for the future condition of urbanization in the basin, considering a meteorological tide of 80 cm, without the effects of climate change and in the absence of control over land use (Scenario 4);

Figure 7: Shading obtained for the future condition of urbanization in the basin, considering a meteorological tide

of 80 cm, control over land use, but without the effects of climate change (Scenario 5).

In these two scenarios, the effects of urban expansion on the upper course of the basin, jointly with the presence of a meteorological tide, are being tested, disregarding the effect of a rise in sea level due to climate change. In these conditions, one observes an increase in the spate only in the lower

stretch of the basin and along the banks of the Pilar River. In the upstream stretches, the variation in tide had little influence, confirming that urbanization of the upper stretch is the main factor in the aggravation of the spates in the consolidated urban areas.

The Figures presented below correspond to the following scenarios:

Figure 8: Shading obtained for the future conditions of urbanization in the basin with expansion of urbanization without control over land use; meteorological tide of 80 cm and a 60 cm rise in the average sea level due to climate change (Scenario 6);

Figure 9: Shading obtained for the future conditions of urbanization in the basin with control over the land use; meteorological tide of 80cm and effect of climate change, with a 60 cm average rise in sea level (Scenario 7).

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

In short, as much the urban expansion as 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 populations resident in this basin. If planning measures are not taken in advance, it will be very difficult to mitigate their impacts.

5. Conclusions

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.

There are reasons to believe that the new institutional arrangements in effect 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 with 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 aimed at urban development on a sustainable basis. However, master plans for urban development still lack mechanisms of intermunicipal coordination and regional agreements orientations that may prevent eventual unintended consequences of land use regulations, from one municipality to another.

The Iguaçú-Sarapuí river basin still embodies conditions favorable 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 mountain ranges that rise abruptly and the lowland itself. This enables the maintenance of areas with high soil permeability rates, provided that the urban fabric does not expand to these areas.

The disorderly occupation in the Fluminense Lowland 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.

Some of the actions proposed by this study were:

- maintenance of spaces free of urbanization, preventing the aggravation of flooding at the consolidated urban areas;
- land use regulation and control, by means of the establishment of Environmental Preservation Areas;
- implementation of urban parks;
- 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 municipalities urban planning instruments.

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 uses control and develop environmental education campaigns about the risks of worsening the floods.

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i The 1988 Constitution extinguished the municipal dominion over the waters, in accordance with the Código das Águas [Water Code] of 1934, making authorization of its use the exclusive legal competence of the states and the Federal Government

ii Law no. 10.257, issued on 10th July 2001, regulated new administrative and legal instruments for city planning.

iii The Metropolitan Ring Road is a Federal Government work, whose estimated cost is approximately US\$ 16 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.

iv Statistical probability of a river overflow event occurring with a periodicity and intensity corresponding to the 20 year interval.

v The urban areas are not visible in the Figures due to the fact they are only a graphic output from the model.