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METROPOLITAN RING ROAD - LAND USE AND FLOOD CONTROL IN THE RIO DE JANEIRO METROPOLITAN AREA

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ABSTRACT: The Metropolitan Ring Road is one of the major works in progress in the Rio de Janeiro Metropolitan Region. The new road will act as a bypass for the long-distance traffic between the South / Southeast and the North / Northeast regions, its arc connecting with five federal highways and intersecting a railroad, as well as serving several large industrial complexes being established in the metropolitan area. Moreover, the Metropolitan Ring will provide broader accessibility to the Port of Itaguai in Sepetiba Bay, such as for the Petrochemical Complex of Rio de Janeiro (COMPERJ), located in Itaboraí. Also it will permit the establishment of logistics terminals that will reduce travel times and transport costs, as well as improve connections to consumer markets. On the other hand, the construction of the ring road will introduce new vectors of urban expansion for the municipalities located in its area of influence, thus potentially changing the land use. The new road will cross the Baixada Fluminense, a lowland region notorious for flooding problems. Sustained urban development of this zone would have to provide flood control in the Iguaçu-Sarapuí river basin, which could only be achieved by controlling the urban sprawl and land use. Some areas of this zone are still free of urbanization, the vegetation cover and natural soil infiltration being responsible for retaining some of the rainfall runoff in the upper reaches of the Iguaçu-Sarapuí drainage basin. This paper aims to discuss strategies for the Baixada Fluminense to maintain its areas of low hydrological impact and keep the open spaces free of urbanization.

Key Words: flood management, urban plan, flood control

1. INTRODUCTION

The Iguaçu-Sarapuí river basin is situated in the Fluminense Lowland, and is one of the main sub-basins of the hydrographic region of the Guanabara Bay basin. Its drainage area covers around 727 km^2, all of which is situated within the Rio de Janeiro Metropolitan Region.

The Iguaçu River's headwaters lie in the Serra do Tinguá massif, reaching 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 the Iguaçu-Sarapuí river basin is characterized by two main relief units: the Serra do Mar mountain range and the Fluminense Lowland, 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^o C. The rivers descend from the mountains in torrents with great erosive force, losing speed upon reaching the plain, often overflowing their banks and forming extensive wetlands.

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 organizational capacity on the part of its population vis-à-vis questions related to citizenship and the 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.

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, that is excluding the Rio de Janeiro municipality, had an average monthly per capita income of one minimum salary (US$ 330.00, at the current exchange rate).

The population of all the municipalities, including Rio de Janeiro municipality, according to the same 2000 IBGE Census data, was 8,591,621 approximately 8.6 million, and it is estimated that about 1.4 million lived in the territory covered by this basin.

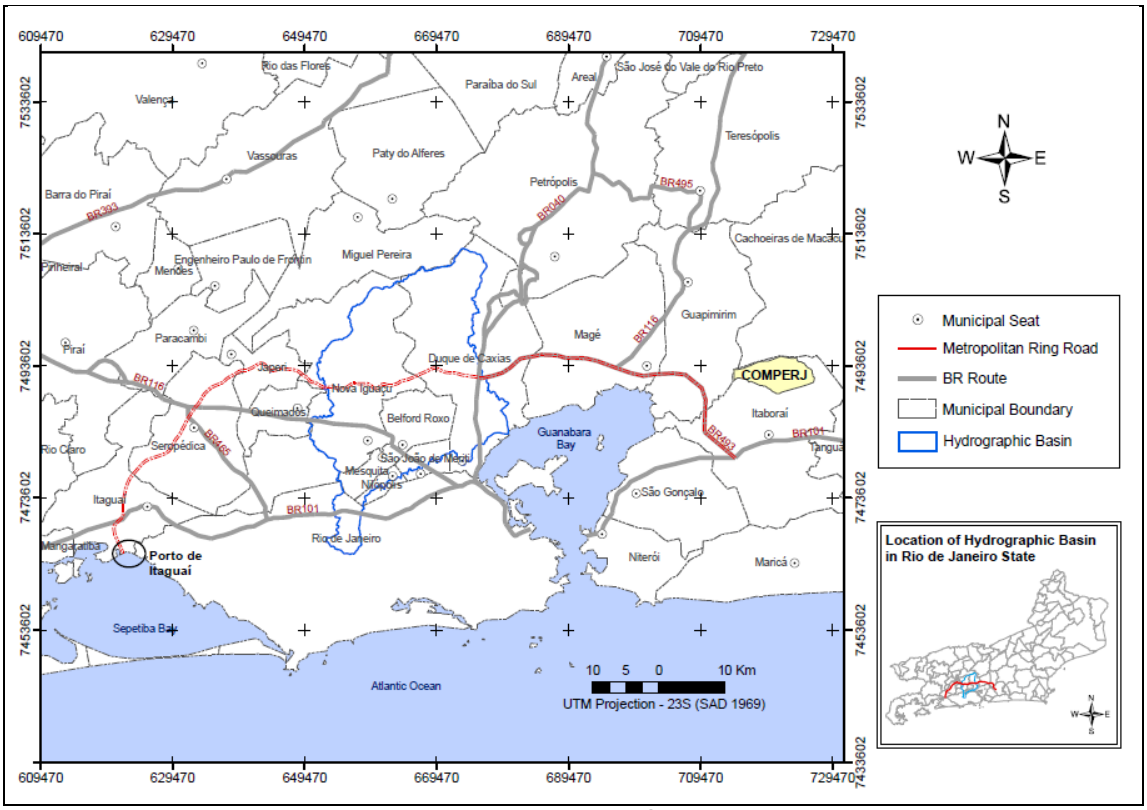

Figure 1: Iguaçu-Sarapuí River Basin

According to Britto and Bessa (2008), investments made in the region by different state governments as of the 1980s amount to R$ 3 billion (US$ 445 million), without, however, effectively guaranteeing universal access to water and 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 to correctly orient the profile of intervention; (ii) discontinuity and disintegration among the programs and projects implemented throughout these years; (iii) political disputes that often decharacterized 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) lack of institutional capacity, allied to the centralizing culture of the state governments in relation to sanitation management; (vi) strong clientelistic culture in the municipal administrations; (vii) growing demobilization of organized movements, which need qualified staff for critical accompaniment of the implementation of policies.

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 Lowland. In this process, the aggravating factors are: lack of urban infrastructure; deficiency of the sewage and waste collection services; uncontrolled exploitation of mineral deposits; disorderly, illegal occupation of river banks and floodplains; lack of construction and adequate maintenance of public paved roadways; obstruction or strangulation of drainage due to structures built without concern for their interference with river channels (rail and road bridges, water pipelines, walls and buildings). 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, the damage caused and the number of people indirectly affected 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.

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

2.1 Brief Description of ModCel

For hydrodynamic modeling of the basin, ModCel (Miguez, M. G., 2001; Mascarenhas, F.C.B. and Miguez, M.G., 2002 and Mascarenhas, F.C.B., and Miguez, M.G., 2005), a mathematical model of rural and urban floods, was used. With the aid of this model it was possible to analyze flows and variations in water level caused by spates, as much on the mountain slopes as on stretches on plains. The modeling through cells 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 (Magalhães, L. P. C., Magalhães, P. C., Mascarenhas, F. C. B., Miguez, M. G., Colonese, B. L., and Bastos, E. T., 2005). Based on this, 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 those that are predominantly flat, have potential for major flooding. Upon escaping from the drainage network, the water can follow any path dictated by the pattern of urbanization. Sidewalks and streets lining the banks may become veritable spillways for overflowing rivers, these new channels being able to inundate constructions, parks or squares, which can then act like reservoirs, penning up 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 their 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 recommendable to use of a model with systemic characteristics, capable of representing the basin surface hydraulically and hydrologically in a distributed form. This need is supported in the conception of flow cells. The representation of urban space by cells, which act as homogeneous compartments integrating the space in the basin, make it interact according to the flow that occurs over it, leading to achievement the objectives of the urban flood modeling.

2.1.1 Criteria utilized in the simulations

The main objective of the modeling of the lower and middle stretches of the Iguaçu 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 the Metropolitan Ring Road.

The method of calculation of 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 (Carneiro, 2008).
2) Present situation: the CNs were determined by land use mapping, made on the basis of images from the 2006 Aster sensor (Ibid, 2008).
3) Future situation: assuming that the flat, still rural areas of the sub-basins of the Rivers Iguaçu (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 or sealing of the soil, as presented in Chart 1.

The recurrence time utilized for the spates was 20 years[ii]. The precipitations and the times of concentration of the basins were extracted from the Iguaçu Project (Laboratório de Hidrologia e Estudo do Meio Ambiente - COPPE/UFRJ-PNUD, 1996).

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 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 climate change.

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

2.1.2 Results obtained in the modeling

Figure 2 represents the areas susceptible to flooding for the former conditions of urbanization in the 90s, [at the time of the Iguaçu Project (Laboratório de Hidrologia e Estudo do Meio Ambiente - COPPE/UFRJ-PNUD, 1996)], without taking into account the meteorological tides and the effects of climate change. Referring to flooding conditions more than 15 years ago, it is, therefore, a condition of reference for

comparison of the current and future scenarios. It is observed that there are significant differences in floods in past conditions from those in the present scenario. The alteration that has 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 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 a future situation of urbanization of the basin, considering disorderly urban expansion, typical tides and without the effects of climate change (Scenario 2).

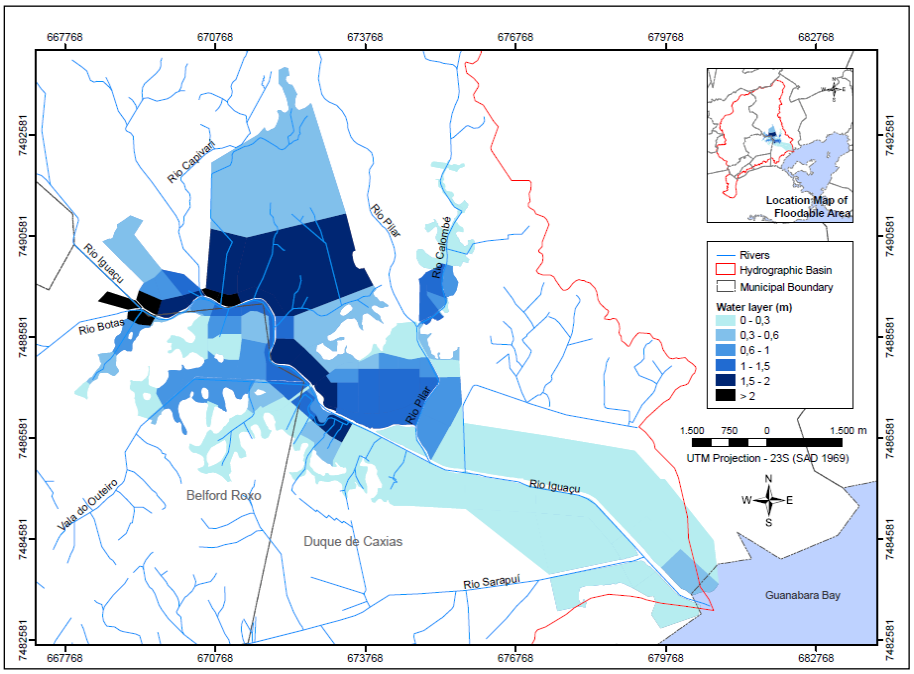

Figure 2: Reference flood map for the former urban condition

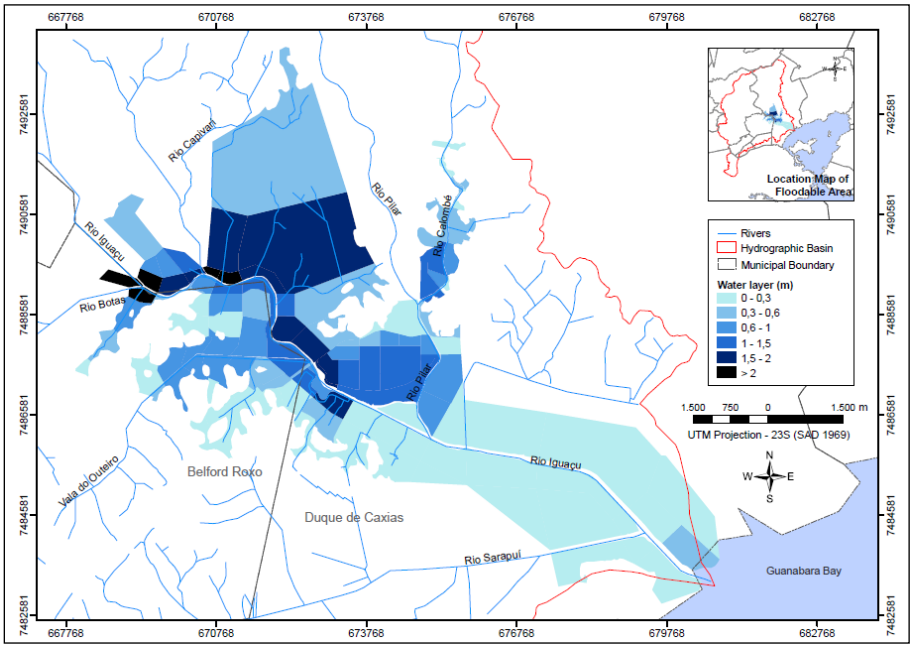

Figure 3: Flood map obtained for the present condition - Scenario 1

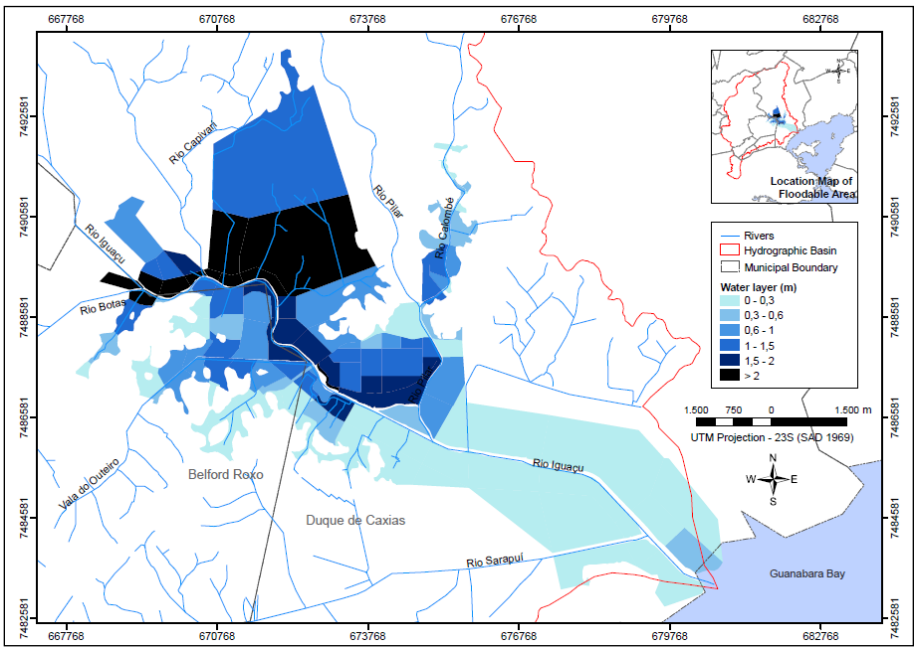

Figure 4: Flood map obtained for the future condition - Scenario 2

The comparison among these three scenarios allows assessment of the isolated effect of urban expansion on flooding. When the CN is altered for the upper reaches of the drainage area, in the simulation corresponding to Scenario 2, a significant aggravation in flood conditions is noticed, even without any other worsening factor, 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 would be possible to avoid the worsening of floods in the referred sub-basins. A reduction in water levels is perceived in the densely urbanized areas, when compared with the previous development situation, namely without any control over land occupation.

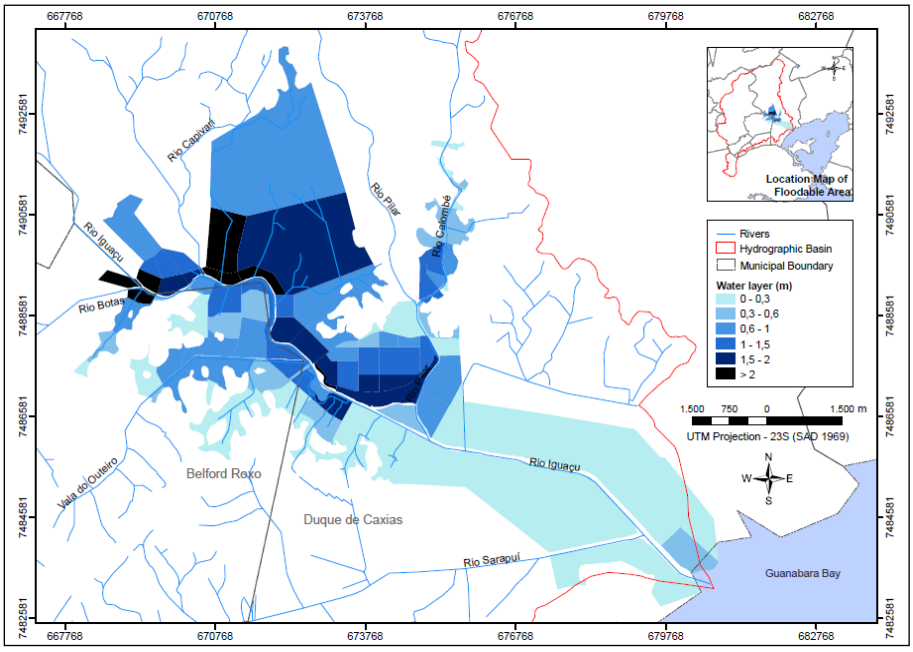

Figure 5: Flood map obtained for a controlled future condition - Scenario 3

Figures 6 and 7 correspond to the following scenarios:

- Figure 6: Flood map obtained for the future conditions of basin urbanization 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 change (Scenario 4);
- Figure 7: Flood map obtained for the future conditions of basin urbanization, with control over land use development; meteorological tide of 80cm and climate change effects, with a 60 cm rise in mean sea level (Scenario 5).

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

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

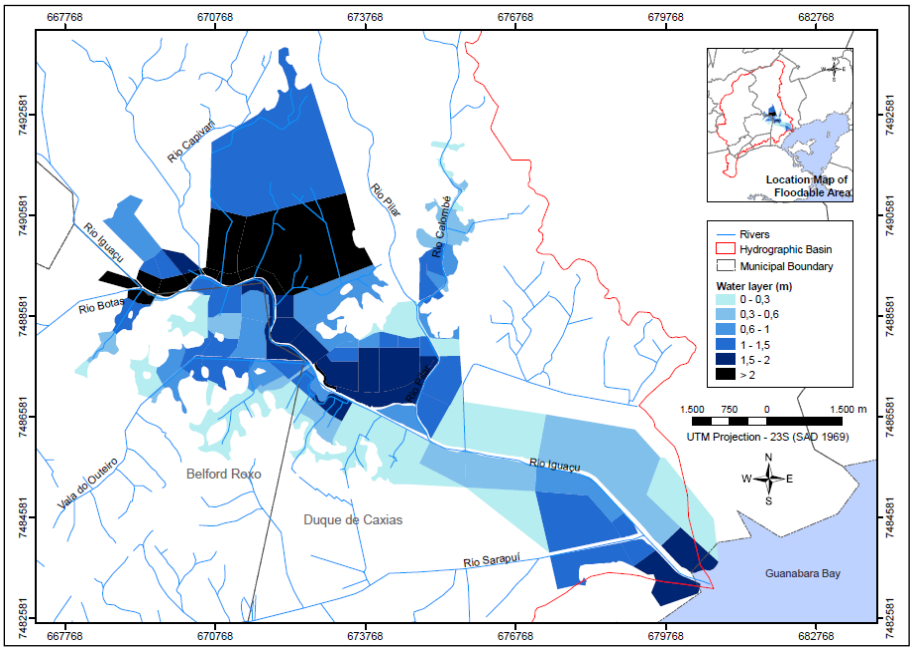

Figure 6: Flood map obtained for a future condition, in the context of climate change - Scenario 4

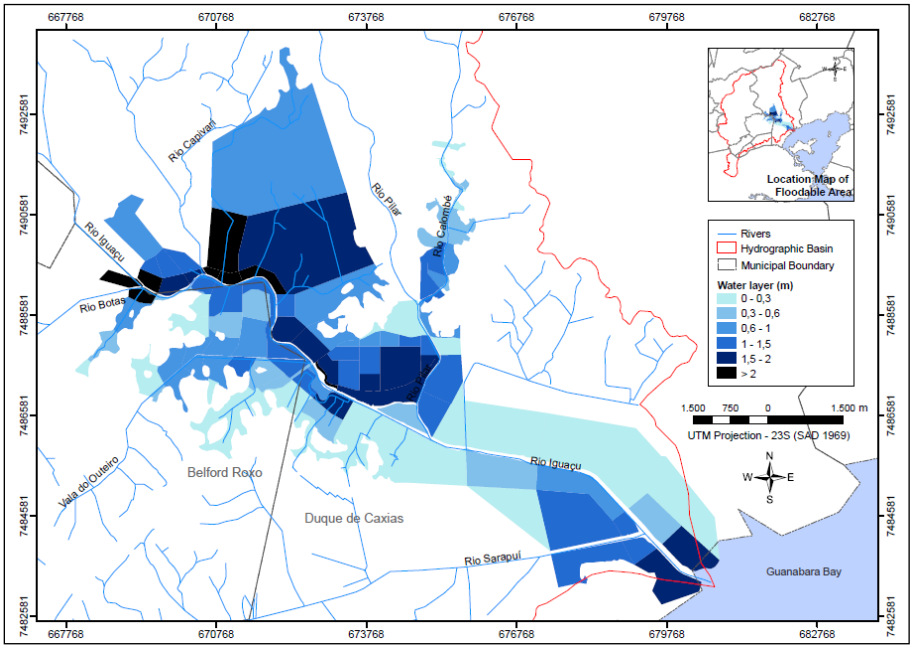

Figure 7: Flood map obtained for a controlled future condition, in the context of climate change - Scenario 5

3. CONCLUSION

The Metropolitan Ring Road will cause significant changes in the urban structure of the Baixada Fluminense, creating new vectors of expansion and new urban centralities. This work has multiple objectives and strategic importance for the Metropolitan Region of Rio de Janeiro, linking five federal highways, a railroad and several large industrial centers that are being developed in the metropolitan area. At one end, the Ring will have the Petrochemical Complex of Rio de Janeiro (COMPERJ), located in Itaboraí, currently under construction, and, at the other, the Port of Itaguai, in Sepetiba Bay.

Its route, however, will cross the only non-urbanized areas in the Guanabara Bay basin, introducing new vectors of urban expansion in its area of influence. Expanded occupancy of the spaces not yet urbanized may intensify environmental degradation, soil sealing and consequent increased flooding, as demonstrated in this study.

The new regulatory framework in force in the country can offer alternatives to the land use management shared between states and municipalities, especially in large conurbations. Specifically regarding the role of the municipality, there is a wide field of possibilities to be pursued using the legal instruments established by the national law, the City Statute. The new urban master plans of metropolitan municipalities can and should incorporate more effective mechanisms for land use management, using a wider range of legal, economic and fiscal instruments for sustainable urban development. However, as demonstrated in our analyses (Carneiro, 2008), the municipal master plans for urban development in the Rio de Janeiro metropolitan region still lack coordination mechanisms and inter-municipal cooperation in order to prevent the urban development of one area from hindering the development of another .

Sustained urban development of the Baixada Fluminense depends, inexorably, on flood control, which can only be achieved by properly managing land use, that is, preventing urban sprawl in the Iguaçu-Sarapuí basin.

This region has favorable conditions for further planning to control urban flooding, when considering the long term. A significant part of the territory remains as areas not yet incorporated into urban development - especially the areas between the steep mountain slopes and the marshland. This makes it possible to

maintain areas with high rates of soil permeability, provided that the urban fabric does not expand to these areas.

The Baixada Fluminense has three major subdivisions within its territory. The first consists of the remaining forest areas under legal protection and situated on steep hills that surround the basin and where the sources of the rivers lie. They are: the Biological Reserve Tinguá and municipal APAs (protected areas established by law), such as Rio d'Ouro and Tinguazinho, the Gericinó- Mendanha and the Pedra Branca State Park. These areas protected by local, state and federal laws, despite suffering threats of all kinds, are still important reserves of Atlantic Rain Forest ecosystems, with a high diversity of flora and fauna. Besides the ecosystem and biological importance of these forests, they provide incommensurable environmental services that contribute to regulation of the climate and hydrological system in the Baixada Fluminense.

The second subdivision is the portion of the basin adjacent to the Tinguá Biological Reserve. This area, formed of plains interspersed with rounded hills, features open spaces not yet incorporated into the urban fabric. This portion of the basin has a strategic role in controlling urban flooding, as described in Section 2. It also functions as a "buffer zone" for the Tinguá Biological Reserve and other protected areas located in the upper reaches of the Iguaçú river and tributaries, this being a "transitional zone" between the protected areas and the urban areas.

The third subdivision consists of the urban area itself, located mainly in flat areas just above sea level. The occupation of these areas was consolidated in the 1940s with the improvement in transportation between Rio de Janeiro City and Nova Iguaçu City, due to the electrification of the railway line and the opening of the Presidente Dutra highway in 1951.

Understanding the interrelationship between these three macro zones is essential for planning the land use to take into account urban flood control measures for the basin.

The Iguaçu Project (Laboratory of Hydrology and Environment Study COPPE/UFRJ- UNDP, 1996) indicated the following as necessary steps to control floods in this area: land use control, setting up polder areas, and river bank recovery by restoration of riparian vegetation and erosion control. These are fundamental measures to ensure the proper functioning of interventions concerning flood control.

However, even if these measures are correctly implemented, in the long run, they may not be sufficient to the contain flooding in these areas. In fact, it is necessary to consider the process of urban expansion in the entire territory of the river basin and the progressive increase in the rate of soil sealing, which will result in increased flooding.

Thus, the volume of water that fails to infiltrate the soil results in an increase in runoff. This additional flow from the sealed drainage basin, associated with rapid flow afforded by the rectified channels, will increase the parameters of the peak flows.

In Brazil, the conservation of natural areas, keeping them free from occupation, is regulated by the Forest Code and its determinations. Permanent preservation areas (APPs) can be established. These kinds of areas can also be established by Federal Law No. 6.766/79 (currently under review in Congress) that determines indexes of open spaces and/or green areas as a percentage of urbanized land. Local and state laws can also set up permanent preservation areas.

The determination and maintenance of these areas free of urbanization - which would help to retain a portion of the precipitation through vegetation cover and natural soil infiltration, consequently acting to reduce runoff upstream of urban areas - may offset the consequences of an increase in the occupation of areas already urbanized in the lower basin.

The strategies listed in this study consist of the following main actions to contain the urban sprawl: 1) regulation and control of land use through the establishment of environmental protection areas statewide (State Protected Areas - APAs Estaduais), transferring to state level the task of defining standards for

land use; 2) revision and adaptation of municipal master plans to meet the need to control urban sprawl; 3) creation of a public consortium focused on integration of public policies that impact the territory, ones that concern multiple municipal interests; 3) implementation of compensatory measures targeting sustainable drainage flow damping in the upper parts of the basin .

Moreover, it is important to ensure that these areas do not end up having outcomes different from those established. It is also essential that municipal governments, together with the state government, ensure proper legal regulation for these areas. These regulatory actions, combined with control actions and urban planning, must target one of the most pressing issues in the Baixada Fluminense, namely the housing deficit.

This coordinated set of strategies to ensure the maintenance of natural spaces in the river basin, keeping them free of urbanization, is a fundamental aspect for preventing the worsening of floods in the consolidated urban areas, as shown in the simulations.

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[i] 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.

[ii] Statistical probability of a river overflow event occurring with a periodicity and intensity corresponding to a 20-year interval.