Sustainability **2015**, *7*, 11068-11097; doi:10.3390/su70811068

OPEN ACCESS

sustainability

ISSN 2071-1050

www.mdpi.com/journal/sustainability

Article

Urban Floods in Lowlands—Levee Systems, Unplanned Urban Growth and River Restoration Alternative: A Case Study in Brazil

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Academic Editor: Marc A. Rosen

Received: 21 February 2015 / Accepted: 28 July 2015 / Published: 14 August 2015

Abstract: The development of cities has always had a very close relation with water. However, cities directly impact land use patterns and greatly change natural landscapes, aggravating floods. Considering this situation, this paper intends to discuss lowland occupation and city sustainability in what regards urban stormwater management, fluvial space, and river restoration, aiming at minimizing flood risks and improving natural and built environment conditions. River plains tend to be attractive places for a city to grow. From ancient times, levees have been used to protect lowland areas along major watercourses to allow their occupation. However, urban rivers demand space for temporary flood storage. From a systemic point of view, levees along extensive river reaches act as canalization works, limiting river connectivity with flood plains, rising water levels, increasing overtopping risks and transferring floods downstream. Departing from this discussion, four case studies in the Iguaçu-Sarapuí River Basin, a lowland area of Rio de Janeiro State, Brazil, are used to compose a perspective in which the central point refers to the need of respecting watershed limits and giving space to rivers. Different aspects of low-lying city planning are discussed and analyzed concerning the integration of the built and natural environments.

Keywords: urban growth; urban flood control; lowlands; levee systems; river restoration; sustainable cities

1. Introduction

Water has always played an important role in the life of cities. In the last decades, however, cities have been increasingly suffering from an unbalanced relationship with their waters, resulting in floods and degradation. This kind of negative impact, very frequently related with uncontrolled land use, is one of the major threats to many countries worldwide [1], with more significant impacts on developing countries [2].

This paper intends to discuss sustainability in regards to urban water management, fluvial space, and river restoration, aiming to build a healthier city environment, while minimizing flood risks. Nevertheless, managing urban stormwaters is not a simple task. The urbanization process greatly changes natural landscapes [1], modifying the water cycle, especially due to the increase of imperviousness, while occupying flat lands along the flood plains. In this context, growing cities tend to degrade environments that strike back, increasing urban floods. Land use planning and control seem to be key factors in this discussion. Serrao-Neumann *et al.* [3] affirm that effective planning policies and response can reduce the communities' vulnerability to extreme weather events.

When discussing cities and sustainability, an actual trend points towards compact cities as an alternative for less consuming resources, improving mobility and infrastructure uses in general. However, there is a practical limit for compactness regarding urban flood control, because storm waters demand space for accommodating the runoff surplus generated by urban surfaces. Urban rivers also demand space for temporary flood storage. So, sustainability is a very general concept that has to be considered in a broad systemic view. Although we are aware that sustainable cities have to be built over three equally important pillars, considering social, economic and environmental aspects, we will focus the discussion of this paper to the physical aspects that contribute to sustainability as a whole. Organizing the natural and built environments to harmonically coexist in terms of cities' relations with urban rivers and flood control will be the main driver of this study. Fulfilling this aim indirectly leads to more economic solutions (once working with nature induces less maintenance costs) and social benefits (due to reducing flood risks and valorizing urban land as a consequence).

This way, in simple terms, we will consider that urban drainage sustainability implies not transferring negative flood impacts in space and time. River plains are usually attractive places for a city to grow: they offer flat areas, fertile lands, easy access and water for drinking and sanitation purposes. However, when urbanization stresses river space [4–7], these attractive areas can become traps: flooding can increase in magnitude and frequency and the hydraulic risks introduced are difficult to mitigate due to the lack of space. The possibility of having to find space in the cities to accommodate flood flows is a great challenge, not only in terms of engineering, but also, and, principally, in terms of urban planning [8]. Sustainable cities have to find a compromise between natural and built environment, recognizing the functional limits imposed by the watershed. According to Weather and Evans [8], decisions on where to build houses and infrastructure are now recognized as a key tool in the management of flood risks.

In this context, this paper particularly discusses the urbanization process in lowlands and the increased hydraulic risks introduced in the process, when river space needs are not considered in city growth policies, resulting in an unsustainable city pattern [9] in regards to urban stormwater and flood risk management. A typical solution in low lying areas refers to levee systems, used to protect cities or villages from flooding, but usually affecting environment quality, interrupting landscape patterns and segregating city areas. In this case, the conflict for space between natural and urban environment is solved by artificially cutting off space from rivers and adding it to the urban tissue. However, flood risk management, as previously said, is a process associated with allocating space for floodwaters. In this context, narrowing flood plains may become a critical issue, while an adequate integration of different (and competing) land uses is a primary challenge. According to Jha *et al.* [10], it is vital to link urban flood risk management to urban planning and management.

From ancient times, levees have been used to protect lowland areas along major watercourses—there are records of levees constructed by the Romans. In present times, some important levee systems may be cited as examples: the Mississippi [11–14] and Sacramento Rivers in the USA [15,16]; and the Po, Rhine, Meuse, Rhone, Loire, Vistula and Danube Rivers [17], in Europe.

However, this type of measure may raise some problems. A lowland area protected by a levee will be defended against a pre-defined flood design event of a fixed return period, as usually considered in design procedures. The feeling of safety brought by these works tends to attract more people to the protected areas near the river. However, the possibility of occurrence of a higher magnitude flood event (greater than that defined for design purposes) can put more people, goods and buildings at high risk [18]. Mapping the hazard should impose urban restrictions to land use. Nevertheless, several times the planning process loses track of the original hazard mapping.

Besides, traditional urban drainage interventions (like levees and canalizations) do not seem to be effective over the long run. Frequently, this effectiveness reduction happens because land use is not properly managed. As an illustrative example, we may report a personal experience regarding a field visit in the Po River basin, Italy. This river flows between levees along its downstream reach until discharging in the Adriatic Sea. Ferrara is one of the cities in the downstream reaches of the basin and there is an old palace in the city center that shows records of floods from the 1700s, carved into one of its pillars. It is noticeable that the flooding level has been increasing over time. The mark of the flood of 1705 is registered at a height a little bit greater than that of a man. From this first mark, subsequent registered floods have always increased over time. The flood that occurred in 1951 tops the pillar, and the most recent important flood could not be engraved because it surpassed the pillar height.

However, considering the Po river Basin, Nardini and Pavan [19] discussed possible alternatives for intervening in the Chiese River, one of its tributaries, considering river restoration measures (proposed to bring the river into a more natural state). The authors argued that "the actions against risk have so far been driven by the paradigm of putting the territory into safe conditions." This kind of choice implies hard engineering works, like levees, dams and canals, leading to an increasing spiral of operation, maintenance and replacement costs.

This way, our study argues that designing with nature rather than against nature must be considered for more sustainable, resistant and resilient cities [5,20–22]. In this context, the basin of the Iguaçu-Sarapuí Rivers in the Baixada Fluminense region of Rio de Janeiro state, Brazil, is used here to discuss the questions posed in this introduction.

Departing from a systemic perspective that considers the basin as a whole, four local cases in this basin are analyzed to discuss different aspects of low-lying city planning. The set of four case studies were part of a major project, developed by the Federal University of Rio de Janeiro for Rio de Janeiro State Government. The first case refers to a levee system, where the protected area is occupied by an unplanned urban community, limiting storage space, which causes the flood control intervention to fail. This case shows how this type of hard engineering work may fail if urban planning and land use control are not in place. The second case refers to a new urban development proposed to revitalize a degraded riverside slum area, introducing a levee that makes the water levels rise in the Sarapuí River. The third case shows the opportunity of opening a levee to recover part of the natural flood plains of the Iguaçu River. The fourth case discusses the effect of preserving a natural floodplain near the confluence of the Botas River with Iguaçu River. These last two cases show the possibility of considering some of the aspects related to the river restoration concepts [23,24] in a flood control project, even if only in partial terms and recognizing the several existing constraints in urban areas.

The approach developed in this paper intends to assess the behavior of river restoration strategies (compared to the traditional engineering approach relying on levees) through the prospection of mathematical modeling results obtained for the empirical case studies presented. It is worth noting that a central discussion in all these cases refers to the need to give space to the rivers. Besides, we link this need with city planning, concerning the integration of the built and natural environments, respecting the limits imposed by the latter, in order to produce better and safer cities [20,25].

2. The Water and Cities

Cities, from the beginning of their history, have always had a close relation with rivers, or, more precisely, with the need of water and its several usages. It is also possible to say that the urbanization process, and cities, by consequence, is greatly related with the civilization concept. Urbanity and civility were converging concepts. Several Ancient cities, like Rome, for example, had shown examples of living well with their waters; however, after the fall of the Roman Empire, cities gradually lost their importance and sanitation practices deteriorated during the Middle Ages, when streets or superficial canals were used to convey all effluents [26]. Afterwards, the Industrial Revolution greatly changed cities and shaped them towards what we experience today. In what concerns the relation of waters and the city, this is also a critical period, when several water borne diseases and epidemics related with lack of sanitation caused substantial loss of life. In order to face this problem, the urban drainage system was conceived to promptly convey storm and waste waters from city centers, highlighting hygienist purposes. However, with the expanding city areas and the common effect of paving urban surfaces, increasing runoff also led to increasing floods. Simply conveying stormwaters started to transfer problems instead of solving them. This option showed to be rather unsustainable, once conveying discharges pointed at the consequences of the urbanization process, while the problem of generating increasing discharges was not addressed.

Moreover, repeated expansion of city borders led entire new neighborhoods to occupy risky areas, mainly lowlands and flood plains. Social problems and poverty, especially in developing countries with late (and fast) urbanization, also pressed for the occupation of these areas. This way, cities have been accumulating losses with urban flood aggravation, including damages to houses and infrastructure, degradation of the built environment, natural environment impoverishment, public health problems, among others.

Global statistics show that floods are the natural phenomenon that causes the major damages around the world. Freeman [27] indicated that, among natural disasters, floods caused 60% of human life losses and 30% of economic losses. The book *Cities and Flooding: A Guide to Integrated Urban Flood-Risk Management for the 21st Century*, from the World Bank [10], stress that the number of great inundation events has been significantly increasing in the last decades and, considering only the year of 2010, 178 million people were affected by floods.

From the beginning of the 1970s, a shifting tendency on urban drainage has driven the design efforts to source control measures, focusing on the flood causes, that is, in minimizing and reorganizing superficial flows. Infiltration and storage measures started to be seen as an option to the traditional canalization methods [28]. Sustainable urban water management practices have to be integrated with a water sensitive urban design, composing an institutional, legal, technical and social-economic framework, bringing water to the center of urban development discussion. The need to reintegrate the rivers and their floodplains into the urban landscape and city life is an important factor to face the unsustainable dichotomy created between watershed and city needs.

The contemporary understanding of flooding and the city, according to White [29], is directly related to the concepts of resilience and water management. According to him, floods will always occur and the planning system should provide sustainable and adaptive responses that increase the cities resilience.

3. Lowlands, Levee Systems and River Restoration as an Alternative

The construction of levees avoids river overflow, isolating the riverine area from the main river and interrupting river connectivity with floodplains. From the hydraulic point of view, the drainage of the internal protected areas is guaranteed by the implementation of local canals and ponds to temporarily store rainwater. The stored water is conducted back to the main river through flap gates, when the main river allows, or by pumping stations. Systems composed of an auxiliary channel and temporary reservoirs connected by flap gates with the main river are also known as polders [30]. Polder is a Dutch word, which is frequently associated with sea protection.

The more the levees are constructed, the more the floodplains become isolated from the main river channel and the river discharges become confined to the main channel. Normally, river flows should spread over the floodplain, in a natural laminating process that damps the peak flows to downstream. Therefore, the construction of levees along rivers tends to transfer flooding problems to downstream areas, leading these affected areas to require the construction of new levees or even higher levees where they already exist [18,31].

Besides, unplanned development can also lead to several problems, with critical effects on the levee systems themselves. Some problems can arise from urban sprawl towards the temporary reservoir area needed inside the levee systems, limiting its capacity. Particularly in developing countries, slums can sometimes occupy the levee crests and change their configuration (by lowering their tops), increasing the risks. These less attractive areas end up being an alternative to a parcel of the community, which lay down on irregular settlements, due to poverty and lack of an adequate housing system. The growing urbanization process coupled with the lack of efficiency in providing an adequate urban infrastructure creates serious problems for cities, degrading both the natural and the built environment.

It is important to remember that levee systems are designed to provide a specific level of protection, considering a certain design event. This approach requires complementary actions, generally non-structural, involving land use zoning to regulate the occupation of areas subjected to possible losses in case of major events. The risk of a greater event exceeding the designed protection and eventually leading to an unexpected failure may be called residual risk [18]. The sense of safety created by the levees and the relatively low probability of flooding make the inhabitants of these protected areas often forget that there is still a risk of flooding [32]. Sometimes, flood damages associated with great events can be much greater than that if the levee had not been built [33].

According to Wesselink *et al.* [34], loss of life is almost certain when flood defenses, such as levees, are breached and the internal area inundated. Some examples, among others of this type, may be found in the literature: large floods that affected the US Midwest along the Mississippi and Missouri rivers and their tributaries in 1993 and 1995, caused by levee failure [10,11,32]; the disastrous flooding of New Orleans provoked by Hurricane Katrina in 2005, also associated with a levee failure; and two important events that occurred in 1993 and 1995 [35], in The Netherlands, a low-lying country with approximately 20% of its area below sea level [36] where large polders have been constructed to protect the country against floods [32,37]. These two last cited events are usually considered as alarms that later triggered the "Room for the River" approach, which changed Dutch flood risk management strategies.

Making room for rivers is an alternative for putting the territory in safer conditions and it is often related with the premises of the river restoration approach, which aims to adapt the territory to a better environmental arrangement. The first studies about this theme were developed in the 1960s, seeking to improve rivers' water quality [38]. In the following decades, in the 1970s and 1980s, greater attention was given to ecosystems [39]. Flow regimes, river connectivities (mainly with flood plains) and ecology of fluvial corridors became the main concerns [40]. From the 1990s, the worry about sustainability has increased and river restoration has gained space. In 1992, for example, the U.S. National Research Council published a treatise about restoring aquatic ecosystems, with numerous practical examples [41]. The EU Water Framework Directive, published in 2000, gave an important impulse to this theme. In parallel, Canada and Australia also followed similar paths. In brief, from reviewing the literature it is possible to say that river restoration, in a broad view, seek to examine the territory and rethink land use as well as reorganize settlements and infrastructure. Many times, river degradation, water shortages or floods are problems derived from basin practices, such as plant cover removal and paving, causing hydrological balance changes, greater pollution and erosion. On the fluvial corridor scale, a river restoration project should try to give space back to the river, by reconnecting flood plains and dismantling levees and other riverbank protection works. Plate [18] mentions that not only in Germany, but also in other countries, people are already talking about removing some of the existing flooding protection works, such as the existing dams, as a way of giving space back to nature and also because of the possibility of dam failure. Interesting alternatives to materialize actions like these can include government purchase of land or establishing agreements with landowners, so that the environmental services they provide can be recognized and remunerated [19]. Flood risk reduction is one of these services.

In urban areas, river restoration is a very difficult task, due to the modifications introduced both in the fluvial corridor and the watershed. In this case, there are greater restrictions and a compromise solution has to be established between the natural and built environments. Dufour and Piégay [42], for example, state that previous conditions should not be used for benchmarking, because a past state is not necessarily better than any other, and human influence (and needs) has to be considered. Besides, no one is free from being integrated in cultural processes where the roles of nature and society can be perceived in different ways.

A successful urban river restoration process needs to be integrated with the urban planning process, allowing broad participation of the different actors that manage, use or live in the basin. It is important for the community to embrace the river, recognizing its presence as a natural value in the urban landscape, and providing an environmental service.

4. Baixada Fluminense Lowlands—Rio de Janeiro Metropolitan Area

Baixada Fluminense is an important region of Rio de Janeiro state, located in the western portion of Guanabara Bay, in Brazil. Part of this region composes the metropolitan area of Rio de Janeiro City. Baixada Fluminense has several Municipalities, settled in very flat lowlands and its development has been marked by flood control challenges (Figure 1). The basin fully encompasses the municipalities of Belford Roxo and Mesquita, also hosting part of the municipalities of Rio de Janeiro, Nilópolis, São João de Meriti, Nova Iguaçu and Duque de Caxias. The main watercourse crossing this area is the Iguaçu River, while the Sarapuí River is its main tributary, reaching the Iguaçu River from its right margin, near the outfall of the basin in the Guanabara Bay. The Iguaçu-Sarapuí basin (as it is usually called) drains an area of 727 km^2 and their tributaries flow from the inland mountains in torrential regime with strong erosive power. When reaching the plains the river system loses energy and inundations may occur. At these areas, terrain elevation is near the mean sea level.

Urbanization of the basin is relatively recent, but it has been very intense in the last decades. In a general view, land use on the basin encompasses natural forests in the upper reaches, as well as rural, urban and industrial areas. The urban areas are located mainly at the lowlands and there are about 1.5 million people living there. Low-income communities are frequent and dwellings are often substandard. 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. Fast urban growth, land use and occupation without adequate planning or control, lack of investment in urban infrastructure and discontinuity in public policies are characteristics of the basin's development history.

In the early decades of the twentieth century, some projects involving levees and canalizations were proposed to control flood levels for agricultural purposes, when the majority of the basin occupation was rural. Later, agriculture suffered an important decay and the lowlands of Baixada Fluminense became more populated as bedroom communities of Rio de Janeiro city. A migratory process towards this area began on the 1950s and accelerated from the 1970s on. When these urban settlements spread over the basin, favored by commuter railway expansion, urban floods and sanitation problems were aggravated due to the lack of proper infrastructure and the small protection provided by the original flood control measures, once they were conceived for agricultural purposes. The fast urbanization process resulted in the occupation of the main rivers bed, what has made almost impossible the maintenance of this watercourses; the acceleration of the process of rivers sedimentation due to deforestation of the slopes and inadequate solid waste disposal; and the increase of the runoff, due to uncontrolled vegetal removal and consequent substitution by impervious surfaces.

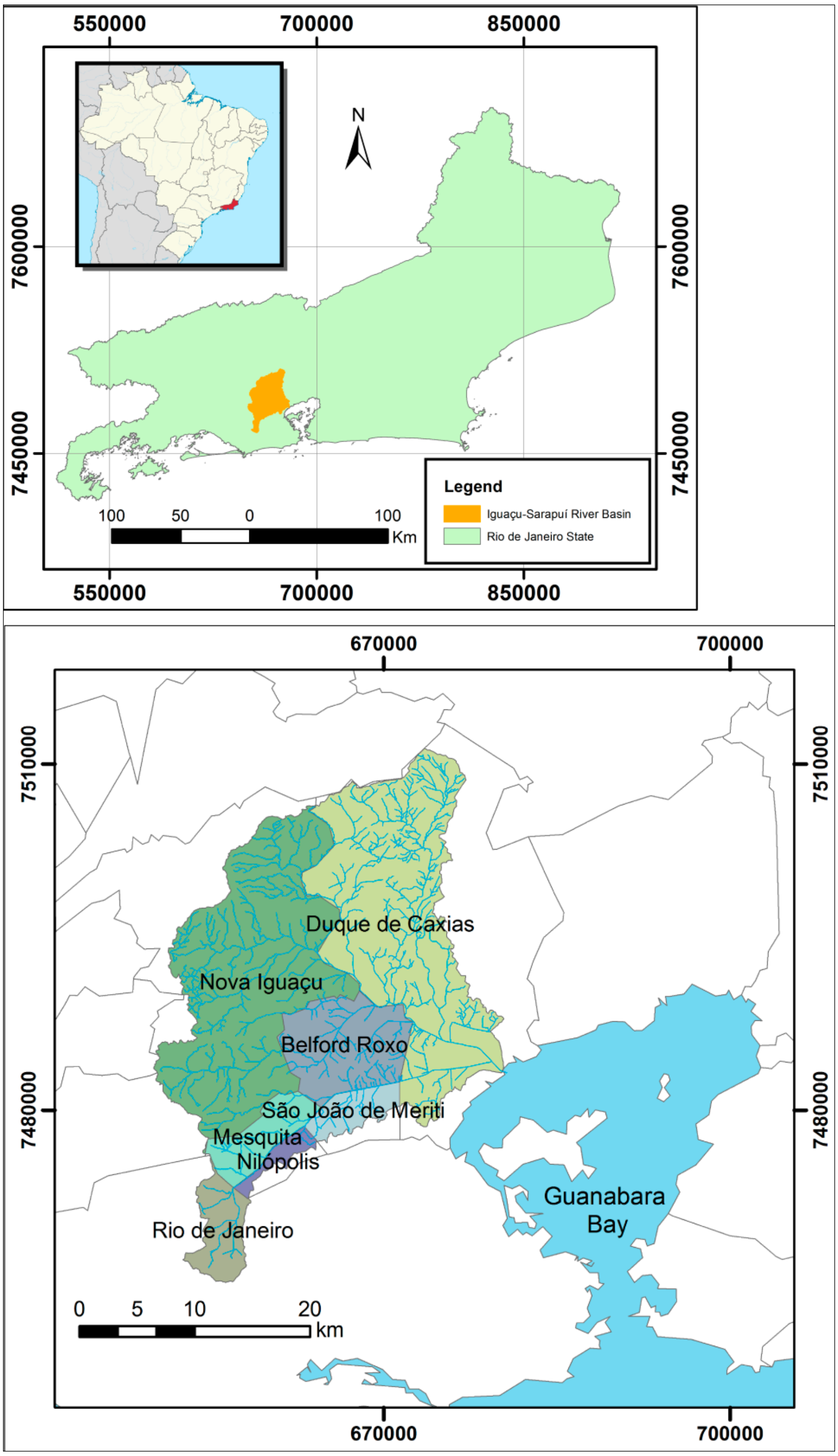

Figure 1. Iguaçu-Sarapuí River Basin at Baixada Fluminense Lowlands in the Metropolitan Area of Rio de Janeiro [43].

The analysis of income per capita and the structural capability to finance investments by municipalities in the region, according to the Observatory of the Metropolis [44], show strong differences between these municipalities belonging to the Metropolitan Region of Rio de Janeiro. Such differences constitute obstacles to cooperation in solving common problems in a large scale (in the watershed scale, for example). Moreover, the limited technical capacity of the municipalities' staff, particularly in the areas of planning, design and budget, strengthens uncertainties, discouraging long-term partnerships in infrastructure projects that could be used to promote social and economic development for the region [45].

It is important to remember that Brazil is a federative country. Therefore, the jurisdiction of the municipality in federative countries focuses on roles that are generally related to the provision of infrastructure systems and local public services, planning land use and city development at the local scale. The municipalities are, in fact, in the frontline of the executive actions regarding land use and urban growth—urbanization is their prerogative. The Brazilian Federal Act known as the "City Statute" [46], established rules for public land use order and social interest that regulate the use of urban property in favor of the collectivity, the security and well-being of citizens and environmental balance. The urban policy aimed to fulfill the social functions of a city and the urban properties. A set of general principles were proposed to guide the actions over the cities' territories, from which some of them are detached in the sequence:

- Cities have the right to sustainable urban development, meaning the right of adequate housing, environmental sanitation, urban infrastructure, transport and public services, and work and leisure for present and future generations.
- Planning the development of cities has to prevent and correct the distortions of urban growth and its negative effects on the environment.
- Urban infrastructure and public services have to be supplied to serve the interests and needs of the population.
- Land use control should avoid pollution, environmental degradation and excessive or inadequate use in relation to urban infrastructure.
- Protection, preservation and restoration of the natural and built environment, as well as the cultural, historical, artistic and landscape heritages, are general directives.

However, although the City Statute provides several indications that urban growth and environmental concerns should walk together, there are several constraints to this matter. In what regards water resources management, for example, the municipal role is very limited. Water resources management is a matter of river basin management and cannot be restrained to an administrative territory jurisdiction, as formally stated by the Brazilian Federal Act known as the "Water Act" [47].

Despite the fact that the municipal administrative level is the one closest to social reality, its range of political and administrative roles does not allow a systemic vision of the territory in which it is inserted (both in terms of larger watersheds, in regards to the natural environment; and considering the metropolitan issues, in regards to the built environment). Urbanization, as discussed in the first sections of this paper, is one of the main drivers of flood aggravation. Municipalities have the urbanization prerogative, they should guarantee a sustainable development while preserving environment, but frequently they do not act in the basin scale. Consequently, urbanization tends to amplify urban floods that degrade the urban environment, while natural environment also impoverish. The spatial configuration of a metropolitan area also aggravates the situation, because local solutions taken in one city (at the city scale, and without considering the watershed basic functions) also transfer floods downstream, initiating a snowball effect, where the next city defends itself and continues the process of transferring stormwaters downstream.

In the beginning of the 1990s, Baixada Fluminense as a whole sheltered more than two million inhabitants in six counties. More than 350 thousand of these inhabitants suffered the effects of significant floods. The uncontrolled urbanization process resulted in the occupation of the riverine areas and, sometimes, of the main rivers bed. Inadequate solid waste disposal and the increase of the runoff, due to the spread of impervious surfaces aggravated floods and their consequences. Figure 2 gives an overview on the land use of the basin, while Figure 3 shows the estimated inundation map by that epoch and also offers the location of the case studies discussed in this manuscript.

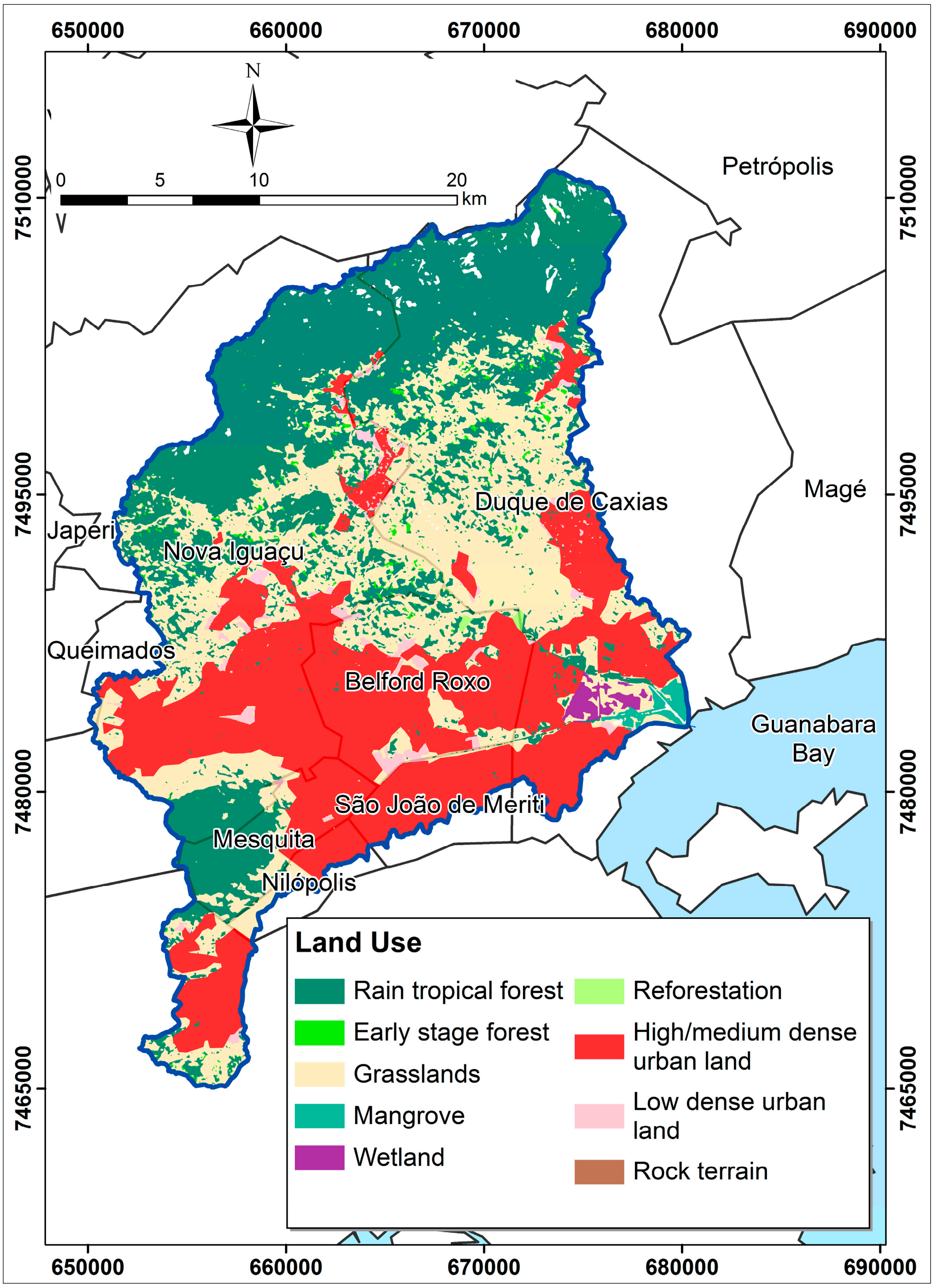

Figure 2. Land use map for Iguaçu-Sarapuí River Basin [43].

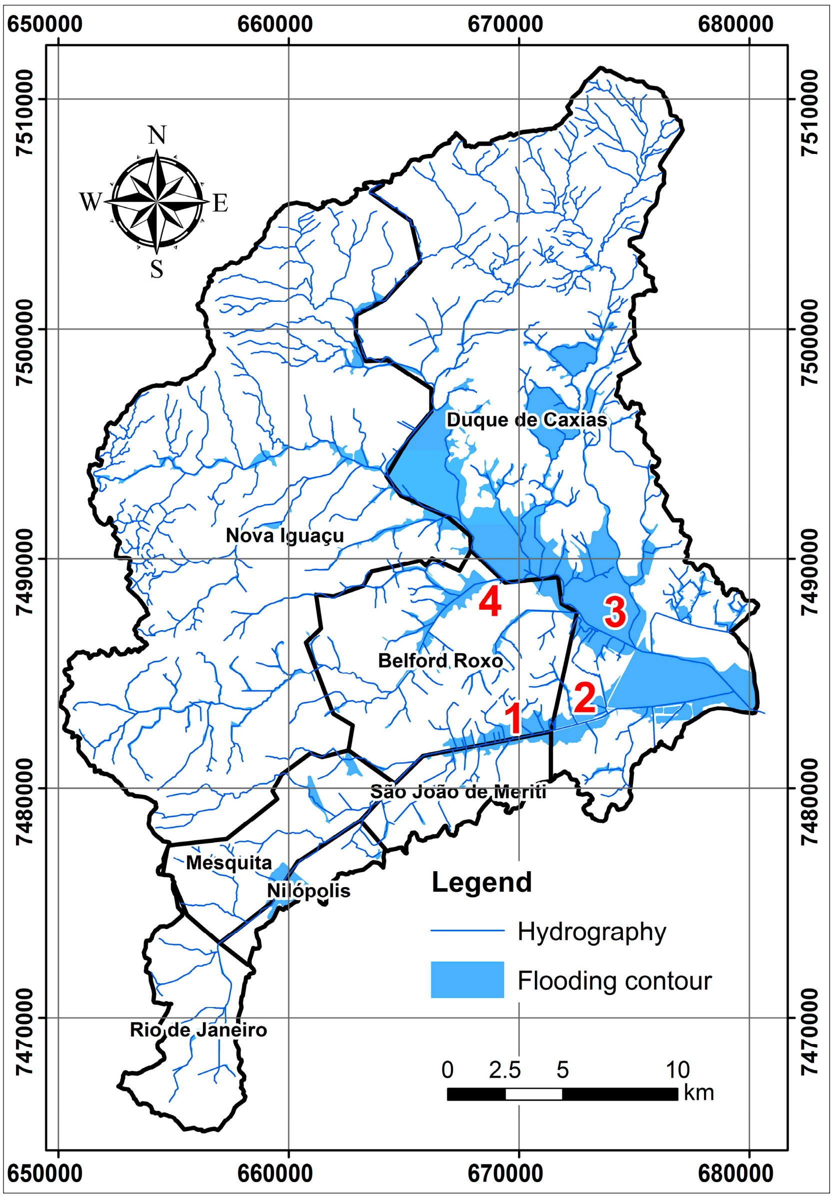

Figure 3. Iguaçu-Sarapuí River Basin critical inundation areas [43]. Points 1 and 2, in the Sarapuí River floodplains, point 3, in the Iguaçu river floodplains, and point 4, at Botas River confluence on the Iguaçu River, refer to the places where the case studies presented in Section 6 were developed.

In this context, the State Government of Rio de Janeiro (note that Rio de Janeiro State has the city of Rio de Janeiro as its Capital—they are two distinct administrative entities: one at the level of a federative state; the other at the municipal level) started to articulate important actions to control floods and improve sanitation aspects.

An important milestone in the search for better flood protection for Baixada region was the launch of the Integrated Iguaçu-Sarapuí River Basin Flood Control Master Plan [48], coordinated by the State Environmental Institute (INEA). The Federal University of Rio de Janeiro (UFRJ) helped INEA in this action. This plan studied the basin in an integrated way, with different solutions articulated to propose a certain adequate level of protection against floods. Due to the set of flood control measures inherited from past actions, however, several traditional structural measures were proposed, mainly focusing on retrofitting levee systems and adapting land use. Safety levees heights were defined, a minimum terrain level was established for urban development and new subdivisions, main channels were dredged and some tributaries were canalized and directed to temporary storage areas. However, these actions were mainly developed from the engineering design perspective. A fragile articulation with the municipalities, in fact, prevented them to incorporate the required land use controls to help in sustaining the definitions provided by the Plan.

Further uncontrolled urbanization caused a critical scenario: ten years later, some urban areas had grown far larger than planned, some storage areas were not preserved, levees were occupied and modified (with partially removal of the landfills for construction purposes) and slums spread inside temporary reservoir areas. The case of Alberto de Oliveira levee system, between the cities of São João de Meriti and Duque de Caxias is an example of these problems. The temporary reservoir was occupied in more than 80% of its total area, including formal urban occupation developed by the municipality that lost control about what areas should be preserved as natural storage ponds [49]. Some new levee systems other than those originally proposed were implemented. On the other side, some areas did not develop as expected and a few of the proposed levee systems remained almost unoccupied. All these factors led to an unexpected basin behavior, not predicted in the design scenarios. The consequences were related with flooding, either by local stormwaters or by river overtopping flows surpassing the levees.

Another consequence raised from the Plan actions showed that the generalization of levee systems as the preferred intervention in the Iguaçu-Sarapuí Rivers basin almost entirely enclosed these rivers, strongly limiting their connections with the flood plains. This situation was responsible for a dangerous elevation of the flood levels in the rivers. Old levees started to be subject to overtopping threats and the total risk increased.

Between 2007 and 2009, a complete revision of this study was carried out, with the intention of creating an updated technical design base to provide flood control projects that could be financed by the federal government's Growth Acceleration Program (PAC) [50]. Again, the State Government tried to orchestrate actions in the basin scale joining the municipalities. This study, held by the Federal University of Rio de Janeiro to support INEA, proposed a set of integrated actions to provide environmental preservation and prevent degradation of urban areas, through structural and also non-structural measures. Among these proposals we can cite, land use zoning was revised to include flood mapping; urban parks were suggested and designed both in the urban tissue (to prevent further paving) and along the rivers (to avoid irregular occupation of river banks and provide storage capacity for damping flood peaks); a set of rural transitional areas between natural forests of the upper basin and the cities were defined as formal Environmental Protection Areas, which future development will be regulated by the State of Rio de Janeiro; and all levee systems were re-designed and one of the levees was suggested to be removed to recover floodplain connection. These actions were based on sustainable concepts of urban flood control, using storage measures, restoring watercourses' natural characteristics and avoiding floodplain occupation to guarantee a proper "fluvial space" for the natural overflows. Multifunctional landscapes were considered as an alternative and new environmental protection areas were proposed to avoid upstream urbanization and the loss of important green areas. In this context, a selected set of works developed for Iguaçu-Sarapuí Rivers basin are presented in the sequence, to illustrate the points brought into discussion in this paper.

5. Methodology

The discussion developed for Baixada Fluminense was supported by mathematical modeling. A hydrodynamic model developed at UFRJ, called MODCEL [51,52], was used to represent the flood prone areas, integrating the main river flows, flood plains and levee systems. This model was the same that was used in the project developed jointly with INEA.

In brief, the construction of MODCEL was based on the concept of flow cells [53] and intended to provide an alternative tool for integrated urban flood simulation, considering altogether superficial flows, the storm drain network and the main rivers. This is a free open model, conceived as a design and research aid tool. The flow cells are homogeneous “compartments”, which are used to characterize the watershed surface. Each cell may assume particular patterns, representing land use, hydrological features and a storage capacity. A rainfall–runoff transformation is also made inside each cell. The resulting mash of cells integrates all the watershed area and interacts through cell links, using several available hydraulic laws.

Therefore, MODCEL integrates a hydrologic model, applied to each cell in the modeled area, with a hydrodynamic looped model, in a spatial representation that links surface flows, channel flows and storm drain flows. This arrangement can be interpreted as a hydrologic–hydraulic pseudo 3D-model, although all mathematical relations written for the model are one-dimensional. Pseudo 3D representation may be materialized by vertical hydraulic links that 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. Some applications of MODCEL may be found in [7,54–57].

Previous studies from the Integrated Iguaçu-Sarapuí River Basin Flood Control Master Plan [48] were taken as the base for the hydrological modeling and the adopted premises were as follows:

- The design rainfall was based on four rain gauges, Nova Iguaçu, Xerém, Bangu and São Bento [48], and it was calculated for a return period of 20 years, weighed by the influence area of each considered gauge.
- The total duration of the rain coincided with the time of concentration of the whole basin. The design rainfall was taken distributed in time. Considering the method of alternate blocks, with a time step compatible with the time of concentration of the local scale. Thus, the resultant flood can be considered critical not only in global scale, but also at local scale, for the entire basin.
- Total time of concentration of the Iguaçu-Sarapuí basin reached 17 h. In the levee systems, this time varied from place to place, ranging from a few minutes to hours.
- The total rainfall obtained for the considered return period of 20 years was 97 mm.

In order to represent the Iguaçu-Sarapuí Rivers Basin, MODCEL was applied both in the basin scale and at the local scale, depending on the necessity. The whole basin behavior needed to be represented, once it affects individually each levee system operation. Besides this, the basin representation was important to assess the systemic effect of the levees in raising water levels on the main rivers. However, detailed representation of the levee system was also necessary especially to represent local behavior related to unpredicted urban growth. Because of these different needs in the modeling scale, the following procedure was used to optimize the simulations:

- The Iguaçu River was modeled using 306 flow cells—upstream reaches and upper sub-basins were considered as boundary conditions and solved with simple hydrologic modeling and downstream boundary condition represented the tide effects in Guanabara Bay.
- The Sarapuí River was modeled using 403 cells—the upstream boundary condition was given by the operation of Gericinó Dam, designed to control floods, while downstream boundary condition was imported from the Iguaçu model.
- Each levee system was modeled in detail as necessary and the downstream boundary condition was taken from the Iguaçu or Sarapuí models. Note that all individual levee systems, with fewer details, also appeared in the Iguaçu and Sarapuí river models.

6. Discussion Cases

6.1. Jardim Redentor and Jardim Glaucia Levee Systems—Uncontrolled Urban Growth

Originally, Jardim Redentor and Jardim Gláucia were two independent levee systems, proposed in the original Iguaçu-Sarapuí River Basin Flood Control Master Plan [48]. They are separated by Automóvel Clube Avenue and located on the left margin of the Sarapuí River, between the cities of Belford Roxo and Duque de Caxias. The watershed that contributes to these levee systems drains an area of approximately 19.3 km^2. If the levee system were not in place, in this case of flood plain urbanization, more than 3700 dwellings would be directly exposed and affected by inundations. However, the disordered occupation process, both resulting from informal urbanization and from regular settlements implemented without proper planning, exerted great pressure on the areas designated as temporary reservoirs, substantially reducing the storage capacity proposed in the Iguaçu Project [48]. Jardim Redentor levee system was the most affected one and started to fail frequently.

A previous result [58], obtained for Baixada Fluminense as a whole, accounts for losses varying from about 11% to 22% of the value of structures and their contents, per event, for events varying from 2 to 50 years of return period. Salgado [58] build depth–damage curves for the region, considering buildings typology, contents and population income, relating the results with total monetary losses.

Considering a design horizon of 50 years and using the same curves to estimate the losses expected for the area protected by Jardim Redentor and Jardim Glaucia Levee Systems, it is possible to obtain a value of almost R$290,000,000.00 (in "Reais", the official currency in Brazil, which represents a value of approximately 83,000,000.00 Euros—1 EUR = R$3.50), for the inundation depth resulting from Sarapui River floods.

In order to equate the new flood problems, considering the structures already implemented Jardim Redentor and Jardim Gláucia levee systems were joined by a new auxiliary channel, and the storage system was redesigned to work together. However, the need to have a large storage area to manage the rainfall volumes drained at the old Jardim Redentor levee system, upstream, required some dwelling relocation. Approximately 420 families were living in areas needed for the proposed reservoir. These families should be relocated, which would imply an estimated cost of R$12,000,000.00. This was a side effect of the unplanned growth that could not be avoided in the design process. With the aim of assuring the future operation of the proposed project, recreational areas were suggested along the reservoir edges, integrating the reservoirs with the urban surroundings and serving the community as multifunctional landscapes. The flooding areas were organized in different levels, some of them designed to be flooded only by events of greater magnitude. These recreational areas were divided into different urban park typologies [59], each one with its own function:

- Urban flooding parks: Longitudinal parks, constructed in areas with low elevations, to allow frequent inundation, working to laminate floods.
- Urban fluvial parks: Longitudinal parks with the purpose of protecting river banks or the urban flooding parks, avoiding future irregular reoccupation by low-income people.
- Environmental urban parks: Large parks, occupying plain areas or not and not necessarily near the river, covering green areas and aiming to minimize runoff generation, but also for environmental preservation.

The set of interconnected reservoirs proposed is seen in Figure 4, resulting in an area of a little bit more than 1 km^2, with heights varying from 0.5 m to 1.8 m. All these areas are urban flooding parks. Two other upper areas were defined as environmental parks—they are located at the north of reservoir 4 and at the east of reservoir 2, and are also shown in Figure 4. This way, the proposed solution accounted for hydraulic structures, urbanization and landscaping, with an estimated implantation cost of R$70,000,000.00 and a maintenance cost summing R$140,000,000.00 along 50 years (same horizon adopted for the estimated losses on dwellings and their contents).

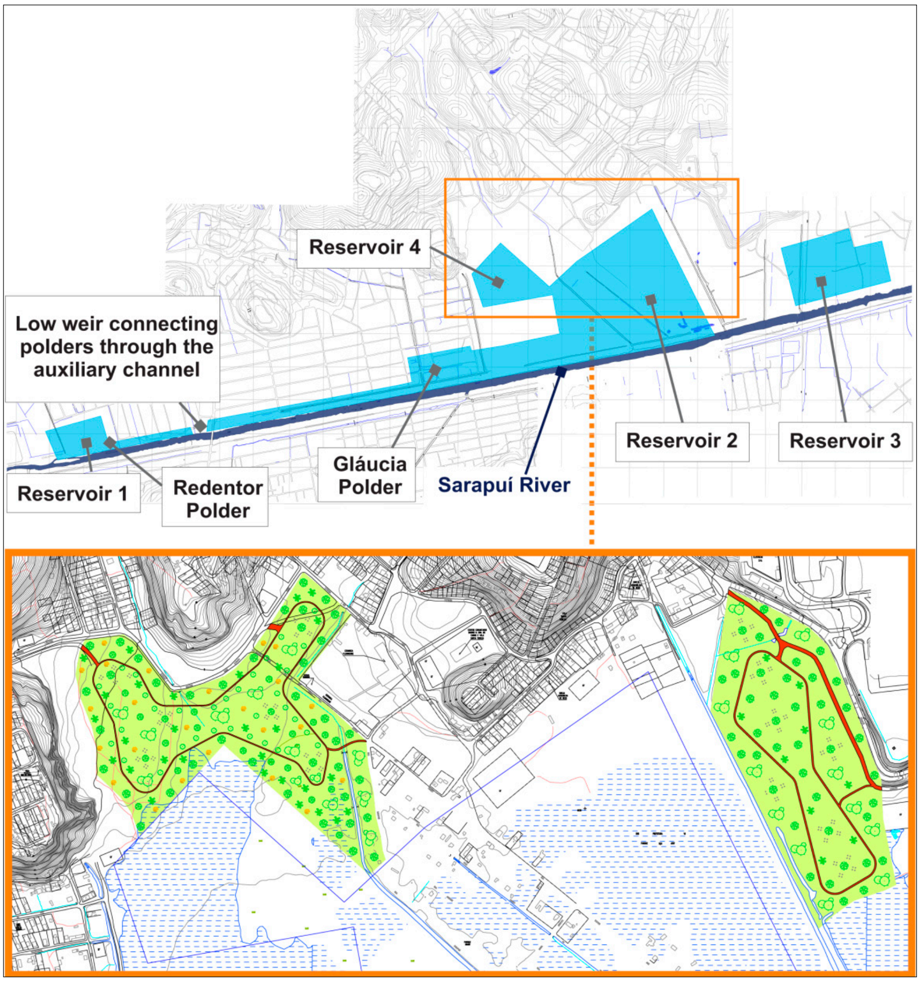

Figure 4. Jardim Gláucia and Jardim Redentor Levee Systems.

The benefit/cost (B/C) ratio in this case gives 1.30 and this result is surely underestimated once just one type of damage was considered (to people's homes). If damages to public infrastructure, public cleansing and public health costs, economic losses due to services disruption, among others, were considered, benefits would be even greater.

This way, we can perceive that it is important to protect people subject to flooding and the B/C ratio shows a positive result (including the possibility to improve built environment with multifunctional landscapes used also for leisure). However, it is also important to note that protection required isolating the flood plain, which should not have been urbanized if a proper development plan was in place. To put this territory in safe conditions, an annual maintenance cost of almost R$3,000,000.00 had to be introduced.

6.2. Vila Fraternidade Community

Vila Fraternidade is a shantytown resulting from irregular occupation of low-lying riverine areas, covering 0.83 km^2, located in the left Sarapuí River bank in the city of Duque de Caxias. The region suffers from a lack of sanitation and absence of general infrastructure. This area constantly witnesses flooding. Some houses are located only 1.00 m above mean sea level [60] and tide effects aggravate the situation. To minimize flood problems, a levee system was proposed in the revision of the Integrated Iguaçu-Sarapuí River Basin Flood Control Master Plan [61].

The final design adopted for Vila Fraternidade (Figure 5), with the implementation of Gomes Freire levee system, consisted of:

- Recovery of an old existing levee on the left bank of the Sarapuí River, with an elevation of 2.20 m.
- Implementation of a reservoir and an auxiliary channel to connect this reservoir to Gomes Freire Channel.
- Installation of flap gates in the reservoir and in the connection between Gomes Freire Channel and Sarapuí River.
- Implementation of a recreational area, next to Gomes Freire Channel, with an intermediate elevation, so that the area will act as an alternative detention reservoir only when required by more severe floods.

Considering the scenario when the levee system is installed, Vila Fraternidade shows a controlled flood situation, enabling the urban revitalization of this area, which was the aim that guided the project. General improvement of the area was observed, resulting in flood reduction inside the levee system. In some areas, it was possible to see reductions of more than 0.50 m in the water depths. The internal canals and reservoirs are under control and some areas had their ground levels raised to meet the restrictions imposed by the new urbanization standards.

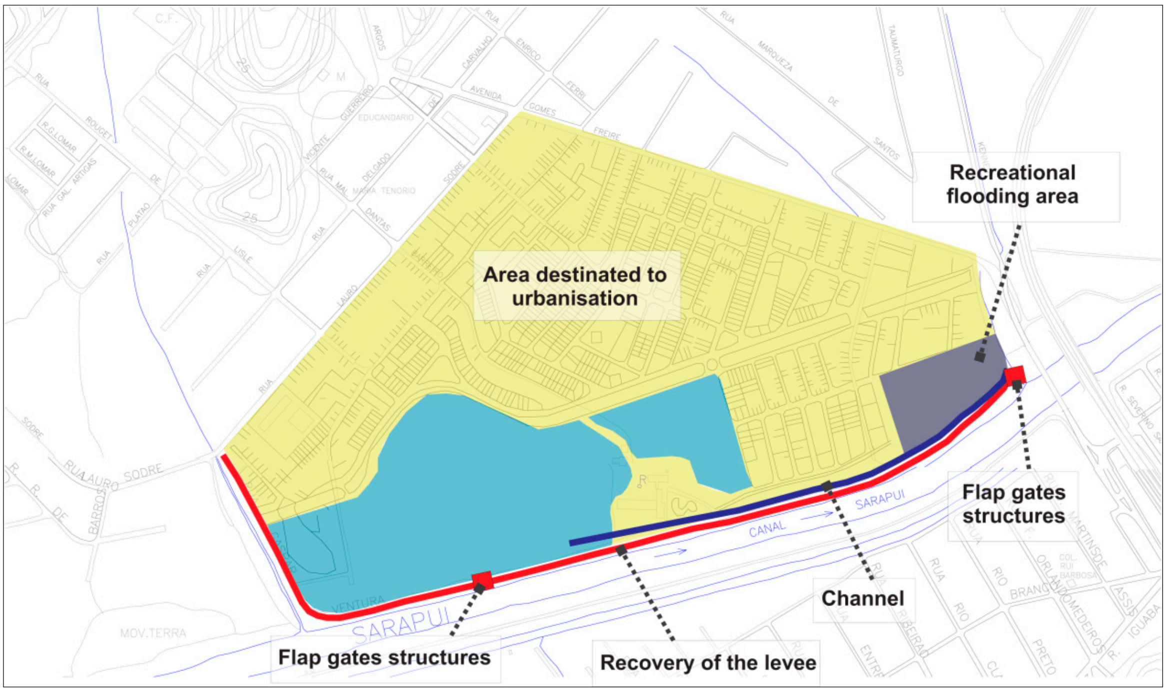

Figure 5. Major drainage diagram.

On the other hand, the installation of this levee on the left Sarapuí bank raised the river's water levels by approximately 0.20 m. Figure 6 presents these results, comparing the level of the river before and after interventions.

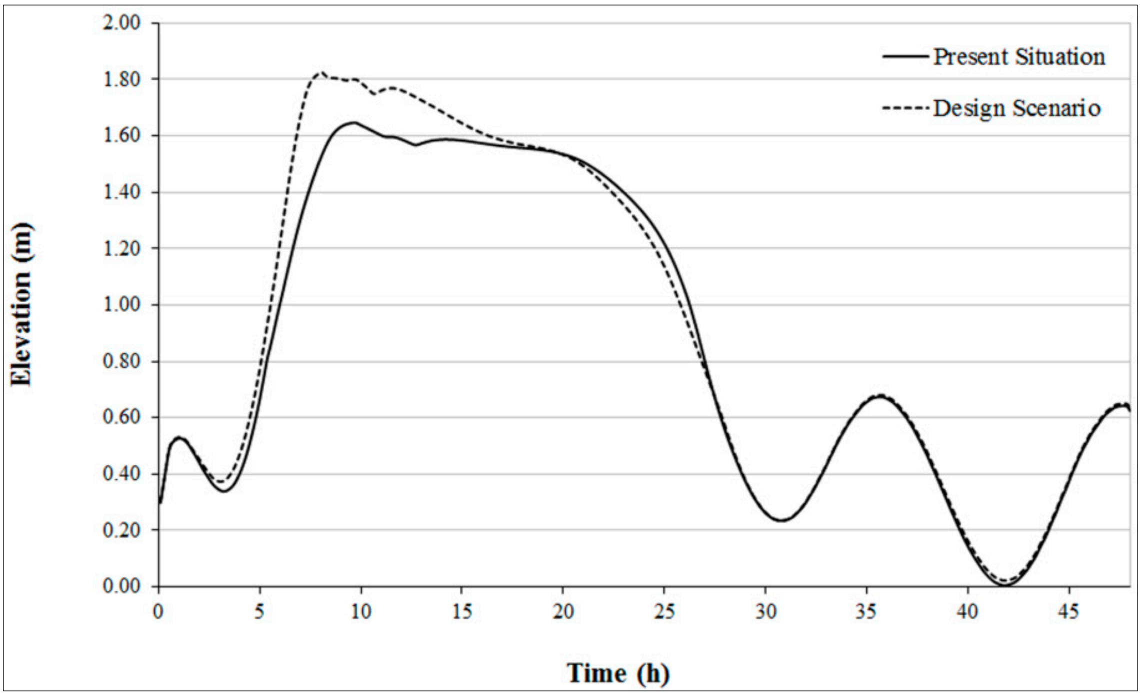

Figure 6. Sarapuí River flow behavior before and after interventions.

Considering that this levee system represents only 4% of the river extension, and that this is a typical solution for lowlands, the consequences of this kind of solution over larger extensions may lead to new flood problems, with possible overtopping discharges and consequent higher risks [60].

6.3. Flood Levels along the Iguaçu River and in Cidade dos Meninos Levee System

Cidade dos Meninos levee system is also situated in Duque de Caxias city, bounded by the Pilar and Capivari Rivers. On its south side, it is limited by the lower reach of the Iguaçu River, as observed in Figure 7. This levee system drains an estimated area of 15 km^2.

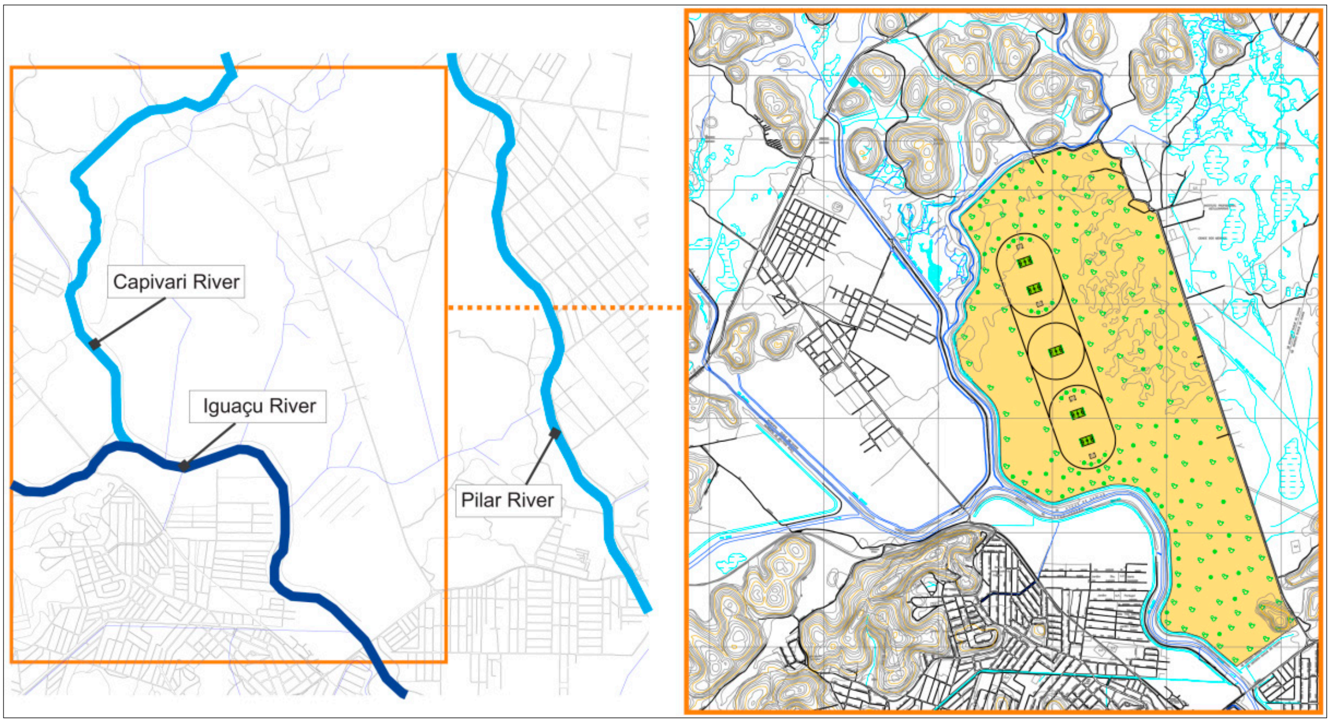

Figure 7. Cidade dos Meninos levee system and the storage area for the Iguaçu River.

The lower reaches of the Iguaçu River, from the confluence of the Botas River (just upstream Cidade dos Meninos levee system) to its mouth in Guanabara Bay, are bordered by dikes along nearly their entire length. In the past, these levee systems were constructed for urban development purposes. However, this expectation was not confirmed in all places and Cidade dos Meninos levee system still has low occupation. Thus, the use of the protected void internal space as a storage area for Iguaçu River, allowing the recovery of its connection with the floodplain, is something to be considered. However, the municipal government still intends to expand the city towards this region. A compromise among flood control, river restoration and urban development was searched, reintegrating the west portion of the protected area as a flood plain and leaving the east portion of the levee system for urban development. The opening of the levee system should be made by the removal of the levee on the left margin of the Iguaçu River, downstream from the confluence with the Capivari River. The final solution, proposed after mathematical simulations, considered this region floodable, with a total area of 6 km^2, recovering space for the river. Caioaba Street, which was already in place, was able to act as a levee, allowing the remnant areas to be urbanized at higher and safer elevations. Figure 7 represents this area and the proposed solutions.

The total cost of this intervention is reasonably low, when compared to other actions, summing up to R$1,000,000.00, considering the opening of the existing dyke and the relocation of 27 families to new houses. Certainly, if this area was considered as urbanizable, it could increase in value and generate taxes for the Municipality, but it would also bring new maintenance costs and increasing risks downstream, demanding new works. However, although these aspects are not developed in details in this study, an acceptable compromise between urban growth and the natural limits imposed by watershed needs was found: the Municipality accepted transforming part of the available land (as proposed) into a natural park. This configuration helps in maintaining under control all the downstream Iguaçu River reaches (and other existing levee systems).

Figure 8 presents the Iguaçu River water level profile for both the present situation and considering the design scenario implemented. It is possible to observe that the water level falls when Cidade dos Meninos levee system is opened and the river reconnected to part of its floodplain. Figure 9 presents the hydrograph of a section of the Iguaçu River downstream from Cidade dos Meninos levee system, also for both simulated scenarios, showing the damping effect of the floodplain (about 15%).

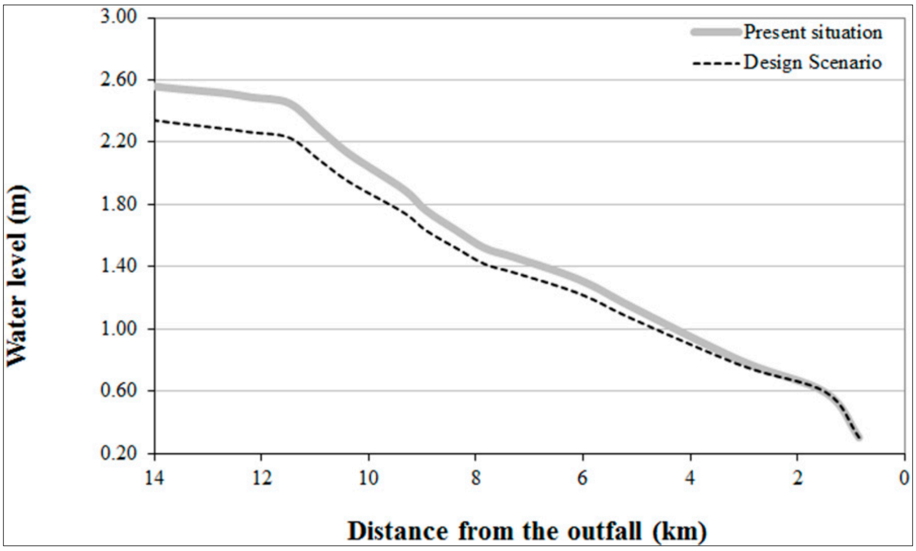

Figure 8. Iguaçu River water level profile—return period of 20 years.

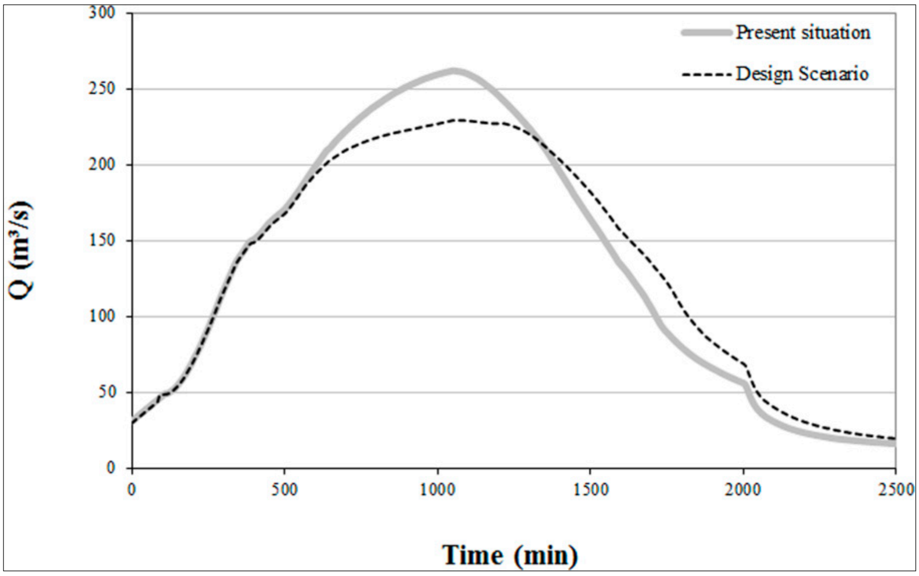

Figure 9. Hydrograph of a section in Iguaçu River downstream from Cidade dos Meninos Polder—return period of 20 years.

6.4. Botas River Outfall

This case study considers the downstream region of the Botas River just before entering the Iguaçu River. It is located upstream Cidade dos Meninos levee system, which was discussed in the previous case. This area is still covered by natural vegetation and, although the river has been rectified, it is still connected with its floodplains (Figure 10). In this study, this area is simulated in its present condition and then two levees are implemented on both margins, in a modeled scenario to "protect" the riverine area and allow its occupation, in order to map the consequences of this action.

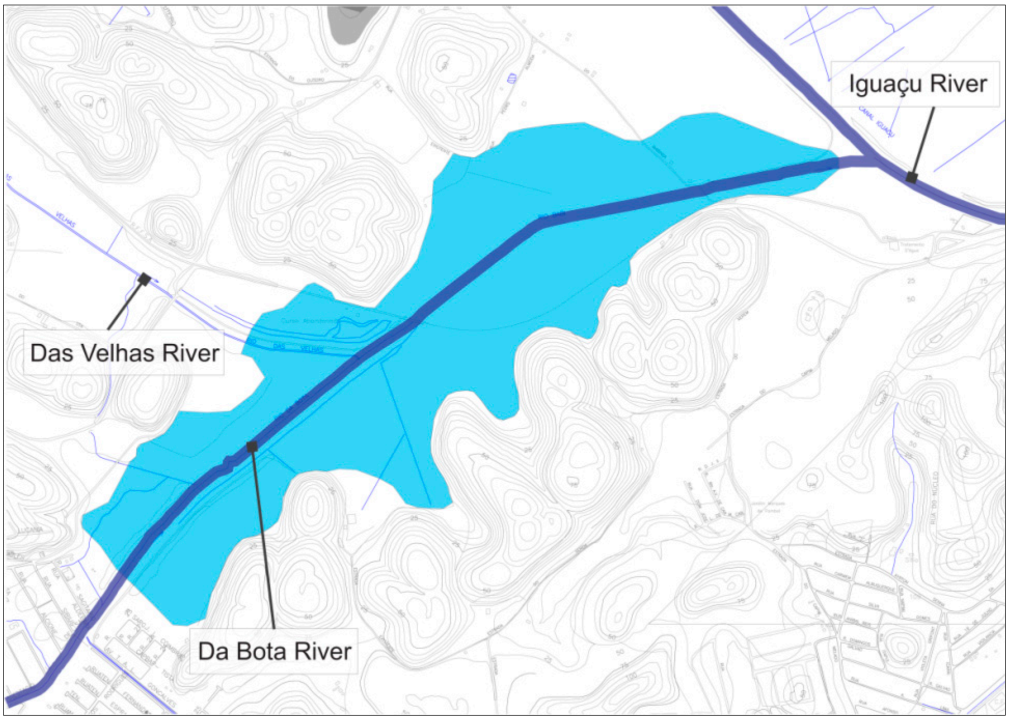

Figure 10. Schematic representation of the flood plain at Botas River outfall.

The conservation of the Botas River bank in natural conditions allows the flooding of a large free area, damping the discharges by approximately 40% compared with the levee system alternative (Figure 11). In terms of water levels, the implementation of levee systems in the Botas River outfall would imply an increase of approximately 0.50 m in the Iguaçu River (Figure 12), which is an already critical region. This way, the alternative of "doing nothing" except for preventing riverine areas occupation and ordering land use would result in a safer downstream system, with virtually no additional costs.

These results show how important the lateral connectivity of a river is, interacting with the floodplains. It also shows the importance of urban growth's consequences. After this study, the state government transformed this area into an environmental protection area, to prevent future occupation, recognizing its importance.

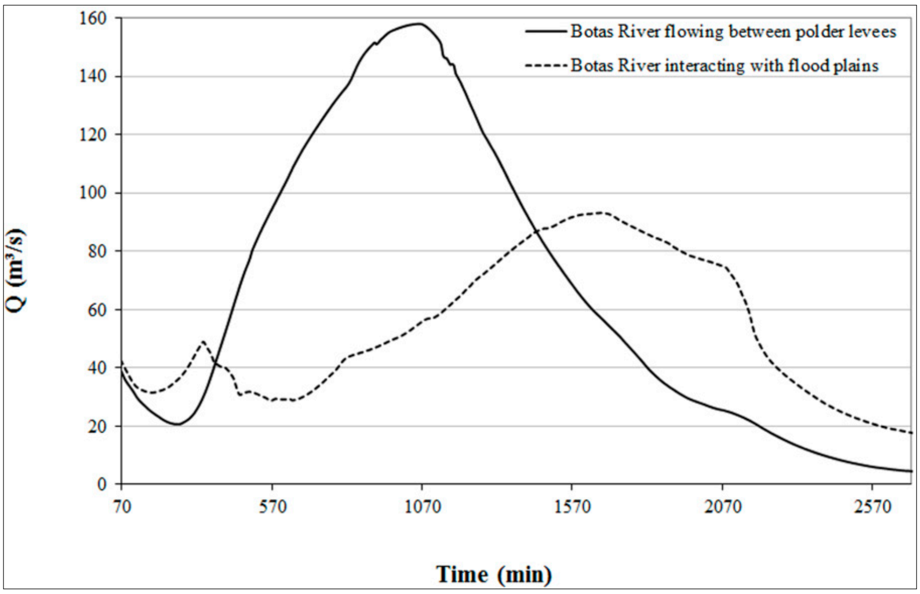

Figure 11. Hydrograph at Botas River outfall—return period of 20 years.

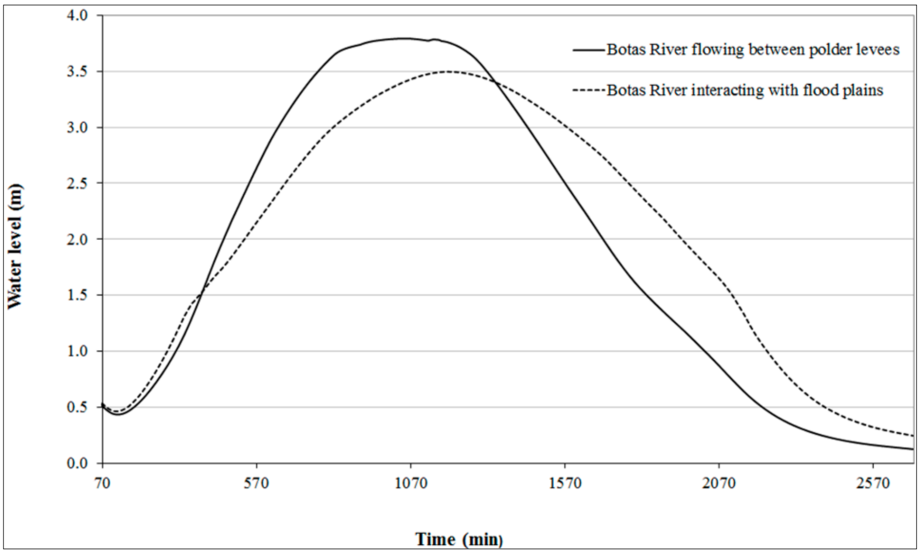

Figure 12. Water levels at Iguaçu River after Botas River outfall—return period of 20 years.

7. Discussion

Departing from the literature review and observing the case studies developed, some lessons can be confirmed, and others have been learned. The main findings can be summarized in the topics, indicated below:

- Without proper urban planning and control, the efficacy of flood control measures can be lost over time. The first case studied showed how the lack of control and the false feeling of safety can lead people to inhabit risky areas. The absence of clear knowledge about the risks causes people to occupy the storage areas in the reservoirs. Without the proper storage capacity levee systems cannot operate correctly. Therefore, flood control solutions should be integrated with the urban environment, offering additional uses to nearby communities, in order to guarantee that they will be operational along time. A set of urban parks was proposed to avoid bank occupation, to work as temporary reservoir and to prevent exceeding imperviousness.

- Levee systems can aggravate floods downstream by confining the river and increasing water levels. The second case showed that a local solution can be useful for protecting a certain area and possibly bring a local urban retrofit. However, these local solutions, without an overall vision, can lead to problems downstream. The water elevation in the Sarapuí River when confined to its main channel can cause overtopping of the previous constructed levees. Besides this, the generalization of this type of solution is able to provoke serious accidents, in the extreme case involving sudden waves produced by structural failure.
- On the other hand, the third case showed that recovering space for rivers can be effective and workable, reducing risks and costs over time. However, space given to the river represents less space for the city. In this case, fluvial space must be incorporated in the city landscape and recognized as an urban value, performing environmental services, including flood control.
- The last case showed another important lesson that should be incorporated in urban plans: preserving flood plains is the easiest way to avoid future flood problems. Flood zoning and consequently respecting fluvial space is probably the simplest sustainable path for better control of flood consequences. Recognizing the natural limits imposed by the basins should be the first step in the design process.

It is possible to say that the third and fourth cases support the idea that preserving and/or restoring rivers may be functional alternatives to face the increasing risk of urban flooding and the co-related river degradation threats, especially when there is free space and it is possible to plan in advance. On the other side, the traditional approach plentiful of defensive works (levees, bank protections, *etc.*), often proposed in a short perspective and in a local scale, tends to confine river flow and increase water levels, transferring effects. In most cases, this situation may raise risks due to the possibility of functional or structural failure in the long run or at downstream reaches (that is, this solution may fail along time and/or over space). The river restoration approach, even in urban environments, where alternatives are restricted by built areas, seeks a more compatible balance between human needs and natural dynamics. However, when urbanization has already grown in flat floodable plains, it is difficult to make room for the river—space in this case is a limiting constraint (as seen in first case, where a levee system was used, but it was integrated with a series of urban parks trying to find a compromise between natural and built environments, while saving the community from important losses caused by flooding).

In order to develop an urban river restoration strategy, it is important to reintegrate the river in the urban landscape. Considering all the difficulties found in the urban environment and the minimum spaces available, the main objective should rely on recovering river lateral connectivity, providing some space for floods and reorganizing flood flow patterns. Table 1 presents a summary of the four case studies, explicitly comparing the relevant features, outcomes and lessons learnt of each one.

Table 1. Summary of the relevant features, outcomes and lessons learnt of the case studies.

Case Study	Original Situation	Design Proposition	Expected Outcomes	Lessons Learnt
Jardim Redentor and Jardim Glaucia Levee Systems (Uncontrolled Urban Growth)	• Independent levee systems on the left margin of the Sarapuí River. • Great pressure from urbanization expansion, substantially reduced their designed storage capacity. • Recurrent floods.	• Interconnection of the two system reservoirs to make them work together. • Relocation of dwellings in risk areas to provide space for a larger storage area. • Creation of fluvial parks, integrated with the urban surroundings and acting as multifunctional landscapes for the community. • Two other upper areas were defined as environmental parks.	• Optimization of the storage capacity, with the integration of the reservoirs. • Mitigation of flooding inside the levee systems. • Urban revitalization (mainly driven by the parks) and environmental valorization. • Although several tributaries were redeveloped in the area, Sarapuí River was not reconnected to its floodplains—the exposed area would be prohibitive.	• Without proper urban planning and control, the efficacy of flood control measures can be lost over time. • The lack of control and the false feeling of safety can lead people to inhabit risky areas (in this case, they moved towards the dyke, occupying the temporary storage area provided in the 1990s). • Flood control solutions should be integrated with cityscape, offering additional uses to nearby communities, to guarantee that they will be well-accepted and fully operational along time.
Vila Fraternidade Community (Irregular Urban Growth)	• Irregular occupation of low-lying riverine areas. • Lack of sanitation and absence of general infrastructure inside the area. • Frequent flooding	• Recovery of an old existing levee on the left bank of the Sarapuí River; implementing a reservoir connected to the Sarapuí River by flap gates. • Creation of new multifunctional areas, in different terrain levels for different flood recurrences.	• Controlled flood situation inside the levee system. • Possible regular urban occupation in the new zoned areas with a minimal terrain level defined to avoid flooding. • Urban revitalization.	• Local solutions, without an overall vision, can lead to problems downstream, such as the increase of the water levels, by transferring floods in confined efficient channels. • The water elevation in the river can cause overtopping of the previous constructed levees. In the extreme cases, accidents may occur involving sudden waves produced by structural failure.

Table 1. *Cont.*

Case Study	Original Situation	Design Proposition	Expected Outcomes	Lessons Learnt
Flood levels along the Iguaçu River and in Cidade dos Meninos Levee System	• Cidade dos Meninos Levee System drains an estimated area of 15 km^2, but this area remained unoccupied due to an environmental accident with chemical contaminants. • The lower reaches of the Iguaçu River are bordered by dikes along nearly their entire length.	• Opening of Cidade dos Meninos levee system, removing its dyke and reconnecting the river to part of its floodplain, restoring 6 km^2 to the river space. • The hydrograph of a section of the Iguaçu River downstream from Cidade dos Meninos levee system indicates about 15% of damping effect of the floodplain.	• Flood control downstream. • Environmental mitigation of the degraded area as a first step to allow river reconnection to its floodplains. • General environmental improvement in this reach. • River restoration effects with fluvial ecosystem improvement. • Low maintenance costs. • Lost apace for urbanization.	• Recovering space for rivers can be effective and workable, reducing risks and costs over time. • Fluvial space must be incorporated in the city landscape and recognized as an urban value, performing environmental services, including flood control.
Botas River Outfall	• The downstream flood plains of the Botas River are still in natural conditions, although the river itself is rectified.	• Preserve floodplains, controlling urban growth with the establishment of formal environmental preservation areas.	• The conservation of the Botas riverine areas in natural conditions results in damping discharges by approximately 40%, compared with the levee system alternative. • Inversely, the implementation of levee systems in the Botas River outfall would imply in more 0.50 m added to of water levels in the Iguaçu River.	• The importance of the lateral connectivity of a river, interacting with the floodplains is great. • Planning in advance and preserving river space is one of the simplest ways to avoid flood risks. • It is necessary to map and avoid negative urban growth's consequences.
Implementation	• Iguaçu Project is being implemented in three phases. The first one was finished, comprising river channels and levee systems maintenance, relocation of dwellings in risk areas, especially on the river banks and their vicinity; and implementation of fluvial parks. The conductance of the river flow sections was recovered. The riverine communities embraced the parks. Second phase was initiated and it is expected that the great storage volumes of the park will be implemented. The third phase will come in the future. The state government has already transformed a great area into a formal environmental protection area (including Botas river outfall flood plains), to prevent future occupation, recognizing its importance. People relocation is one of the great difficulties for implementing the project.			

8. Conclusions

The implementation of levees along rivers as a general solution for lowlands protection should be rethought. Although necessary sometimes, if not considered in a systemic approach, their effects can raise new problems. In this case, the systemic approach should consider the watershed functional limits, perceiving that a local approach could be treacherous, once flooding problems could be transferred downstream, instead of being really solved. It is important to stress that a systemic approach should also consider socio-economic aspects, jointly with the physical aspects. However, for the sake of simplicity, this study considered these socio-economic aspects indirectly, assuming that the higher the flood levels, worse the socio-economic losses are. This way, we focused in the potential risks driven by flood hazards. The use of levee systems for urban flood control has been widely adopted to face flooding problems in many riverine areas worldwide. This is also the case of Baixada Fluminense in Rio de Janeiro State, covering a lowland area, in the metropolitan region of Rio de Janeiro city, where this paper focuses attention. However, when this type of intervention is fully adopted along the river (by summing up a series of local dykes), it can transfer floods and lead to significant increases in the water levels inside the main river channel, putting at a higher risk the areas that the levees originally intended to protect. The disconnection of the river and its flood plains may become critical along time.

Baixada Fluminense showed be an interesting case for discussion. It brings a history of floods shaped through the years, first for agricultural purposes, then for urban settlements that grew in association with the metropolitan area of Rio de Janeiro city. This area lies down on the basin of Iguaçu-Sarapuí Rivers. The municipalities in the Iguaçu-Sarapuí Rivers basin shelter a huge population, which occupies both formal and informal city areas. There are several socio-economic problems, including lack of adequate sanitation and substandard housings. The Municipalities have difficulties in acting together and facing the flood problems and the degradation of fluvial and urban environments. In this context, The State Government tried to orchestrate a solution for this basin, which has become in the past few years a stage for articulated actions focusing on flood control and environmental recovery, in the context of revising the "Integrated Iguaçu-Sarapuí River Basin Flood Control Master Plan". This was a study made by the Federal University of Rio de Janeiro for the State Environmental Institute.

Nonetheless, revising the Plan was needed because a first attempt to implement it did not solve all the problems. In the 1990s, the first version of this Plan led to a set of recovering measures to deal with the heritage of past hydraulic works, as well as adaptation measures to order urban growth. However, the lack of urbanization control at the cities scale, experienced along the subsequent decade, rendered the Flood Control Master Plan to be not fully effective and floods turned to happen again. The revised version of this Plan, on a second attempt to act on Baixada Fluminense lowlands, introduced concerns about: integrating urban land use control, flooding control and environmental preservation; river reconnection with flood plains; and use of fluvial parks as multifunctional landscapes, aggregating the aims of preserving river banks and re-introducing storage volumes in the system.

Urban flood control is an issue that is hard to solve, especially in dense cities occupying lowlands. The cases presented in this study show how this problem can vary. Flood control measures, however, must be designed based on the watershed scale instead of considering just the local scale problem.

One final highlight refers to an alert for future developments. Proper zoning could be an effective alternative solution to avoid the use of levee systems. The maintenance of flood plains functions would certainly lead to greater restrictions on urbanization space, by defining higher minimum terrain elevations for urban developments, with less available area. However, this choice would not significantly modify the fluvial regime, probably reducing the total risk and the maintenance costs. Zones near rivers could be transformed into parks and green corridors, combing the natural landscape with the cityscape, focusing on environmental purposes. An important remark, in order to sustain this choice, is that urban planning and land use control must be in line with this alternative, to avoid irregular constructions and city expansion towards risky areas.

Acknowledgments

We acknowledge CNPQ and CAPES for supporting this research. We would also like to acknowledge the undergraduate student Isadora de Moura Tebaldi for helping in the preparation of some figures for this paper.

Author Contributions

The authors are researchers of Universidade Federal do Rio de Janeiro (UFRJ), in Brazil. Jointly, Marcelo Gomes Miguez, Matheus Martins de Sousa and Osvaldo Moura Rezende had worked on an important project for flood control in the metropolitan area of Rio de Janeiro. This work was demanded by the State Government and covered the basins of Iguaçu and Sarapuí Rivers. The case studies discussed at the end of the presented manuscript were part of this work. Marcelo Gomes Miguez and Aline Pires Veról took part in a European Research Project called SERELAREFA (www.serelarefa.com) from 2010 to 2014. This project concerns the context of river restoration and, particularly, they mainly worked on urban case studies. All these experiences helped to support the paper main findings.

In this manuscript, Marcelo Gomes Miguez conceived its general lines and argument. Matheus Martins de Sousa and Osvaldo Moura Rezende did together the modeling of three of the four case studies. Aline Pires Veról did alone the modeling of Vila Fraternidade case study and was also in charge of the final literature review.

Conflicts of Interest

The authors declare no conflict of interest.

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